

GRADES 5-12

Why Do We Really Need Pressure Suits?

Physical Science Lessons
on Temperature, Pressure,
Density, and Human Survival
at High Altitudes



Aeronautics
Research
Mission
Directorate



About This Guide

This curriculum guide is broken down into several sections in order to make it easier to use and easier to find lessons and activities you need for your classroom. Each lesson can be completed as a stand-alone lesson made up of several activities or can be combined with any or all of the other lessons within this guide. The background information applies to all lessons and activities. Due to the interrelated nature of temperature, pressure, and density, some activities in one category explain several concepts simultaneously but were placed in the lesson that seemed to be most applicable to the concept being taught. Overall, in addition to the physical science nature of the lessons within this guide, there is an additional focus on human survival within temperature, pressure, and density parameters.

Introduction

Lessons are broken down as follows:

- Pressure Lesson One: Survival in a Vacuum
 - Four activities
- Pressure Lesson Two: Air Has Pressure
 - Three activities
- Temperature Lesson: Can Water Boil Without Heat?
 - Four activities
- Density Lesson: How To See Density
 - Two activities

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Background

What would happen if you were high above Earth's surface or in space without a protective pressure suit or spacesuit? Would you explode? Would your blood boil? Could you survive? The answers are a bit more complicated than you might think, and these lessons and activities will show you why humans need protective pressure suits in these conditions.

The quick answers to the above questions are as follows:

- Would you explode? No.
- Would your blood boil? That depends, but the water in your body would.
- Could you survive? Yes, but only for about 1 minute.

However, there is much more to those questions. Read on to find out

The higher in altitude we travel, the more protection we need to keep ourselves safe. The higher you travel above Earth's surface, the less atmospheric pressure there is to exert on an object, including humans. Along with pressure, temperature also changes with altitude. So what exactly happens to a human during these travels? To answer that question, we will start with conditions on Earth and work our way into space. The focus will be on **pressure, temperature, and density**, relating each of these to what is needed for human survival.

Before we discuss the layers of Earth's atmosphere, we will also provide a definition of "space." When does "space" start? While there is no visible delineation between Earth's atmosphere and space, it is generally agreed that space begins 50 miles above Earth's surface. In order to earn an astronaut badge, the pilot must fly above 50 miles in altitude.

On Earth, we are subjected to a variance in pressure, temperature, and air density, and these variations are due in a large part to our altitude above sea level, surface weather, and the effects of the geology around us. For pressure, temperature, and density at Earth's surface, averages will be used for this discussion in order to simplify these concepts since our main focus is on what happens to humans when we are above Earth. The section below about the troposphere provides standard averages used for pressure calculations.

Earth's atmosphere is broken up into five basic layers, each of which fluctuates in height depending on seasons of the year and location (layers are thicker at the equator and thinner at the poles). Information about each of these layers can be found below.



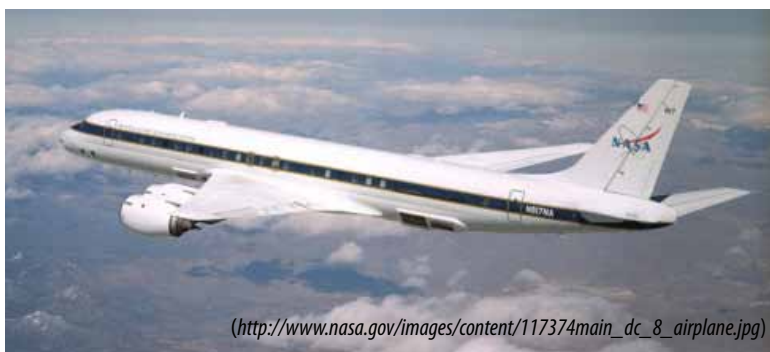
This photograph of the colorful layers of Earth's upper atmosphere was taken from the Space Shuttle, looking sideways across Earth's atmosphere. (Image Credit: NASA, <http://www.nasa.gov/audience/forstudents/k-4/dictionary/Atmosphere.html>)

Layers of Earth's Atmosphere

Troposphere

While studying the atmosphere itself can be a complicated process, the lowest layer of the atmosphere, the troposphere, is perhaps the most complex of the atmosphere's layers because it is a system that involves many different variables, all of which affect conditions within the troposphere. Among these variables are factors such as temperature fluctuations due to seasons, weather, and the uneven heating and cooling of Earth's surface (the other layers are not as susceptible to these kinds of fluctuations). Temperature, density, and altitude are all interrelated, so changes in any/all of these will affect the others as well. Finally, nearly all of the water vapor in our atmosphere is within the troposphere. The effects of water in the atmosphere further complicate the troposphere and atmospheric changes that occur.

The lowest layer of the atmosphere, the troposphere, begins at Earth's surface and reaches up to 7 kilometers (about 23,000 feet) at the poles and to about 17–18 kilometers (about 56,000 feet) at the equator. The height of the troposphere changes with the weather; it is higher in the summer months and lower in the winter (think of gas laws and changes in temperature—as gas temperature increases, density decreases). The decrease in density causes the atmosphere to expand, raising the height of the troposphere. Likewise, when the temperature of the air in the troposphere cools, the air condenses, lowering the height of the troposphere. Commercial aircraft travel in this region.



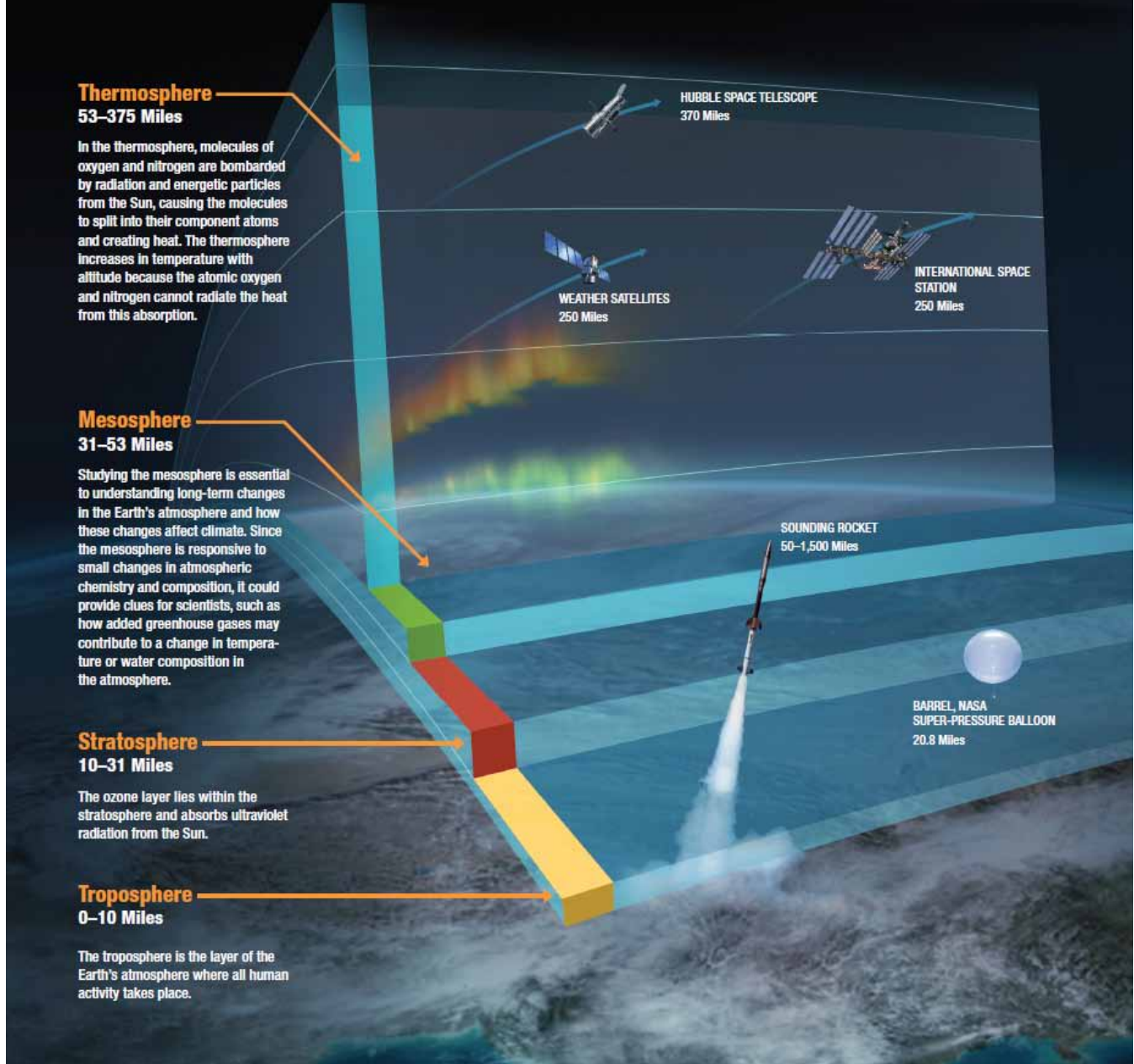
The troposphere is primarily composed of nitrogen (78 percent) and oxygen (21 percent), with only small concentrations of other trace gases.

Uneven temperature fluctuations occur in the troposphere, but overall, air temperature declines with an increase in altitude. On average, temperatures in this region decrease 6 degrees Celsius (C) for each kilometer rise in altitude, which is about 3.6 degrees Fahrenheit (F) for each 1,000 feet. When climbing in altitude, air pressure also decreases. Pressure decreases due to both a lessening of gravity's pull and a lessening of air pressure from above. At Earth's surface, more gravitational pull on air molecules increases density and, as a result, pressure. In addition, there is more air *above* the air closest to Earth's surface (which is also being pulled down due to gravity), which helps to increase air pressure at the surface. The higher in the atmosphere you travel, the less air there is. That means less gravitational pull on molecules and less mass pushing down on that region.

Since most of the air is located closest to Earth's surface, the troposphere is the densest layer of the atmosphere. Up to 75 percent of the mass of the atmosphere is in the troposphere. In fact, 50 percent of the *total* mass of the atmosphere is located in the lower 5.6 kilometers (about 18,000 feet) of the troposphere. At sea level, the atmospheric air pressure is 14.7 pounds per square inch absolute (psia), which is in reference to the absolutely zero pressure that exists in a perfect vacuum. So at sea level, the weight of Earth's atmosphere exerts a force of 14.7 pounds on every square inch of our bodies. The force exerted on about 1,000 square centimeters (about 1 square foot) at sea level is about 1 ton of pressure.

So why aren't we crushed under this pressure? Air *inside* our bodies is also exerting pressure, creating an equilibrium and preventing outside air pressure from crushing our bodies. However, if humans were to travel higher in the atmosphere without some kind of protection, where air pressure is much lower, we would have problems because of the difference in air pressure between what's inside our bodies and air pressure outside our bodies. At higher altitudes, air pressure inside our bodies would be much higher than pressure outside, unless we had some kind of protection to keep that from happening. Without that protection, our bodies would swell as the gases on the inside and the outside attempted to equalize.

The structure of the upper atmosphere. (Image credit: NASA, http://www.nasa.gov/mission_pages/sunearth/multimedia/upper-atmosphere-graphic.html)



At the upper limits of the troposphere, just before the stratosphere, is the tropopause, which is a thin boundary marked by stable temperatures.

Stratosphere

The stratosphere, the second lowest layer of Earth's atmosphere, lies above the troposphere and is separated from it by the tropopause. It extends from the top of the troposphere to about 50 kilometers (about 31 miles; about 164,000 feet).

The stratosphere contains the ozone layer, the part of Earth's atmosphere that contains relatively high concentrations of ozone. The stratosphere defines a layer in which temperatures rise with increasing altitude. This rise in temperature is caused by the absorption of ultraviolet (UV) radiation from the Sun by the ozone layer. Such a temperature profile creates very stable atmospheric conditions, and the stratosphere lacks the air turbulence that is so prevalent in the troposphere. Consequently, the stratosphere is almost completely free of clouds or other forms of weather.

Mesosphere

The mesosphere is the third highest layer in our atmosphere, occupying the region above the stratosphere and below the thermosphere. It extends from the top of the stratosphere to the range of 80 to 85 kilometers (about 50 to 53 miles; about 260,000 to 280,000 feet).

Temperatures in the mesosphere drop with increasing altitude to about -100 degrees C (-148 degrees F). The mesosphere is the coldest of the atmospheric layers. In fact, it is colder than Antarctica's lowest recorded temperature. It is cold enough to freeze water vapor into ice clouds. You can see these clouds if sunlight hits them after sunset. They are called Noctilucent Clouds (NLCs). NLCs are most readily visible when the Sun is from 4 to 16 degrees below the horizon. The mesosphere is also the layer in which a lot of meteors burn up while entering Earth's atmosphere. From Earth, they are seen as shooting stars.

Thermosphere

The thermosphere (literally "heat sphere") is the outer layer of the atmosphere, separated from the mesosphere by the mesopause. It extends from the top of the mesosphere to over 640 kilometers (about 400 miles; about 2,100,000 feet).

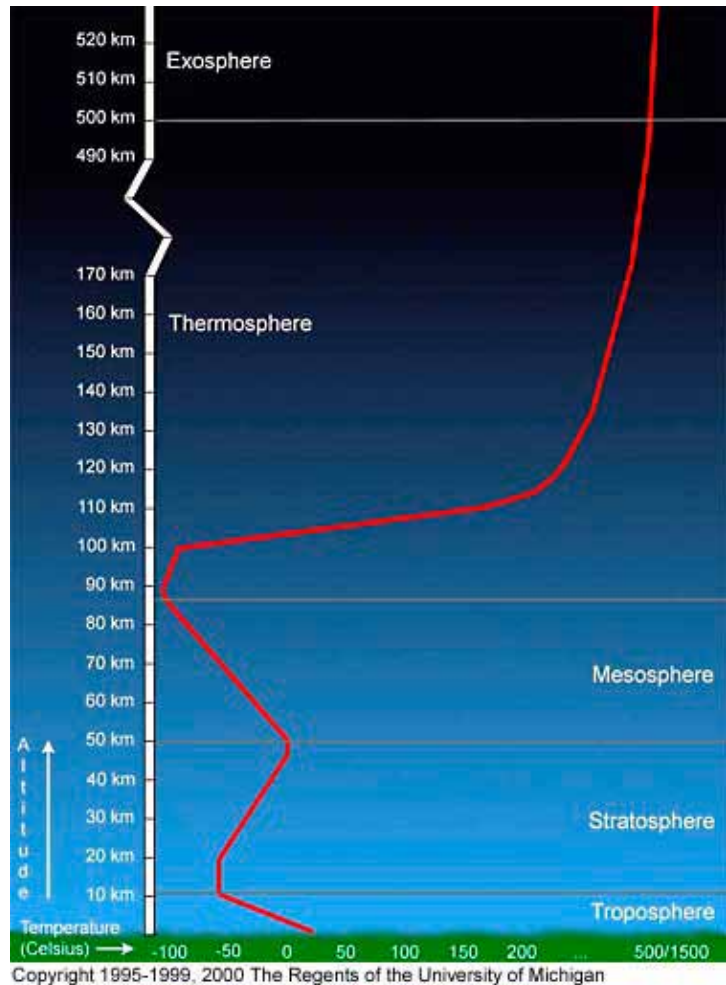
Within the thermosphere, temperatures rise continually to well beyond 1,000 degrees C. The few molecules that are present in the thermosphere receive extraordinary amounts of energy from the Sun, causing the layer to warm to those high temperatures. Although the measured temperature is very hot, the thermosphere would actually feel very cold to us because the total energy of the few air molecules residing there would not be enough to transfer any appreciable heat to our skin.

The lower part of the thermosphere, from 80 to 550 kilometers (49.7 to 341.8 miles) above Earth's surface, contains the ionosphere. Beyond the ionosphere, extending out to perhaps 10,000 kilometers (6,213.7 miles), is the exosphere or outer thermosphere, which gradually merges into space. Temperature increases with height. Although the temperature can rise to 1,500 degrees C (2,730 degrees F), a person would not feel warm because of the extremely low pressure. The International Space Station orbits in this layer, between 320 and 380 kilometers (about 200 and 240 miles).

Exosphere

The exosphere is the highest layer of the atmosphere. It extends from the top of the thermosphere up to 10,000 kilometers (about 6,200 miles; about 33,000,000 feet).

This is the upper limit of our atmosphere. The atmosphere here merges into space in the extremely thin air. Air atoms and molecules are constantly escaping to space from the exosphere. In this region of the atmosphere, hydrogen and helium are the prime components and are only present at extremely low densities. This is the area where many satellites orbit Earth. The exosphere contains free-moving particles that may migrate into and out of the magnetosphere or the solar wind.



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This graphic illustrates the atmosphere's structure, starting with the troposphere at Earth's surface. (Image Credit: NASA, <http://www.nasa.gov/centers/langley/news/factsheets/DIAL.html>)

Aircraft in Earth's Atmosphere

As elevation increases, air pressure decreases, and when we fly at high altitudes, the low pressure in these areas would be impossible for humans to survive in if weren't for humanmade enclosures. In airplanes and spacecraft, internal cabins or cockpits are pressurized to help humans function. Since outside air pressure and density are higher near the ground, commercial aircraft have a higher internal air pressure during takeoff and landing to more closely match outside air pressure.

As the plane ascends, internal air pressure is reduced to decrease the difference between internal and external air pressure. However, on transport aircraft such as commercial aircraft for passengers, the internal cabin pressure will not be lower than air pressure found at an altitude of 2.44 kilometers (8,000 feet), or about 75 percent of the air pressure at sea level, which helps pilots and passengers function without difficulty. The Federal Aviation Administration (FAA) requires that these aircraft be able to maintain a cabin pressure of at least 8.29 psia (equivalent to the atmospheric pressure experienced at 4.6 kilometers [15,000 feet] altitude) in the event of malfunctions in the pressurization system. The reason is that lower air pressure makes it more difficult for humans to breathe and get enough oxygen. Many newer, larger commercial planes have increased the internal pressure to be the same as air pressure at 1.5–1.8 kilometers (5,000–6,000 feet), even while cruising at around 12 kilometers (40,000 feet). This helps passengers, many of whom are not used to dealing with low-air-pressure situations, avoid some of the side effects from lower air pressure and reduced oxygen such as throbbing headaches, dizziness, loss of appetite, and sometimes vomiting. If oxygen levels are too low for living organisms to function properly, hypoxia can occur. Brain cells are particularly sensitive to a loss of oxygen, so aircraft are pressurized when flying above 8,000 feet to prevent these dangerous situations.

High-altitude pilots who are trained to better understand the effects of low oxygen levels and can respond quicker to potential problems when in lower-pressure environments still fly in cockpits that are pressurized, but the pressurization is lower. Throughout aeronautics history, there have been many planes that have flown at high altitudes, requiring pilots to wear specially designed suits. Some of these planes include the SR-71; the WB-57; the U-2;

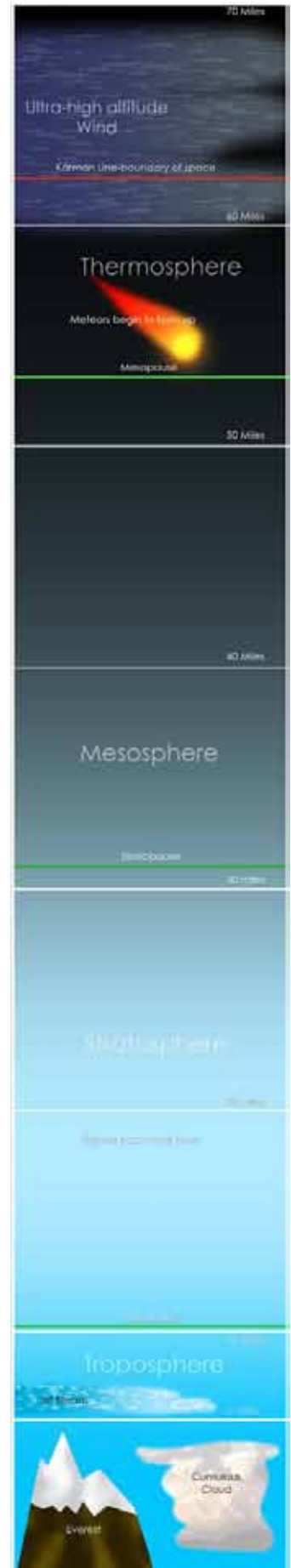


A WB-57 high-altitude aircraft. (Image Credit: NASA, http://www.jpl.nasa.gov/images/earth/wb57_browse.jpg)



Research engineer Marta Bohn-Meyer stands in front of an SR-71. (Image Credit: NASA, <http://www.dfrc.nasa.gov/Gallery/Photo/SR-71/Medium/EC92-2273-1.jpg>)

This graphic provides another illustration of the atmosphere's structure. (Image Credit: NASA, http://www.nasa.gov/images/content/628270main_Atmosphere-map.jpg)



and the U-2's sister aircraft, the ER-2. For example, the U-2 and ER-2 (NASA's ER-2 is the civilian version of the Air Force's U-2 high-altitude reconnaissance aircraft) both fly at an altitude of about 21 kilometers (about 70,000 feet) and have historically kept cockpit pressurization equal to 9,600 meters, or 30,000 feet. To prevent hypoxia from occurring, high-altitude pilots breathe oxygen the entire flight, even when at lower altitude. This helps prevent the buildup of nitrogen in their blood, which can lead to nitrogen narcosis, or "the bends." Early U-2 pilots had no formal training to fly at these altitudes—just bare-bones training at a dry lakebed in Nevada—and only wore partial pressure suits. Now, cockpit conditions are being improved to include more pressurization, which research has shown is better for the human body by helping to prevent decompression sickness, and it also helps the aircraft and sensors last longer. Decompression sickness, or "the bends," is a buildup of nitrogen bubbles in the bloodstream and other areas of the body (scuba divers must also learn how to avoid decompression sickness when they return to the surface after diving deep in the ocean). Pilots now wear full pressure suits and participate in an extensive 9-month training program that includes sessions in the high-altitude pressure chamber, which simulates atmospheric conditions at very high altitudes.

For spacecraft such as the Space Shuttle and the International Space Station, internal pressure has been set at 14.7 ± 0.2 psia. Only astronauts who are going outside the spacecraft in their spacesuits have specific pressure-related preparations, such as breathing pure oxygen before getting fitted to their extravehicular activity (EVA) spacesuits. High-altitude pilots also breathe nearly pure oxygen, called Aviator's Breathing Oxygen (ABO), before flying at high altitudes since they, too, will be breathing oxygen during their mission. ABO is the highest-quality oxygen available (higher than both hospital-grade oxygen and industrial-grade oxygen) due to its stringent safety requirements. For NASA's ER-2 pilots, preflight preparation includes breathing ABO for at least an hour prior to takeoff. NASA describes their prebreathing EVA preparations as follows:

Spacewalkers must wear pressurized spacesuits in order to work in space. These suits have pressures significantly lower than [the] ambient cabin pressure of a spacecraft. This makes spacewalkers subject to decompression sickness, more commonly known as the "bends." Decompression sickness results from nitrogen bubbles forming in the tissues or blood stream and moving to other areas of the body. Therefore, spacewalking crewmembers must perform a pre-breathe protocol, which is designed to wash out any excess nitrogen from the body, before a spacewalk. This protocol takes advantage of the fact that exercise increases the speed at which nitrogen is removed from the body by increasing blood circulation through the extremities. The ISS pre-breathe protocol involves breathing pure oxygen for a total of 2 hours and 20 minutes and includes a short period of high-intensity exercise at the beginning of the pre-breathe procedure.

Station astronauts begin the pre-breathe protocol by exercising vigorously on the space station's cycle ergometer for a total of 10 minutes while breathing pure oxygen via an oxygen mask. After 50 total minutes of breathing pure oxygen, including the 10 minutes initially spent exercising, the pressure in the station's airlock will be lowered to 10.2 pounds per square inch, or psi. During airlock depressurization, the spacewalkers will breathe pure oxygen for an additional 30 minutes. At the end of those 30 minutes, with the airlock now at 10.2 psi, the spacewalkers will put on their space suits. Once their spacesuits are on, the spacewalkers will breathe pure oxygen inside the suits for an additional 60 minutes before making final preparations to leave the station and begin their spacewalk. This protocol provides a total of 2 hours and 20 minutes of pre-breathe time, including the 10 minutes of vigorous exercise at the beginning of the procedure. ("Working Outside the International Space Station," <http://spaceflight.nasa.gov/station/eva/outside.html>)



STS-104 mission specialists Michael Gernhardt (dark shirt) and James Reilly (white shirt) are photographed wearing oxygen masks during their pre-breathe before an Extravehicular Activity (EVA) in the Quest airlock of the International Space Station (ISS). (Image Credit: NASA, <http://archive.org/details/s104e5146>)

Temperature

Oftentimes, when we think about temperature, we think about how warm or cool the air is, along with how hot or cold something is to the touch. Think about a pot of boiling water on your stove. As the water begins to heat up, you can see small bubbles beginning to form on the side of the pot. Those bubbles get bigger and bigger until they rise to the surface of the water and break, and steam also rises from the pot. You learned when you were young that you should never stick your fingers into this boiling water because you will get hurt. When that same pot of water is taken off the stove, you still wouldn't stick your fingers into the water because it would still be hot for some time. You may have also learned that water boils at 212 degrees Fahrenheit (100 degrees C) and that it freezes at 32 degrees Fahrenheit (F) (0 degrees C). However, that is not always the case. Those numbers are given for the boiling point and the freezing point of water at 1 atm (atmosphere) of pressure, or standard pressure and density at sea level. These numbers change depending on air pressure and density. If you live at a higher altitude, water boils at a lower temperature. In Denver, CO, for example, where the altitude is around 5,200 feet (just about 1 mile above sea level), reduced air pressure causes water to boil 4 to 5 degrees C (39–41 degrees F) below the standard 100 degrees C (212 degrees F). This makes a difference when cooking or



A life-support technician assists a pressure-suited pilot into the cockpit of NASA's ER-2 earth resources aircraft. (Image Credit: NASA, <http://www.dfrc.nasa.gov/Gallery/Photo/ER-2/Small/EC00-0037-27.jpg>)

baking at higher altitudes. If you look at a bag or box of cookie and cake mix, you will notice separate instructions for baking at these altitudes. These instructions adjust the amount of water and flour in our batter in order to still get cake and cookies that taste good.

When we talk about temperature in terms of flying at high altitudes or when traveling in space, temperature can take on different meanings. In general, when we get higher in altitude, air temperature decreases. However, when we are in space, sunlight directly affects molecules with which it comes into contact, which makes those molecules heat up substantially. But that does not mean that space is "hot." In the near vacuum of space, there is no air or ambient temperature, since there is no air. Instead, the temperature of the object in space, such as the Space Station, an astronaut working out in space, or even larger objects like the Moon or Earth, changes when the Sun shines on them. During an EVA, the outer layer of an astronaut's spacesuit may be 248 degrees F (120 degrees C) for the side facing the Sun, and the part of that same suit facing away from the Sun could have an external temperature of -148 degrees F (-100 C).

When pilots fly at higher altitudes, they must also be protected from outside temperatures. The higher a plane flies, the fewer and fewer air molecules there are. Fewer molecules running into each other, along with less pressure to contain these molecules, makes temperatures decrease because a gas's temperature decreases when the pressure does. Pressurized, controlled cockpit environments protect the pilots from the reduction of air higher in the atmosphere, but if they were outside this protective environment, they wouldn't be able to survive without a suit to keep them warm. Extreme skydivers and high-altitude balloonists also need to wear pressure suits to maintain pressure on their bodies, but in addition, they must wear protection from the colder temperatures of the upper atmosphere.

Human Survival Above Earth

Different kinds of suits have been designed to help in different situations. A primary designation for types of suits is the partial pressure suit and the full pressure suit. Partial pressure suits are basically form-fitting garments that cover the body from the neck to the wrists and ankles. Inflatable tubes called capstan tubes are added to the suit; these will inflate to provide additional pressure when necessary (see the picture of the partial pressure suit sleeve with a capstan tube below). The added pressure from the partial pressure suit, and at times from the inflated capstan tubes, provides just enough counterpressure to allow pilots to breathe and prevent hypoxia at very high altitudes. While earlier partial

pressure suits have been redesigned to cut down on heat buildup, weight, and bulk, the suits are not known to be comfortable. Imagine wearing a full-body blood pressure cuff while flying an airplane! Capstan tubes are inflated only in an emergency, such as a loss of cabin pressure. When capstan tubes are inflated, the extra pressure is much like the inflation



of that blood pressure cuff. The pressure suit does not provide oxygen for the pilot to breathe, however; that is supplied through an attached helmet and mask.

Arm of a partial pressure suit with a capstan tube. (Image Credit: Maria Werries/NASA)

Full pressure suits are self-contained living environments for pilots and astronauts. Full pressure suits have the ability to enclose the pilot or astronaut in an envelope of pressurized gases. Everything needed for survival—breathing oxy-

gen, pressure exerted on the body, and, for spacesuits, even a heating and cooling system—exists within the suit. Along with providing protection, these suits must also be functional. Cockpit controls and other equipment must still be used while wearing larger gloves and fully pressurized suits. For high-altitude pilots, the suits are pressurized with air instead of pure oxygen in order to reduce the dangers associated with the flammability of oxygen. There is a seal surrounding the pilot's face that prevents that air from escaping the suit. The resulting face cavity, which is the face area of the pilot's helmet, is the only area to have nearly pure oxygen for pilots to breathe.

Different options are added to partial and full pressure suits to account for different situations. For example, fighter pilots aren't subjected to the same low-pressure extremes as pilots who fly the U-2, which flies in the upper limits of Earth's atmosphere, at about 21 kilometers (about 70,000 feet), so they don't need some of the additional components U-2 pilots do. Instead, fighter pilots wear g-suits, which help their bodies handle g-forces, or the additional forces exerted on their bodies when flying at very high speeds and making quick maneuvers. High-altitude pilots who fly extended missions that sometimes last more than 12 hours have helmets specially made to allow them to eat and drink while keeping their helmets on. Pilots must be able to consume high-altitude rations without using utensils or removing their helmets, so the food comes in a tube. Pilots attach a special straw to the tube, which is then inserted through a valve in the helmet. Spacesuits worn by astronauts as they work outside the International Space Station are full pressure suits, but they must contain additional components that will keep the astronauts alive outside their spacecraft; unlike aircraft pilots, they need protection from micrometeors and extreme temperature fluctuations. Depending on where the astronaut is facing, the temperature on the side of the suit facing the Sun can be nearly 135 degrees C (275 degrees F) warmer than the side in the shade. Since astronauts also have to be able to move and work in space, their suits are pressurized at 4.3 psia of oxygen for both breathing and pressurization, which is enough pressure to allow astronauts to work, but not so much as to prevent the suits from being moveable (if a spacesuit were pressurized at 14.7 psia, the suit would be too stiff to move properly). Since the suits are pressurized with pure oxygen instead of air, the pressure can be lower and astronauts can still have enough oxygen to breathe and function well.

Likewise, U-2 and ER-2 pilots also breathe ABO and wear pressurized suits. At 30,000 feet, atmospheric pressure is 4.3 psia. In an emergency, the pilots' suits will pressurize to nearly an additional 3 pounds per square inch (that is, 3 pounds per square inch gauge, or psig—pressure that is measured in addition to the atmospheric pressure at that location) while maintaining a slight positive pressure of 0.04 psi within



A NASA Airborne Science ER-2 aircraft. (Image Credit: NASA, <http://www.nasa.gov/centers/dryden/news/FactSheets/FS-046-DFRC.html>)



Astronaut Rick Mastracchio, STS-118 mission specialist, on the mission's first planned session of extravehicular activity (EVA). (Image Credit: NASA, <http://archive.org/details/HSF-photo-s118e06305>)

the face cavity of the helmet. This positive breathing pressure environment will remain the same whether the suit is inflated or not. These suits are also equipped with standard survival gear for short-term water and land survival. When comparing air pressure psi, at sea level Earth's surface air pressure is about 14.7 psia. At about 9.1 kilometers (30,000 feet), air pressure is 4.3 psia. Astronauts on spacewalks use suits pressurized at 4.3 psia, and the pressure in high-altitude pilot suits varies with the altitude but rarely goes above 3 psi.

Other explorers, including high-altitude balloonists as well as deep ocean explorers, also need protective suits or environments. While their basic needs are the same—the regulation of pressure and temperature, the ability to breathe, and the ability to perform specific tasks—they are accomplished differently depending on the outside environment. In high-altitude, low-pressure environments, pressure suits or pressurized capsules of some kind are needed to exert pressure on the body. In contrast, for deep sea, high-pressure environments, humans must be protected from the excessive pressure outside their

bodies. For deep sea exploration, pressure suits cannot protect us. Instead, we need to rely on an enclosure that will prevent too much pressure from pushing in on us. Historically, early designers such as Auguste Piccard worked on creating gondolas, in this case metal spheres, that would protect both high-altitude balloonists and deep sea explorers. In 1930, Piccard designed a pressurized aluminum gondola that would allow balloonists to reach heights of up to 75,000 feet (about 22,860 meters) without a pressure suit. Then, in 1937, he worked on a steel gondola for deep ocean exploration, which the French Navy redesigned and ultimately used to take men safely to 13,701 feet (4,176 meters) below the ocean surface. While the pressures were different for each situation (low pressure for high altitude and high pressure for ocean exploration), the human need for pressure regulation was the same. Today, high-altitude balloonists must either stay inside a pressurized gondola or wear full pressure suits. Deep sea explorers must remain inside pressurized gondolas or vehicles while in the depths of the ocean.



The deep sea submarine Ben Franklin made space exploration history in 1969 by studying the behavior of aquanauts in a sealed, self-contained, self-sufficient capsule. (Image Credit: NASA, <http://www.nasa.gov/vision/space/preparingtravel/px15.html>)

So what exactly happens to the human body in low-pressure environments?

Information about what happens to humans in low-pressure or vacuum environments is limited because there haven't been many situations in which humans have had to survive in these conditions. However, we have gained information about human survival in extremely low pressures in several incidents including pilot and suit testing in vacuum chambers, in a situation in which an astronaut punctured his glove, in a high-altitude balloon experience when the pilot lost a glove, and in an incident during a Russian spacecraft reentry problem.

The first part of the explanation will cover the human body in space, since that is the most extreme of the high-altitude environments for humans. If a human being were to be subjected to space without a spacesuit of any kind, there would be a lack of air, which means both a lack of oxygen to breathe and a lack of air pressure to help our bodies function as they were meant to. Hypoxia would occur, which is an inadequate oxygen supply to the cells and tissues of the body.

The central nervous system, which includes the brain and the eyes, is particularly sensitive to oxygen deficiency. Very low

oxygen levels result in impaired judgment and ability to concentrate, lack of night vision acuity, shortness of breath, nausea, and fatigue. For about the first 9 to 11 seconds, there would probably be some degree of consciousness, although you would only have between 5 and 10 seconds to help yourself. (High-altitude pilots and astronauts are trained to react quickly to try to help themselves in these situations. Although they can't extend the amount of time to think and function in an emergency, they are prepared to take steps to help themselves and/or others within that time.) After 13 seconds, the human brain is acutely impaired. Because of this danger, the FAA requires an oxygen supply to be provided if the vehicle's cabin pressure is equal to or less than that found at 15,000 feet (about 4.6 kilometers).

While in space, your body would swell without a pressure suit because liquid in your soft tissues and, to a lesser extent, water in your circulatory system would begin to vaporize. Contrary to some existing myths, you would not explode—your skin is too strong for that to happen.

Your blood would not immediately boil in your veins because as long as blood was circulating through your system, circulating blood pressure would keep the water in your blood below its boiling point for that pressure. But within 1 minute, blood would no longer circulate. Gas and vapor would flow out of airways, cooling the mouth and nose to near-freezing temperatures. The water in your nose and on your tongue would begin to boil. Soon after that, the water that lines your lungs would also boil. In 1965, a test subject at NASA's Manned Spacecraft Center (which is now Johnson Space Center) was in a vacuum chamber while wearing a leaking space suit. When the vacuum chamber's pressure was at a near vacuum (less than 1 psia), the test subject remained conscious for about 14 seconds, then lost consciousness until the people running the experiment could repressurize the chamber. Once the chamber was repressurized to the equivalent of that found at 15,000 feet in altitude, or about 8.3 psia, the test subject regained consciousness. Later, he reported that as he was losing consciousness, he could hear air leaking from his body and could feel the water on his tongue begin to boil.

You would not instantly freeze solid, as some movies have shown. Space doesn't have an actual temperature since there are no molecules to measure. It is actually a good insulator because it is difficult to transfer heat to nothing. In fact, it is harder for humans to cool off when out in space. On Earth, this concept is used in vacuum bottles (such as a Thermos), which use a vacuum for insulation between the outside and inside of the bottle to help keep liquids warm.

Lungs are perhaps the most vulnerable part of the body if decompression occurs. Since the lungs contain a large volume of air and the lungs are made up of intricate airways, air's expansion within low pressures and/or the vacuum of space would most definitely affect the lungs. If a human were to hold his or her breath before going into space, the effect would be especially disastrous, since there would be little room for expansion. This effect is very similar to air embolisms that can occur in scuba divers if they ascend from lower depths while holding their breath.

If recompression occurred within about 60 to 90 seconds, as long as the person didn't hold his or her breath, it would be possible for him or her to survive, and recovery would be quick.

Because of the human body's vulnerability in low-pressure environments, there has been years of research and development of methods to help humans both survive and function in low-pressure situations. A properly fitted pressure suit can restrain the body and prevent both swelling and water vaporization in soft tissues under pressures as low as 15 millimeters of mercury (mmHg) absolute, which is 0.29 psia. While the description above discusses the most extreme of low-pressure environments—the vacuum of space—other low-pressure situations in which high-altitude pilots fly have similar reactions. The higher the altitude, the more serious the effects on the human body.

Below are some NASA video resources that can be used to help explain concepts discussed above:

Where does space begin? BrainBites:

<http://brainbites.nasa.gov/#/where-does-space-begin>

Earth's atmosphere video clip:

http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/Earths_Atmosphere.html

Spacesuit video:

http://www.nasa.gov/mov/196817main_052_A_Look_At_Spacesuit.mov

EVAs and problems we encounter in space video clip:

http://www.nasa.gov/mov/217387main_079_Space_Environment.mov

How do you scratch your nose in space?

<http://brainbites.nasa.gov/#/scratch-nose-in-spacesuit>

What Is Atmospheric Pressure? video:

http://www.nasa.gov/audience/foreducators/topnav/materials/listbytype/What_is_Atmospheric_Pressure.html

Pressure Lesson One: Survival in a Vacuum

GRADES
5–12

Objective

Students will learn about the properties of matter and the changes of these properties in matter, as well as the structures and functions in living systems, as they conduct experiments on pressure.

Lesson Overview

Students will conduct basic experiments on pressure using a vacuum pump, marshmallows (or Peeps), and balloons in order to help them understand what happens to the human body in a reduced-pressure and/or near vacuum environment. In addition, students will develop a method for retaining the marshmallow at normal pressure while in a vacuum chamber, simulating the effects of a pressure suit.

Materials

Vacuum pump and jar¹ (please see options below for other ways to conduct this lesson)

Small balloons

Large marshmallows or Peeps (Peeps make a much more dramatic demonstration)

Small marshmallows

Various materials for students to develop a pressure suit for their marshmallows (items could include tape, latex or nitrile gloves, and small containers such as film canisters)

Large plastic syringes (60 cubic centimeters) with caps or clay to block the tip

Design packet (can be downloaded at http://www.nasa.gov/pdf/324206main_Design_Packet_II.pdf)

Student worksheets

Safety note: As a component of good safety practices, advise students that they should never eat their experiments, even if the materials are candy.

Introduction

When high-altitude pilots and astronauts travel above the lower layers of Earth's atmosphere, the air pressure exerted on them would be significantly reduced if they were not protected from the outside environment by a pressurized cockpit or capsule or a specially designed suit. This reduction in air pressure would be harmful or even fatal to a pilot or astronaut. To protect pilots from this situation, engineers have developed various types of pressure suits that allow pilots and astronauts to function in these environments. Pressure suits exert pressure on the human body when external environments lack the pressure usually provided by the air at lower altitudes. In the event of aircraft cabin pressure loss at high altitudes, such as about 70,000 feet, where high-altitude aircraft such as the U-2 *fl*, engineers have developed partial pressure and full pressure suits. Development of high-altitude pilot suits led to the evolution of the spacesuit (background information at the beginning of this curriculum discusses these types of suits in further detail). Loss of cabin pressure on aircraft flying

¹ There are several alternatives to using a more-expensive vacuum pump for this activity. Science supply companies also sell less-expensive vacuum pump options such as hand-operated vacuum pumps and microscale bell jar and vacuum sets. Both of these options create a partial vacuum environment, which would be suitable for this experiment.

Alternatively, you could use a food sealer instead of the more-expensive vacuum pump. Many kitchen vacuum food sealers have an optional jar sealer that can be attached to a mason jar that works well to create a partial vacuum environment.

at lower altitudes does result in hazards to fliers such as loss of consciousness or hypoxia but does not lead to other medical problems experienced by fliers at higher altitudes. So how does a reduction in air pressure, whether high in Earth's atmosphere or in space, affect living organisms? The following activities allow students to simulate the effects of reduced pressure on objects and to develop their own "pressure suits" to tackle the challenge of preventing those effects.

The NASA Aeronautics Research Mission Directorate's 2012 publication, *Dressing for Altitude: U.S. Aviation Pressure Suits—Wiley Post to Space Shuttle*, is a book about the development and operation of pressure suits in aviation and access to space via the Space Shuttle. This book contains more detailed information about pressure suits and can be accessed as a free download in multiple formats for most platforms from the following location: http://www.nasa.gov/connect/ebooks/dress_for_altitude_detail.html.

Procedure

The first two activities can be completed as an introductory demonstration. After background information has been given to students, allowing them to connect the demonstration and last two activities to human survival in a high-altitude, low-pressure or near vacuum environment, students will be able to see why humans need assistance to survive in these situations. Several links to short video clips are also included, which may be shown to help explain low-pressure environments.

Caution: If you have never used a vacuum pump and bell jar before, use caution when placing objects in the vacuum chamber. Objects can break when exposed to vacuum conditions, sometimes damaging the bell jar in the process. Always check to make sure the bell jar is in good condition (no cracks or signs of excessive wear), that seals and gaskets are clean, and that you know how to operate a vacuum chamber. When you repressurize the chamber following an activity, items in the chamber will not stay where they are when air floods back in (for example, the marshmallows or Peeps will bounce all over the inside of the chamber), so use care. Also take into consideration that many of your students' pressure suit designs for activity four may not hold up in a vacuum chamber, so be aware of what materials they are using for their suits.

Activity One: Peeps in Peril

The human body, when exposed to the vacuum of space, would swell if it were not contained in a pressure suit. Large marshmallows or marshmallow Peeps will also expand in a vacuum, so this demonstration is a good replication of what the human body would do without a suit.

Materials

Vacuum pump and jar²

Large marshmallows or Peeps

Student worksheets

- 1) Ask students what they think will happen when the marshmallow or Peep is placed in a vacuum and why. Have them record their answers on their worksheet.
- 2) Place your marshmallow and/or Peep in the bell jar (you can put more than one in the bell jar at once).
- 3) Turn on the vacuum pump and have students observe the difference in size of the marshmallows. Ask students why they think this is happening.
- 4) When finished, turn off the pump and repressurize the chamber. Have students observe what happens to the marshmallow or Peep. If necessary, explain that the air has been forced out of the marshmallow or Peep during the vacuum process. Based on that piece of information, ask them to explain why the marshmallows are now shriveled once air pressure has been reintroduced.



Marshmallow Peeps before the vacuum pump was turned on.



Marshmallow Peeps during air evacuation from pump.



Marshmallow Peeps at full vacuum.



Marshmallow Peeps after repressurization.

² There are several alternatives to using a more-expensive vacuum pump for this activity. Science supply companies also sell less-expensive vacuum pump options such as hand-operated vacuum pumps and microscale bell jar and vacuum sets. Both of these options create a partial vacuum environment, which would be suitable for this experiment.

Alternatively, you could use a food sealer instead of the more-expensive vacuum pump. Many kitchen vacuum food sealers have an optional jar sealer that can be attached to a mason jar that works well to create a partial vacuum environment.

Activity Two: Balloons in a Vacuum

Like the marshmallows and Peeps, balloons will expand in a vacuum environment. Your skin and your lungs, which are somewhat similar to a balloon, can expand and stretch, but only to a certain point. Placing a small balloon inside the vacuum chamber will show students what would happen to your lungs if you were in a vacuum environment such as space.

Materials

Vacuum pump and jar³

Small balloon

Water (optional)

Student worksheets

- 1) Inflation a small balloon and place it inside the bell jar. Be careful not to overinflate the balloon or place too large of a balloon in the jar. The balloon will expand to many times its normal size, so leave plenty of room for expansion in the jar.
- 2) Turn on the vacuum pump and ask students to observe what is happening to the balloon in the vacuum.
- 3) **Optional:** For an extension to this activity, place a small balloon filled with water in the chamber. The balloon will expand when the pump is turned on, but not as much as with an air-filled balloon since water does not expand as a gas does. However, there is still air in the balloon, which allows the balloon to expand somewhat. The water in the balloon will begin to boil, even though the water's temperature is not increasing. (Information about water's boiling point can be found in the background information of this curriculum, and more activities about the relationship between temperature and pressure can be found in the temperature section of this guide. In addition, the short NASA video clip at http://www.nasa.gov/mov/196817main_052_A_Look_At_Spacesuit.mov shows water boiling in a balloon.) Use a transparent balloon so students can see the water.



Small balloon under normal sea-level pressure.



Small balloon under normal sea-level pressure.



Balloon in vacuum.

³ There are several alternatives to using a more-expensive vacuum pump for this activity. Science supply companies also sell less-expensive vacuum pump options such as hand-operated vacuum pumps and microscale bell jar and vacuum sets. Both of these options create a partial vacuum environment, which would be suitable for this experiment.

Alternatively, you could use a food sealer instead of the more-expensive vacuum pump. Many kitchen vacuum food sealers have an optional jar sealer that can be attached to a mason jar that works well to create a partial vacuum environment.

Activity Three: Hands-On Vacuum Environment

Although watching demonstrations about pressure is helpful, allowing students to create a vacuum and manipulate their own mini vacuum chamber strengthens their understanding about the effects of air pressure. In this activity, students will take small marshmallows and place them in a large plastic syringe. They will create a miniature pressure chamber that will allow them to change the amount of pressure acting on their marshmallows; then they will note the effects of various amounts of air pressure on the marshmallows.

Materials

Large plastic syringes with caps or pieces of clay to plug the ends of the syringes (one per student or small group of students)

Small marshmallows (several per student or group)

Student worksheets

Safety note: Always use a cap or piece of clay to cover the syringe tip opening (don't use your finger as a cap) to avoid injury.

- 1) Have students place a small marshmallow inside their syringe.
- 2) Have students replace the plunger of the syringe, making sure the rubber piece is about halfway down the syringe.
- 3) Once the plunger is in place, have students put the cap or the piece of clay on the tip of the syringe.
- 4) Once students have capped the tip of the syringe, ask students to pull back on the plunger, creating a lower-pressure environment. Students should note what happens to the marshmallow (it should expand).
- 5) Also have students push the plunger in as far as they can to create a higher-pressure environment, again noting what happens to the marshmallow (it should contract).
- 6) Let students experiment on their own with the marshmallow, noting the effects of changes in air pressure inside the syringe as they do so. Remind students that the effects of pressure on the marshmallow are similar to effects on human bodies as they go higher into Earth's atmosphere and then into space (the higher they go, the less pressure is exerted on them), but also as they travel underwater (the deeper they dive or swim, the more pressure is exerted on them).



Large syringe and marshmallow.



Creating a low-pressure environment for the marshmallow.

Activity Four: Designing a Pressure Suit

At this point, the activities have focused on the effects of pressure on objects and the human body. The final activity asks students to design a pressure suit for marshmallows or Peeps that would keep the Peep from expanding in a vacuum environment like it would without a pressure suit. An alternative activity follows the same procedure but uses a water balloon instead of a marshmallow. Students must design a pressure suit that will keep the water balloon from expanding and allowing the water in the balloon to boil. Activity One in this section shows students what happens to a marshmallow in a vacuum, and Activity Two shows students what happens to a balloons filled with air and with water. (More can be found about water boiling in a vacuum in the background section of this curriculum and in Activity One in the section about temperature.)

The two basic types of pressure suits are partial pressure suits and full pressure suits. In general terms, a partial pressure suit uses a tight-fitting suit to cover the body; then, when needed, the suit is squeezed using capstan tubes to stop the body from expanding (capstan tubes are inflatable rubber tubes covered by nylon restraint sleeves). Gloves with bladders that inflate to restrict the hands from expanding are also used. In general, a hard helmet with a partial face shield is used to protect the face and provide air to the crewmember, such as the one used with the classic MC-3 suits.



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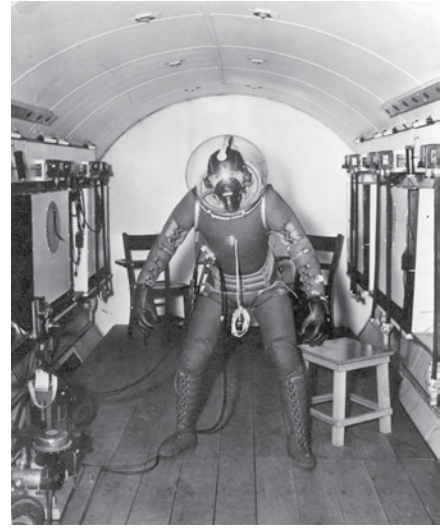
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A full pressure suit encases the body in its own environment. Think of a balloon filled with air, protecting the body. However, as the pressure decreases around a balloon, the balloon expands. A person could not function in that situation, so a restraint layer is also needed to keep the bladder layer, or balloon, from expanding past a certain size. Full pressure suits also usually have an exterior layer to protect the wearer and the inner workings of the suit. It is normally made out of a brightly colored (for visibility), fire-retardant material such as Nomex. Suits may also include anti-g garments as a layer, sometimes inserted along with an exposure layer to protect the occupant in case of a water landing. Anti-g layers are restraint layers of a suit that help counteract changes in pressure exerted on the body resulting from changes of gravitational pull (due to abrupt turns and maneuvers often encountered in fighter aircraft, as well as strong g-forces during rocket launches and landings). Most modern-day high-altitude aircraft use full pressure suits such as the S1034 used in the U-2 aircraft, while the Shuttle used both full and partial pressure suits, completing the program with the Advanced Crew Escape Suit (ACES) full pressure suit.



Crew members for Space Shuttle Endeavour's STS-126 mission depart for Launch Pad 39A. The sleeves of their tube-lined thermal suits are visible beneath their orange launch-and-entry suits. (Image Credit: NASA, http://www.nasa.gov/images/content/298053main_126_walkout_lg.jpg)

Additional information on partial and full pressure suits can be found in *Dressing for Altitude*. You can ask students to create either a partial pressure suit or a full pressure suit or let them choose which kind of suit they would like to design.

Materials

Larger marshmallows or Peeps (as before, Peeps make a more dramatic activity; in this case, they also simulate fitting a pressure suit around a person or animal)

Vacuum pump and bell jar⁴ (see below for additional equipment ideas)

Various materials for students to develop a pressure suit for their marshmallows (items could include tape, latex or nitrile gloves, and small containers such as film canisters and small plastic water bottles)

Design packet and student worksheets

- 1) Review the background information about pressure suits and the need for humans to have the restraint layer of the suit as they function in high altitudes and/or in space.



Food sealer vacuum chamber.

- 2) Tell students that they will need to design a pressure suit for their marshmallow or Peep that will keep it from expanding like it did in the earlier demonstration.

- 3) Have students complete steps 1 through 4 of their design packet (which can be downloaded at http://www.nasa.gov/pdf/324206main_Design_Packet_II.pdf).

- 4) Once the students have designed their pressure suits, have them construct their suits from available materials. Students will also complete step 5 in their packets.

⁴There are several alternatives to using a more-expensive vacuum pump for this activity. Science supply companies also sell less-expensive vacuum pump options such as hand-operated vacuum pumps and microscale bell jar and vacuum sets. Both of these options create a partial vacuum environment, which would be suitable for this experiment.

Alternatively, you could use a food sealer instead of the more-expensive vacuum pump. Many kitchen vacuum food sealers have an optional jar sealer that can be attached to a mason jar that works well to create a partial vacuum environment.

- 5) Test student designs in the vacuum chamber. Use an unprotected marshmallow or Peep as a control inside the chamber as well. Have students complete step 6 of their design packets.
- 6) Allow students to refine their designs and retest, using a new marshmallow or Peep. This is step 7 in their packets.
- 7) Finally, if time allows, have the students present their pressure suit prototypes to the class. Encourage the students to explain and share their designs, along with any challenges, hurdles, or failures along the way.

Activity hints: There are many variations to a pressure suit that can work for this activity. Several ideas include using tape to restrict expansion, cutting off fingers from rubber gloves (not thin, latex gloves, but rubber gloves used for household cleaning) and placing the Peep inside the finger, and placing the Peep inside a small water bottle.

NATIONAL SCIENCE STANDARDS

5–8

Abilities necessary to do scientific inquiry
Understanding about scientific inquiry
Properties and changes of properties in matter
Motions and forces
Structure and function in living systems
Abilities of technological design
Understandings about science and technology
Science and technology in society
Science as a human endeavor
Structure of the Earth system

9–12

Abilities necessary to do scientific inquiry
Understanding about scientific inquiry
Structure and properties of matter
Motions and forces
Natural and human-induced hazards
Science and technology in local, national, and global challenges
Science as a human endeavor

Survival in a Vacuum Student Worksheets

GRADES 5-12

Pre-Lab Questions

Before beginning your activities for this lesson, answer the following questions.

- 1) What concerns do you think humans have when flying or working in a high-altitude situation?

- 2) What do humans need to worry about when living or working in space?

- 3) Describe what you think happens in the following situations:
 - a) Pressure as you travel from sea level on Earth up to space:

 - b) Pressure as you travel from sea level on Earth down to the bottom of the ocean:

 - c) Air density as you travel from sea level on Earth up to space and why:

Activity One: Peeps in Peril

Observations

- 1) Make a drawing of the marshmallow or Peep prior to its being placed in the vacuum jar. Include the approximate initial measurements of the item.

- 2) Draw and describe what happened to the item while in the vacuum jar. Again, include the approximate measurements of the item while the vacuum pump was turned on.

- 3) Why do you think it reacted this way?

Activity Two: Balloons in a Vacuum

Observations

- 1) Make a drawing of the balloon prior to its being placed in the vacuum jar. Include the approximate initial measurements of the inflated balloon.
- 2) Draw and describe what happened to the balloon while in the vacuum jar. Again, include the approximate measurements of the balloon while the vacuum pump was turned on.
- 3) Why do you think it reacted this way?

Questions for Optional Water Balloon Activity

- 1) Draw and describe what happened to the water-filled balloon in the vacuum jar.
- 2) Compare and contrast the water-filled balloon's reaction with that of the air-filled balloon in a vacuum.
- 3) Why do you think the water-filled balloon and the air-filled balloon reacted differently?
- 4) Explain how the reaction of the water-filled balloon is similar to how the human body would react in a vacuum.

Activity Three: Hands-On Vacuum Environment

For this activity, you will be creating a miniature pressure chamber with a large plastic syringe and a cap or piece of clay to seal the tip of the syringe. Follow the instructions below and complete the questions.

Be sure to follow the steps in the correct order so you create the proper pressure within your chamber.

- 1) Place a small marshmallow inside your syringe.
- 2) Replace the plunger of the syringe, making sure the rubber piece is about halfway down the syringe.
- 3) Once the plunger is in place, put the cap or the piece of clay on the tip of the syringe. **Do not place the cap on the tip of the syringe until the plunger is halfway down the inside of the syringe or you will not be able to properly change the pressure inside your chamber.**
- 4) Once you have capped the tip of the syringe, pull back on the plunger.
 - a) What is happening to the pressure as you pull back on the plunger? Explain this in a complete sentence and draw a picture of the air molecules inside the syringe at this point.

 - b) What happened to the marshmallow? Explain in a complete sentence and draw a picture.
- 5) Now push the plunger in as far as you can.
 - a) What is happening to the pressure as you push in the plunger? Explain this in a complete sentence and draw a picture of the air molecules inside the syringe at this point.

b) What happened to the marshmallow? Explain in a complete sentence and draw a picture.

6) Experiment on your own with the marshmallow, noting the effects of changes in air pressure inside the syringe as you do so. The effects of pressure on the marshmallow are similar to effects on human bodies as they go higher into Earth's atmosphere and then into space (the higher they go, the less pressure is exerted on them). In addition, increasing the pressure inside the chamber mimics the effects of traveling underwater (the deeper you dive or swim, the more pressure is exerted on you).

a) Describe some of the effects of your own experimentation with the marshmallow inside the pressure chamber.

d) Pressure suit for high-altitude skydiving (high-altitude skydiving occurs at least 23,000 feet above Earth's surface)

Type of Suit	Abilities of Suit	Limitations of Suit	Changes from Original Design
Original design: partial or full (circle one)			n/a
1.			
2.			

Survival in a Vacuum Student Worksheets

GRADES

5-12

Answer Key

Pre-Lab Questions

Before beginning your activities for this lesson, answer the following questions.

- 1) What concerns do you think humans have when flying or working in a high-altitude situation?

Answers will vary but may include the need to protect against temperature extremes or UV radiation, the need for oxygen to breathe, and the need to wear a pressurized suit.

- 2) What do humans need to worry about when living or working in space?

Answers will vary but will probably be similar to the answers for question one. Some students may also add the need to protect against micrometeors. For the longer term, humans also need to worry about muscle loss, osteoporosis, and many other health factors.

- 3) Describe what you think happens in the following situations:

- a) Pressure as you travel from sea level on Earth up to space:

Students should answer that pressure will decrease

- b) Pressure as you travel from sea level on Earth down to the bottom of the ocean:

Students should answer that pressure will increase. As a side note, students may wonder if a pressure suit can be used underwater. The suits do not protect divers underwater because pressure suits **exert** pressure and do not help a diver **withstand** existing pressure, which is what a diver encounters underwater.

- c) Air density as you travel from sea level on Earth up to space and why:

Students should answer that air density will decrease because there is less and less air the higher you travel in the atmosphere.

Activity One: Peeps in Peril

Observations

- 1) Make a drawing of the marshmallow or Peep prior to its being placed in the vacuum jar. Include the approximate initial measurements of the item.

Answers will vary.

- 2) Draw and describe what happened to the item while in the vacuum jar. Again, include the approximate measurements of the item while the vacuum pump was turned on.

Answers will vary, but students should notice that the marshmallows expanded while the pump was turned on (then shriveled once the pump was turned off and the chamber as repressurized).

- 3) Why do you think it reacted this way?

Answers will vary, but students should be able to answer that before the marshmallows or Peeps were placed in the vacuum chamber, the air pressure pushing in on the marshmallow was equal to the pressure exerted by the trapped air inside the marshmallow—approximately 14.7 psia or pounds per square inch absolute. As the pressure decreased inside the chamber, the greater pressure within the marshmallow caused the marshmallow to expand. In addition, some of the air molecules that were contained within the marshmallow were now being pulled out of the marshmallow. As the pressure was equalized after the pump was turned off and the chamber as repressurized, the marshmallow shriveled, allowing students to see that some of the air molecules were pulled out of the marshmallow.

Activity Two: Balloons in a Vacuum

Observations

- 1) Make a drawing of the balloon prior to its being placed in the vacuum jar. Include the approximate initial measurements of the inflated balloon.

Answers will vary.

- 2) Draw and describe what happened to the balloon while in the vacuum jar. Again, include the approximate measurements of the balloon while the vacuum pump was turned on.

Answers will vary, but students should notice that the balloon expands and oftentimes fills the vacuum chamber.

- 3) Why do you think it reacted this way?

The size and shape of the inflated balloon is a relationship between the air pressure inside the balloon and the pressure exerted on the balloon from the outside. When the pressure is reduced around the outside of the balloon, the air molecules inside the balloon can exert more pressure against the inside of the balloon, causing the balloon to expand.

Questions for Optional Water Balloon Activity

- 1) Draw and describe what happened to the water-filled balloon in the vacuum jar.

Students should notice that the water-filled balloon expands a small amount, but not as much as the air-filled balloon. The water in the balloon should begin to boil soon after the balloon is in a vacuum situation.

- 2) Compare and contrast the water-filled balloon's reaction with that of the air-filled balloon in a vacuum.

Answers will vary, but students should observe that the air-filled balloon expands more than the water-filled balloon, although both expand. The water inside the balloon boils. Be sure to clarify to students that the balloon is not getting hot, a misconception students may have since the water begins to boil. Pressure reduction inside the vacuum chamber lowers the boiling point of water, which is why the water begins to boil.

- 3) Why do you think the water-filled balloon and the air-filled balloon reacted differently?

Students should recognize that the air in the balloon is a gas and the water in the other balloon is a liquid. Gases and liquids have different properties, and a liquid does not expand in a vacuum like a gas does.

- 4) Explain how the reaction of the water-filled balloon is similar to how the human body would react in a vacuum.

Like the water-filled balloon, our bodies contain large amounts of water. In addition, our bodies have air, much like the water-filled balloon does. If a human were exposed to the vacuum of space or the low pressure high in our atmosphere, the water would boil inside our bodies and the air would expand.

Activity Three: Hands-On Vacuum Environment

For this activity, you will be creating a miniature pressure chamber with a large plastic syringe and a cap or piece of clay to seal the tip of the syringe. Follow the instructions below and complete the questions.

Be sure to follow the steps in the correct order so you create the proper pressure within your chamber.

- 1) Place a small marshmallow inside your syringe.
- 2) Replace the plunger of the syringe, making sure the rubber piece is about halfway down the syringe.
- 3) Once the plunger is in place, put the cap or the piece of clay on the tip of the syringe. **Do not place the cap on the tip of the syringe until the plunger is halfway down the inside of the syringe or you will not be able to properly change the pressure inside your chamber.**
- 4) Once you have capped the tip of the syringe, pull back on the plunger.
 - a) What is happening to the pressure as you pull back on the plunger? Explain this in a complete sentence and draw a picture of the air molecules inside the syringe at this point.

Pressure is decreasing.
 - b) What happened to the marshmallow? Explain in a complete sentence and draw a picture.

The marshmallow expands.
- 5) Now push the plunger in as far as you can.
 - a) What is happening to the pressure as you push on the plunger? Explain this in a complete sentence and draw a picture of the air molecules inside the syringe at this point.

Pressure inside the syringe is increasing.
 - b) What happened to the marshmallow? Explain in a complete sentence and draw a picture.

The marshmallow should shrivel up.
- 6) Experiment on your own with the marshmallow, noting the effects of changes in air pressure inside the syringe as you do so. The effects of pressure on the marshmallow are similar to effects on human bodies as they go higher into Earth's atmosphere and then into space (the higher they go, the less pressure is exerted on them). In addition, increasing the pressure inside the chamber mimics the effects of traveling underwater (the deeper you dive or swim, the more pressure is exerted on you).
 - a) Describe some of the effects of your own experimentation with the marshmallow inside the pressure chamber.

Answers will vary.

Activity Four: Designing a Pressure Suit

For this activity, use the design packet.

Post-Lab Questions

Once you have completed the above activities, answer the following questions:

- 1) Based on the above activities, explain how a pressure suit would help you if you were working in a high-altitude environment or up in space.

A pressure suit exerts pressure on the person wearing the suit. As the outside pressure decreases, either at high altitudes or in space, a person without a suit would swell to about twice his or her normal size. Wearing a pressure suit would keep the body contained and prevent the person from swelling.

- 2) What is the difference between a partial pressure suit and a full pressure suit?

A partial pressure suit exerts pressure on the body but does not fully contain or seal the person off from the outside environment. The full pressure suit is a fully contained unit that enables the person to exist in a controlled environment.

- 3) Take the design you made for your pressure suit, choose two of the following suit requirements, and explain what would have to happen to the design of your suit in order to meet them:

- a) Full pressure high-altitude pilot suit

A full pressure, high-altitude pilot suit would have to contain air to breathe and exert pressure on the body. Arms and hands would have to be able to move in order for the pilot to land the aircraft. The pilot would also have to be able to see.

- b) Spacesuit designed for working outside the International Space Station

The spacesuit would have to protect the astronaut from the near vacuum of space, from UV radiation, from extreme hot and cold temperatures, and from micrometeors. Like the high-altitude pilot, the astronaut would have to be able to move his or her arms and hands. However, unlike with earlier spacesuits that needed to be functional for walking on the Moon, lower limbs are not really used on spacewalks today.

- c) Emergency suit for use inside the International Space Station

Someone using an emergency suit for use inside the Space Station would need air to breathe and the ability to use his or her hands and arms.

- d) Pressure suit for extreme high-altitude skydiving (as of 2012, three people have made high-altitude jumps over 70,000 feet).

The pressure suit for high-altitude skydiving would be a full pressure suit because the skydiver would need air to breathe, pressurization, and protection from the elements. The suit would be inflated during the full flight up and then the jump. The skydiver would need some mobility to control the flight of the parachute and operate any equipment on ascent and descent.

Type of Suit	Abilities of Suit	Limitations of Suit	Changes from Original Design
Original design: partial or full (circle one)			n/a
1.	Answers will vary.		
2.			

Pressure Lesson Two: Air Has Pressure

GRADES

5–12

K–4: Demonstration

This lesson can be taught as a demonstration at the K–4 level to introduce students to the concept of air pressure. Worksheets and math skills that accompany this lesson are designed for higher grades.

Objective

Students will learn about the properties of matter and how those properties change as air pressure does. Students will also learn about motions and forces as they participate in activities that show that air exerts pressure.

Lesson Overview

Four hands-on activities about air pressure highlight that air has pressure and that air takes up space. Students will try to put a straw through a potato with and without air pressure inside the straw. They will attempt to pull apart Magdeburg vacuum plates, which are held together with air pressure, and will lift a soda can from a flat surface while it is held down with suction and air pressure.

Materials

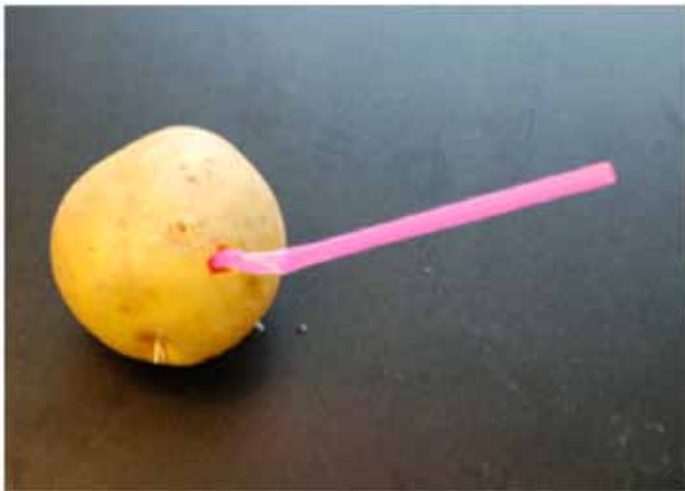
Potatoes and drinking straws (one per student or group)
Magdeburg vacuum plates
Handheld vacuum pump
Lil' Suctioner rubber suction cup
Unopened soft drink can
Student worksheets

Safety note: When stabbing the potato with the straw, place the potato on a flat surface while holding the sides (not the bottom!) to avoid injury.

Activity One: Potato and Straw Experiment

In this activity, students are challenged to stab a straw through a potato without bending or breaking the straw. The key to getting the straw to go through the potato is to create a pocket of air in the straw by placing your thumb over one end. The pressure exerted on the insides of the straw by the air will make the straw strong enough for the task.

Caution: This activity asks students to stab potatoes with a straw. Be sure to caution students about the safety of this activity. Remind students to hold the potato on the sides and not to hold the potato underneath so that they don't stab themselves.



An open straw has equal pressure inside and out. It is not very rigid and will not go very far into the potato without buckling.



When the end of the straw is blocked, pressure increases inside the straw as it is pushed into the potato, thus increasing the rigidity of the straw and preventing buckling.

Materials

Per student or group:

Drinking straw (straight, inflexible straw; cut flexible end off if necessary)

Potato

- 1) Challenge students to stab the straw through their potato without bending or breaking the straw. Tell students they may not add anything to reinforce the straw (such as tape) and ask them how they might be able to accomplish the task. Warn students to be careful to hold the potato on the sides and not the bottom so that they don't stab themselves with the straw.
- 2) You can either show students that it can be done ahead of time, being careful not to give away the secret to the success of the experiment, or you can wait until students figure it out before you show that you, too, can stab your potato.
- 3) Once students have figured out how to correctly stab their potatoes, discuss how air pressure inside the straw was responsible for reinforcing the straw.

Activity Two: Magdeburg Vacuum Plates

Pressure is defined as the amount of force acting on a unit of area (e.g., pounds per square inch). It is usually more convenient to use pressure rather than force to describe the influences upon fluid behavior. Air is a fluid. At sea level, the weight of the atmosphere is pushing down on with a force of 14.7 pounds over every square inch of surface.

In 1684, Otto von Guericke (the inventor of the air pump) placed two empty copper hemispheres called Magdeburg hemispheres (after the name of the town in which the demonstration took place) together and removed the air from between them. Two teams of horses could not separate them.

Students will replicate this classic physics demonstration on the effect of air pressure. A simple hand-operated vacuum pump is used to produce a partial vacuum between two small plastic plates separated by an O-ring. Using the value for standard air pressure at sea level, students will predict the force necessary to separate the two plates.



Magdeburg vacuum plates.

Materials

Magdeburg vacuum plates

Handheld vacuum pump assembly (vacuum pump setup and assembly are easier with two people)

- 1) Attach the hand pump assembly to the vacuum plate that contains the hose port. The assembly consists of several small hoses, two one-way valves, and a branch assembly. The flared side of the one-way valve should face the vacuum plates.
- 2) Attach the large syringe to the branch assembly. This is your vacuum pump.
- 3) Place either the small O-ring or the large O-ring between the vacuum plates and hold the plates together (do not use both O-rings at the same time). Steps 3 and 4 work best with two people.
- 4) Pull back on the syringe plunger to evacuate the air from between the two plates.
- 5) Pump the plunger back and forth a few times to remove as much air as possible (since there is a one-way valve attached to the assembly, you don't have to worry about repressurizing the plates).

- 6) Loosen the hose from the plate; you now have a vacuum between the plates.
- 7) Have two students hold the vacuum plates (one holding on to each plate) and ask them to pull the plates apart.
- 8) Repeat the steps above using the other O-ring. Ask students which one made the plates harder to separate. Why?
- 9) Have students calculate the amount of force needed to separate both sets of plates using the equation **Pressure = Force ÷ Area** or **Force = Pressure × Area**. You can use the standard for atmospheric pressure at sea level of 14.7 psi (pounds per square inch) or if you know the specific atmospheric pressure in your location, replace that value.

Activity Three: Lil' Suctioner

This next activity about air pressure uses a device called a Lil' Suctioner, which is a circular foam section that uses air pressure to hold a soda can on a table. Again, using standard air pressure, students calculate the force of air pressure exerted on the device.

Materials

Lil' Suctioner rubber suction cup
One unopened soft drink can
Scale
Calculator

Safety note: When pulling up on the soft drink can, do not lean directly over the can or allow students to lean directly over the can.



Lil' Suctioner and soda can.

- 1) Have students weigh the soft drink can. Ask them how much force they think is needed to lift that can (force = mass \times acceleration, or $F = m \times a$). In this case, a = the acceleration due to gravity, or 9.8 meters per second squared.
- 2) Ask students to predict what will happen when you stick the can to a flat surface with the Lil' Suctioner.
- 3) Turn the unopened can upside down and stretch the Lil' Suctioner over the bottom of the can (the fabric side should be facing down).
- 4) Turn the can right-side up and slide the suctioner down to about $\frac{1}{2}$ inch from the bottom of the can edge.
- 5) Press the suctioner to a flat, nonporous surface.
- 6) Have one student, or several students, try to pick up the can (you can easily reattach the suctioner to the flat surface by pressing down on it), noting how much force it takes to do that. Students will be able to remove the can, but it will be difficult.
- 7) Ask students why this is happening.
- 8) Finally, have students calculate the weight of the air pushing down on the Lil' Suctioner. (Note: You can easily lift the can from the flat surface by lifting up one edge of the suctioner, repressurizing the area under the suctioner.)

NATIONAL SCIENCE STANDARDS

K-4

Abilities necessary to do scientific inquiry
Understandings about scientific inquiry
Properties of objects and materials

5-8

Abilities necessary to do scientific inquiry
Understandings about scientific inquiry
Properties and changes of properties in matter
Motions and forces
Structure of the Earth system

9-12

Abilities necessary to do scientific inquiry
Understandings about scientific inquiry
Structure and properties of matter
Motions and forces

Pressure Lesson Two: Air Has Pressure Worksheet

Activity One: Potato and Straw Experiment

For this activity, your task is to get the straw through the potato. You cannot use anything else besides the straw, and you cannot alter the straw in any way. Can you do it without bending or breaking the straw?

Caution: When stabbing the potato with the straw, be careful to hold the potato from the sides and not underneath so that you don't stab your hand or fingers in the end.

1) Describe what techniques you tried. Which techniques worked? Which ones didn't work?

2) Explain why some of the techniques you tried didn't work and why some did work.

Activity Two: Magdeburg Vacuum Plates

- 1) Measure the inside diameter of the O-ring that is used to separate the two plastic plates. Use inches if you are figuring out force in pounds and meters if you are measuring force in Newtons. To convert from pounds to Newtons, multiply the number of pounds by 4.45. If you are using kilograms, multiply kilograms by 9.8 to get Newtons.
- 2) Determine the area inside the O-ring ($\pi \times r^2$).
- 3) Using standard atmospheric pressure (14.7 pounds per square inch or 1.013×10^5 Newtons per square meter), determine the force necessary to separate the plates once the air has been evacuated from between the plates. Show your work.
- 4) Repeat steps 1 through 3 to figure out the force necessary to separate the plates using the other O-ring. Again, show your work.
- 5) Explain what is happening to keep these plates together. Add an illustration if needed.

Activity Three: Lil' Suctioner

The Lil' Suctioner is an example of an invention that failed in its original purpose but became useful in another way. A graduate student was trying to develop a flashlight hood that would block glare and improve visibility. The invention did not work as designed, but the designer found that it was very useful for holding items to flat surfaces. In this activity, the Lil' Suctioner will be used to hold a soda can to a flat surface.

Pre-Activity Questions

1) Look at the can of soda. How much do you think a full can of soda weighs in ounces? Using the conversion of 1 oz = 28.4 g, convert your estimate to grams.

2) Explain how you think the Lil' Suctioner works to hold a can of soda to a flat surface. Draw a picture if that helps.

Post-Activity Questions

After the demonstration, answer the following questions:

1) Weigh the can of soda with a scale. How much does it weigh? (You need to write your answer in grams.)

2) Based on your answer to question #1, figure out how much force is needed to lift a can of soda. $F = m \times a$ (force = mass \times acceleration). Use kilograms for mass and 9.8 meters per second squared for the force. Show your work. When using the Lil' Suctioner, air pressure is pushing down on the can and suctioner. Since the air has been removed from under the suctioner, there is no air to help equalize the force of the air from above.

Using the radius of the Lil' Suctioner and standard air pressure, calculate the total force of the air pushing down on the suctioner and can of soda. **$r = 2.19$ inches** and **standard air pressure = 4.7 pounds per square inch**. Use the equation **$\pi \times r^2 \times \text{standard air pressure} = \text{total pressure (pound-force, or lb-F)}$** . Then convert pound-force to Newtons using the conversion 1 pound-force = approximately 4.5 Newtons. Show your work.

- 3) Finally, calculate the amount of force needed to lift the can of soda when attached to the Lil' Suctioner. Use your answer to question #3 to help answer this question. Explain your answer.

Pressure Lesson Two: Air Has Pressure Worksheet

GRADES

5-12

Answer Key

Activity One: Potato and Straw Experiment

For this activity, your task is to stab the straw through the potato. You cannot use anything else besides the straw, and you cannot alter the straw in any way. Can you do it without bending or breaking the straw?

Caution: When stabbing the potato with the straw, be careful to hold the potato from the sides and not underneath so that you don't stab your hand or fingers in the end.

1) Describe what techniques you tried. Which techniques worked? Which ones didn't work?

Answers will vary. Students should note that the straw bent or broke when the top of the straw was not sealed off, which would hold the air inside the straw and strengthen the straw. Covering the top of the straw with their thumb would allow a buildup of air pressure inside the straw to increase the rigidity of the straw and allow them to stab the straw through the potato.

2) Explain why some of the techniques you tried didn't work and why some did work.

Answers will vary, but students should be able to explain that additional air pressure inside the straw is needed to increase the straw's rigidity. In addition, stabbing the potato quickly works better than trying to poke the straw through the potato more slowly.

Activity Two: Magdeburg Vacuum Plates

- 1) Measure the inside diameter of the O-ring that is used to separate the two plastic plates. Use inches if you are figuring out force in pounds and meters if you are measuring force in Newtons. To convert from pounds to Newtons, multiply the number of pounds by 4.45. If you are using kilograms, multiply kilograms by 9.8 to get Newtons.

Larger O-ring (approx.):

In inches: 3.35 in (outside diameter is approx. 3.77 in); radius = 1.68 in

In centimeters: 8.5 cm (outside diameter is approx. 9.5 cm); radius = 4.25 cm

Smaller O-ring (approx.):

In inches: 1.97 in (outside diameter is approx. 2.39 in); radius = 0.99 in

In centimeters: 5.0 cm (outside diameter is approx. 6.0 cm); radius = 2.5 cm

- 2) Determine the area inside the O-ring ($\pi \times r^2$).

Larger O-ring:

In inches: $\pi \times 1.68^2 = 8.86 \text{ in}^2$

In centimeters: $\pi \times 4.25^2 = 56.7 \text{ cm}^2$

Smaller O-ring:

In inches: $\pi \times 0.99^2 = 3.08 \text{ in}^2$

In centimeters: $\pi \times 2.5^2 = 19.63 \text{ cm}^2$

- 3) Using standard atmospheric pressure (14.7 pounds per square inch or 1.013×10^5 Newtons per square meter), determine the force necessary to separate the plates once the air has been evacuated from between the plates. Show your work.

The calculations below will use force (F) = pressure (P) \times area (A). An assumed standard air pressure of 14.7 pounds per square inch will be used. Actual air pressure for your location can be substituted here if you know that number.

Larger O-ring: $A = 8.86 \text{ in}^2$ or 56.7 cm^2

English units: $F = 14.7 \text{ lb/in}^2 \times 8.86 \text{ in}^2$

$F = 130.2 \text{ lb}$

Metric units (convert cm to m): $F = 101,300 \text{ N/m}^2 \times 0.57 \text{ m}^2$

$F = 577 \text{ N}$

Smaller O-ring: $A = 3.08 \text{ in}^2$ or 19.63 cm^2

English units: $F = 14.7 \text{ lb/in}^2 \times 3.08 \text{ in}^2$

$F = 45.3 \text{ lb}$

Metric units (convert cm to m): $F = 101,300 \text{ N/m}^2 \times 0.20 \text{ m}^2$

$F = 203 \text{ N}$

- 4) Repeat steps 1 through 3 to figure out the force necessary to separate the plates using the other O-ring. Again, show your work.

See above for both O-rings.

5) Explain what is happening to keep these plates together. Add an illustration if needed.

Answers will vary, but students should explain that air pressure is pushing on the plates from the outside, and when the air has been evacuated from between the plates, there is no equalizing pressure on the inside of the plates. If there were no difference in air pressure, then the plates would not stay together. However, without air pressure on the inside, between the plates, the normal atmospheric pressure of the air on the outside of the plates is pushing on the plates, keeping them together.

Activity Three: Lil' Suctioner

The Lil' Suctioner is an example of an invention that failed in its original purpose but became useful in another way. A graduate student was trying to develop a flashlight hood that would block glare and improve visibility. The invention did not work as designed, but the designer found that it was very useful for holding items to flat surfaces. In this activity, the Lil' Suctioner will be used to hold a soda can to a flat surface.

Pre-Activity Questions

- 1) Look at the can of soda. How much do you think a full can of soda weighs in ounces? Using the conversion of 1 oz = 28.4 g, convert your estimate to grams.

Cans of soda will vary slightly, but on average, a full can of soda should weigh just under 14 ounces (about 390 g).

- 2) Explain how you think the Lil' Suctioner works to hold a can of soda to a flat surface. Draw a picture if that helps.

With the air removed from underneath the Lil' Suctioner and can of soda, a vacuum is formed. Air pressure from above the suctioner and soda is pushing down on the soda, making it very difficult to pull the can from the flat surface.

Post-Activity Questions

After the demonstration, answer the following questions:

- 1) Weigh the can of soda with a scale. How much does it weigh? (You need to write your answer in grams.)

Cans of soda will vary slightly, but on average, a full can of soda should weigh just under 14 ounces (about 390 grams).

- 2) Based on your answer to question #1, figure out how much force is needed to lift a can of soda. $F = m \times a$ (force = mass \times acceleration). Use kg for mass and 9.8 m/s^2 . Show your work.

$$m = 390 \text{ g} = 3.9 \text{ kg}$$

$$a = 9.8 \text{ m/s}^2$$

$$F = 3.9 \text{ kg} \times 9.8 \text{ m/s}^2$$

$$F = 38.2 \text{ N (N = kg} \times \text{m/s}^2)$$

When using the Lil' Suctioner, air pressure is pushing down on the can and suctioner. Since the air has been removed from under the suctioner, there is no air to help equalize the force of the air from above.

Using the radius of the Lil' Suctioner and standard air pressure, calculate the total force of the air pushing down on the suctioner and can of soda. $r = 2.19 \text{ inches}$ and **standard air pressure = 14.7 pounds per square inch**. Use the equation $\pi \times r^2 \times \text{standard air pressure} = \text{total pressure (pound-force)}$. Then convert pound-force to Newtons using the conversion 1 pound-force = approximately 4.5 Newtons. Show your work.

$$\pi \times (2.19 \text{ in})^2 \times 14.7 \text{ lb}$$

$$3.14 \times 4.80 \text{ in} \times 14.7 \text{ lb} = 221.6 \text{ lb}$$

$$221.6 \text{ lb-f} \times 4.5 = 997.2 \text{ N}$$

3) Finally, calculate the amount of force needed to lift the can of soda when attached to the Lil' Suctioner. Use your answer to question #3 to help answer this question. Explain your answer.

Any force more than 221.6 pounds or 997.2 Newtons would lift the can of soda from the flat surface when attached with the Lil' Suctioner since that is the amount of force holding the can to the surface.

Lesson: Can Water Boil Without Heat?

Intro video: BrainBites—What Temperature Is Space? <http://brainbites.nasa.gov/#/temperature-in-space>

Introduction

Students are used to associating boiling with heat. Water boils when it's hot. However, students often don't think about the effect of air pressure on the boiling point of a liquid—in this case, water. The boiling point is the temperature at which the vapor pressure is equal to the atmospheric pressure around the water. Therefore, if you lower atmospheric pressure, you also lower the vapor pressure, or the boiling point. The background information included in this activity guide provides an introduction to temperature and how a liquid can boil without feeling "hot." Refer to the background information about temperature and its effects on human survival at high altitudes as you complete the activities below.

The following activities about air temperature and pressure will show students that room-temperature water will boil in a vacuum; how increasing gas temperatures in a soda can, then quickly cooling that air, will crush the can; how the students can melt an ice cube with pressure and refreeze that same cube when pressure is reduced; and finally, that a small piece of cotton can be ignited using air pressure.

Activity One: Boiling in a Vacuum

Objective

Students will learn about the properties of matter and how those properties can change; they will also learn about the transfer of energy as they observe room-temperature water boiling in a vacuum.

Lesson Overview

The instructor will demonstrate that room-temperature water will boil in a vacuum by placing a cup of water in a vacuum pump and making it boil. Students will then take warm water in large plastic syringes, create low-pressure environments, and make the water in their syringes boil.

Materials

Vacuum pump

Clear plastic cup

Water (room-temperature for the vacuum pump and warm for the syringe activity)

Large plastic syringes with cap or piece of clay to seal syringe tip (one per student or group)

Optional: Infrared laser thermometer

Student activity worksheets

Safety note: If you have never used a vacuum pump and bell jar before, use caution when placing objects in the vacuum chamber. Objects can break when exposed to vacuum conditions, sometimes damaging the bell jar in the process. Always check to make sure the bell jar is in good condition (no cracks or signs of excessive wear), that seals and gaskets are clean, and that you know how to operate a vacuum chamber. When you repressurize the chamber following an activity, items in the chamber may not stay where they are when air floods back in, so use care.

Vacuum Pump and Water

- 1) Ask students what they think it means to boil a liquid. Also ask them to write down at what temperature they think water boils. Have them write their criteria for boiling water on their worksheets.
- 2) Fill a clear plastic cup about half full with room-temperature water.
- 3) Place the cup in the vacuum pump chamber.
- 4) Turn on the vacuum pump. As air is evacuated from the chamber, the water will begin to boil. Have students record what happens as the water begins to boil, then reaches a full boil.
- 5) **Optional:** Use an infrared laser thermometer to show students that the water in the chamber is not hot as it boils. You will not be able to read the temperature of the water while the chamber is operating because the thermometer will be reading the temperature of the outside of the chamber. However, you can read the temperature of the water before it is placed in the chamber and again once the bell jar is removed; the difference will show a drop in temperature as the water loses energy (i.e., heat).
- 6) Turn off the vacuum pump. Carefully repressurize the chamber, trying not to move the chamber so the water does not spill.
- 7) As quickly as possible, remove the bell jar of the chamber and stick your finger i to the water (it will still be at the same temperature).
- 8) Discuss why the water temperature did not increase as the water boiled.
- 9) Have students complete their worksheets.



Water before pump is activated.



Water boiling in a vacuum.



Testing water temperature immediately after the water leaves the vacuum environment.

Hand-Held Low-Pressure Environment

- 1) Give students the opportunity to create a low-pressure environment of their own, which will allow them to boil warm water in a large syringe.
- 2) Heat a container of water until it is very warm to the touch, but not boiling (hot tap water works for this as well).
- 3) Fill each syringe about $\frac{1}{3}$ full of the warm water; then put the plunger into the syringes (at about the level of the water) and cap the syringes.
- 4) Have students pull back on the syringe plungers, reducing the air pressure inside the syringes. The water should boil.
- 5) When students release the plunger, the air pressure will increase, stopping the water from boiling.
- 6) Students can do this several times until the water cools down so much that the pressure inside the syringe cannot be lowered enough to boil the water anymore.

Activity Two: Collapsing Soda Can

Objective

Students will learn about the properties of matter and how those properties can change; they will also learn about motions, forces, and the transfer of energy as they watch a change in air pressure collapse a soda can.

Lesson Overview

Students will watch a demonstration in which a small amount of water is heated inside an otherwise empty soda can; the can is then quickly placed upside down in a container of ice water. The hot, expanded steam inside the heated can is quickly condensed and cooled when placed in the ice water. This rapid change of phase of the steam inside the can creates a pressure differential between the inside and the outside of the can that is enough to collapse the soda can.

Materials

Empty soda can

About $\frac{1}{4}$ cup of water to pour inside the can

Tongs to handle the heated soda can

Container of ice water (must be larger than the soda can)

Heat source (a Bunsen burner or hot plate works well)

Safety note: Use care when conducting an experiment with a heat source such as a Bunsen burner or hot plate.

The water inside the soda can will be boiling, and the outside of the can will get extremely hot, so use tongs when handling the heated soda can. You may want to practice the activity before demonstrating it to students so that you can see how it occurs and you don't spill boiling water from the can as you flip it over into the container of ice water during the actual demonstration.

In addition, due to safety concerns, this activity should be performed as a demonstration by an adult (not students). Students should stand away from the demonstration in case the water splatters. **THE DEMONSTRATOR SHOULD WEAR EYE PROTECTION.**

- 1) Ask students for ways you can collapse an empty soda can. Have them write as many ideas down on their student worksheet as they can.
- 2) Tell students that you are going to use air to collapse the can. Ask them if they know how that could happen.
- 3) Heat the small amount of water in the otherwise empty soda can (about $\frac{1}{4}$ cup works well, but it doesn't have to be exact) until the water boils. You may see steam rising from the opening of the can.
- 4) Ask students what is happening to the air and the water inside the can as you are heating the can. If necessary, explain that the water is changing phase from liquid to gas and that the air temperature is increasing as well. Although air pressure increases with an increase in temperature, most of the pressure inside the can, once heated, comes from the water, which has turned into steam. This increase is not enough to damage the can, but students will be able to notice steam coming from the can opening.

- 5) Set a container of ice water nearby. Ask students what happens to air pressure as air temperature decreases, along with what happens to water when there is a change in temperature (in this case, when the water is heated, it changes to a gas—steam—and later, when that gas is cooled, it will change phase once more and condense into a liquid). Students should also answer that air pressure decreases with a decrease in temperature.
- 6) Using tongs, take the heated soda can and quickly invert it and submerge the lid into the ice water, which will prevent outside air from entering the can as the steam and remaining air inside the can cool.
- 7) As the air pressure decreases inside the can, and the steam, which took up more space than the liquid water, condenses, the higher air pressure outside the can will cause the can to collapse.



Image of collapsed soda can.

Activity Three: Melting Under Pressure

Objective

Students will learn about the transfer of energy as they observe that pressure can cause ice to melt, then observe that when pressure is reduced, water refreezes. Examples of this process, called regelation, can be observed in nature as the pressure from a glacier causes the underlying water to melt, allowing the glacier to slide along the ground. The water that is left behind then refreezes once the pressure has been reduced.

Lesson Overview

In this activity, two demonstrations will show students that pressure can be used to lower the melting point of ice. First, the pressure of a thin wire attached to weights and stretched over a piece of ice will melt through the ice. The students will observe that when the pressure is removed, as the wire travels through the ice, the water above the pressurized wire will refreeze due to the reduction of pressure. In the second demonstration, a heavy object on top of a second piece of ice will cause the ice to melt faster than a piece of ice without pressure exerted on it.

Materials

Three larger chunks of ice (these activities will work with any piece of ice, but a larger piece of ice allows students to better see what is happening)

For Activity 3A:

One of the above chunks of ice

Thin wire

Two weights wrapped around the wire (water bottles work well)

Shallow tray to hold the chunk of ice

Small shelf to allow the weights to pull down on the wire

For Activity 3B:

Two equal-sized chunks of ice

Larger tray, such as a cookie sheet, to hold chunks of ice

Weight to place on top of one chunk of ice

Student worksheet

Safety note: Do not touch large chunks of ice since your finger may freeze to the ice.



Activity 3A setup.

Activity 3A:

- 1) Place the chunk of ice on the shallow tray; then put the tray on a small shelf, which provides room for the weights to hang down over the sides of the tray.
- 2) Take a piece of thin wire, stretch it across the ice, and then wrap it around your two weights.
- 3) Hang the weights over the sides of the shelf, which will create tension on the wire and put pressure on the chunk of ice.
- 4) Have students observe what happens as pressure is placed on the chunk of ice from the weighted wire.
- 5) After about 15 to 20 minutes, students should see that the wire has melted through some of the ice.
- 6) Ask a student to pull up on the wire after that time; the water above the wire will have refrozen.
- 7) Have students draw what has happened on their worksheet, along with an explanation of why this occurred.

Activity 3B:

- 1) Ask students to list what is needed to make ice melt faster.
- 2) On your larger tray, place two chunks of ice.
- 3) Put a weight on top of one piece of ice while leaving the second piece open on the tray.
- 4) After about 15 minutes, remove the weight from the first piece of ice and have students compare the sizes of the ice pieces. Explain to students that the pressure from the weight increased the temperature above the piece of ice, which made it melt faster.

Activity Four: The Fire Syringe

Objective

Students will learn about the transfer of energy and motions and forces as they observe a demonstration about air pressure in which an increase in air pressure within a chamber ignites a small piece of cotton or paper.

Lesson Overview

Using a fire syringe, you will ignite a small piece of cotton or paper by quickly increasing the air pressure and temperature within the chamber. This dramatic demonstration shows students the direct increase of temperature when pressure is increased.

Materials

- Fire syringe
- Small piece of cotton or paper
- Unbent paper clip to feed cotton into fire syringe
- Student worksheet

- 1) Ask students how they would ignite a piece of cotton or piece of paper. Have them record their answers on their worksheets. Tell students that you will ignite cotton or paper using air pressure.
- 2) Take the fire syringe and put it on a flat surface. Place a small piece of paper or cotton inside the chamber of the syringe. (Hint: Use a **very small** piece of cotton! If using a cotton ball, pull apart a tiny section, leaving lots of surface area. Use the paper clip to place the cotton into the syringe—do not pack it into the bottom. Again, you want lots of air around the cotton.)
- 3) Press down quickly and forcefully on the syringe plunger. The paper or cotton will ignite. If you see only smoke, the precursor to fire, you may not get the cotton to ignite after that. Replace with a new piece of cotton.
- 4) This demonstration can be repeated with different materials. Pieces of paper and cotton should be small so they can easily ignite. **Never place a hazardous material in the chamber to ignite!**

NATIONAL SCIENCE STANDARDS

K-4

Abilities necessary to do scientific inquiry
Understandings about scientific inquiry
Properties of objects and materials
Light, heat, electricity, and magnetism

5-8

Abilities necessary to do scientific inquiry
Understandings about scientific inquiry
Properties and changes of properties in matter
Motions and forces
Transfer of energy
Structure of the Earth system

9-12

Abilities necessary to do scientific inquiry
Understandings about scientific inquiry
Structure and properties of matter
Motions and forces
Conservation of energy and increase in disorder

- 4) Using your own syringe and very warm water, create a low-pressure environment by pulling back on the plunger once the water has been added. Describe what happens to the water. Why is this happening?

- 5) Once you released the plunger, what happened to the pressure inside the syringe? What happened to the water? Why? Did the water change temperature during this time?

- 6) Based on the demonstration and your activity with the syringe, come up with your own definition of the relationship between pressure and water's boiling point.

Activity Two: Collapsing Soda Can

Pre-Lab Question

- 1) List as many ways as you can think of to crush an empty soda can.

Activity Questions

- 1) Draw a picture of what is happening to the water and air inside the soda can as it is being heated. Label your drawing.

- 2) Describe what happened as the soda can was quickly inverted into the ice water bath. Why?

- 3) What would have happened if the opening had not been sealed off by the water? Again, explain why.

3) A chunk of ice that is sitting on a metal cookie sheet.

4) For 2 and 3, which chunk of ice melted faster? Why?

5) The first chunk of ice with the wire pulling down on it is an example of a process known as regelation. Regelation is seen in nature when glaciers melt on the bottom, causing the glaciers to slide along the ground. This process also helps you make great snowballs. Explain how regelation makes it possible to create a good snowball.

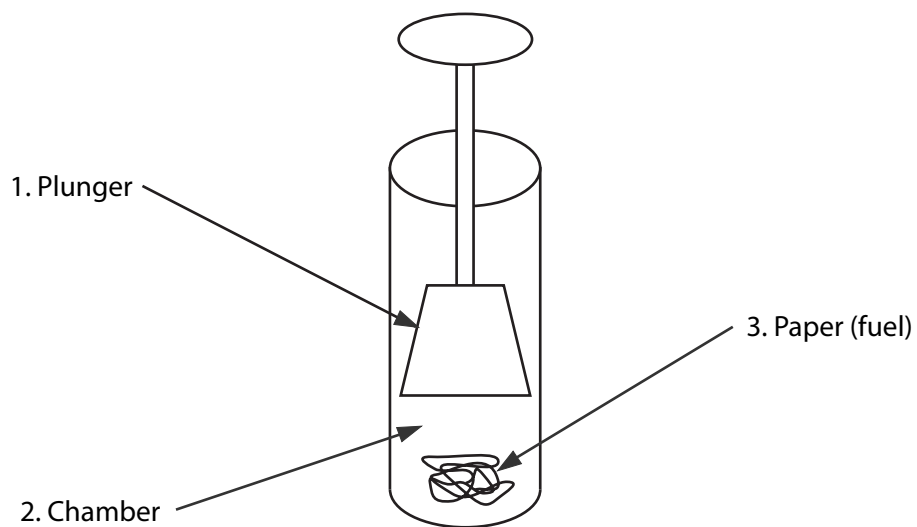
Activity Four: The Fire Syringe

Pre-Lab Questions

- 1) What is needed to make a fire? List as many ingredients as you can think of.
- 2) How would you try to make a fire if you were stranded in the wilderness? Describe the process you would use. What do you think would be difficult about making a fire?

Activity Questions

- 1) As your instructor demonstrates the fire syringe, explain what is happening at each of the numbered areas:



- 2) The Fire Syringe is much like the piston of a diesel engine. What is the fuel for a diesel engine's piston?
- 3) What would be an advantage of having more pistons (or cylinders) in a vehicle engine? What would be a drawback?

Lesson: Can Water Boil Without Heat? Worksheets

Answer Key

Activity One: Boiling in a Vacuum

Pre-Lab Questions

1) Explain what it means for something to boil. Describe what occurs.

Answers will vary, but most students will answer that water boils when it's hot. They may describe bubbles forming on the side of a pot, or churning water as it reaches the boiling point.

2) At what temperature does water boil?

Students will probably answer that water boils at 100 degrees Celsius or 212 degrees Fahrenheit.

Activity Questions

1) As you watch the following demonstration, describe what you see. Draw a picture along with your explanation if that helps.

Students should describe that after the vacuum pump was turned on, the cup of water began to form tiny bubbles along the side, and then the bubbles increased in size until the water began to boil.

2) After the vacuum chamber was repressurized, describe the water. Explain what just happened.

Once the chamber was repressurized, the water immediately stopped boiling. Since a reduction in pressure allowed water to reach its boiling point at a lower temperature, that's when the water boiled (not because of a change in temperature). Once air pressure returned, the boiling point increased. Since the water was not hot enough to boil under normal air pressure, the boiling stopped.

3) Does this support or contradict your original definition of "boil"? How so?

Answers will vary, but for most students, it will contradict their original definition .

4) Using your own syringe and very warm water, create a low-pressure environment by pulling back on the plunger once the water has been added. Describe what happens to the water. Why is this happening?

As students pull back on their plungers, they are reducing the air pressure inside the syringe, which is allowing the warm water to boil.

5) Once you released the plunger, what happened to the pressure inside the syringe? What happened to the water? Why? Did the water change temperature during this time?

As soon as students release the plunger, air pressure increases, which stops the water from boiling. There was no change in temperature, just in pressure—and, because of that, in the boiling point.

6) Based on the demonstration and your activity with the syringe, come up with your own definition of the relationship between pressure and water's boiling point.

Answers will vary, but students should figure out that a reduction in pressure lowers water's boiling point. Likewise, an increase in temperature will raise water's boiling point.

Activity Two: Collapsing Soda Can

Pre-Lab Question

- 1) List as many ways as you can think of to crush an empty soda can.

Answers will vary.

Activity Questions

- 1) Draw a picture of what is happening to the water and air inside the soda can as it is being heated. Label your drawing.

Students should explain that as the water and air inside the can increase in temperature, the pressures of both the water and air increase. However, the pressure only increases to a certain point inside the can, since water vapor and heated air escape the can as vapor.

- 2) Describe what happened as the soda can was quickly inverted into the ice water bath. Why?

Students should observe that the can crushes as soon as it is inverted into the bath. As the air and water in the can cool, the pressure inside the can is reduced. The reduction in pressure, along with the inability of air from outside the can to enter (since the can's opening is under the water in the bowl), allows the higher pressure outside the can to crush the can.

- 3) What would have happened if the opening had not been sealed off by the water? Again, explain why.

If the can opening had not been sealed off by the water, air from outside the can would instead fill the can, equalizing the outside and inside pressure. The can would not crush.

Activity Three: Melting Under Pressure

Pre-Lab Question

The first two activities showed you how temperature and pressure are related. In the following activity, you will be able to see the effects of pressure on temperature. You will then be able to watch as the reaction is reversed.

- 1) Make a list of as many ways as you can think of to melt ice. Why is this sometimes necessary?

Student answers will vary. They may suggest that sometimes we need to melt ice to make driving on the roads or walking on sidewalks safer during the winter and that we use salt or other chemicals to do that. The point to this question is to show that most people don't think of melting ice with pressure; instead, we think of other ways, such as using salt or heating the ice with a more traditional heat source.

- 2) Restate the definition you came up with during the earlier activity for the relationship between temperature and pressure.

Answers will vary.

- 3) Based on your definition, describe what should happen to ice in the following situations:

Answers will vary.

- a) A chunk of ice that has a thin wire pulling down on it.
- b) A chunk of ice that has a heavy weight on top of it.
- c) A chunk of ice that is sitting on a metal cookie sheet.

Activity Questions

Describe what happens to the three chunks of ice in this activity. Draw what you see in addition to your description. For the first activity, explain why this has happened.

- 1) A chunk of ice that has a thin wire pulling down on it.

Students should observe that the ice will melt where the wire is pulling down on it. As the wire melts its way through the chunk of ice, the water above the wire will refreeze as pressure is reduced. Eventually, the wire will be frozen in the middle of the chunk of ice.

- 2) A chunk of ice that has a heavy weight on top of it.

If a heavy object such as a book or weight is on top of the chunk of ice, that ice will melt faster than the chunk without the weight on it. Students should also observe that it melts from the bottom of the chunk.

- 3) A chunk of ice that is sitting on a metal cookie sheet.

This chunk of ice will melt from all sides.

- 4) For 2 and 3, which chunk of ice melted faster? Why?

Students should observe that the chunk of ice with the weight on top melts faster than the others. The wire will melt through the ice quickly as well, but only the section in contact with the wire will melt quickly. The rest of that chunk should melt at approximately the same rate as the ice chunk without any weight on it. Since an increase in pressure increases temperature, the weight on the ice causes the ice to melt quicker.

5) The first chunk of ice with the wire pulling down on it is an example of a process known as regelation. Regelation is seen in nature when glaciers melt on the bottom, causing the glaciers to slide along the ground. This process also helps you make great snowballs. Explain how regelation makes it possible to create a good snowball.

Answers will vary, but when we compress the snowball in our hands or gloves, we are increasing pressure. The increase in pressure increases temperature, which causes some of the ice to melt. This newly melted water allows us to pack the snowballs tighter. Once we release the pressure on the snowball, the water refreezes, creating a tougher snowball.

Activity Four: The Fire Syringe

Pre-Lab Questions

1) What is needed to make fire? List as many ingredients as you can think of.

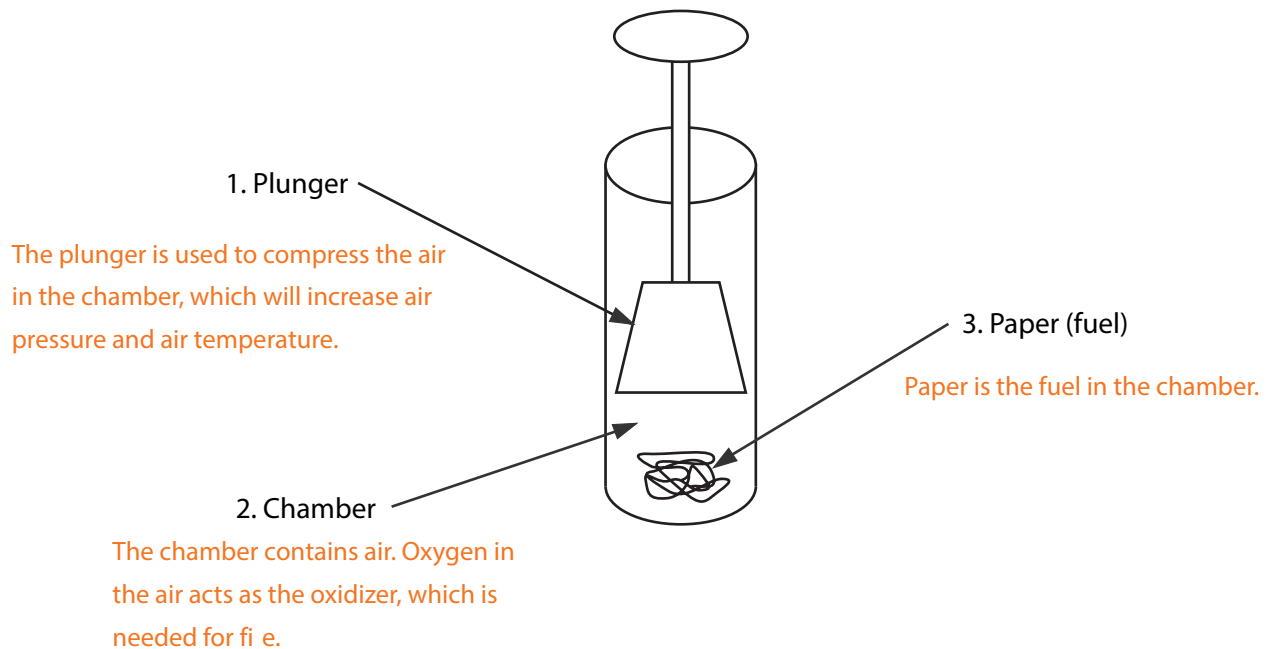
Students should suggest that fuel, heat, and an oxidizer (often oxygen) are needed for fire.

2) How would you try to make a fire if you were stranded in the wilderness? Describe the process you would use. What do you think would be difficult about making a fire?

Answers will vary but may include using matches, rubbing sticks together, etc. Factors that could make building a fire difficult include finding a fuel and/or heat source but not knowing how to use it to build a fire.

Activity Questions

1) As your instructor demonstrates the fire syringe, explain what is happening at each of the numbered areas. Remember that fire needs three ingredients: heat, fuel, and an oxidizer.



2) The fire syringe is much like the piston of a diesel engine. What is the fuel for a diesel engine's piston?

Diesel fuel is the fuel used in a diesel engine.

3) What would be an advantage of having more pistons (or cylinders) in a vehicle engine? What would be a drawback?

Answers will vary, but more pistons or cylinders would provide more energy for the vehicle. However, more pistons require more fuel, are heavier, and have more parts that need to work together.

Lesson: How To See Density

Activity One: Sinking and Floating Bowling Balls

Objective

Students will learn about the properties of matter and how they can change as the students learn about the density of solids and liquids.

Lesson Overview

Students will predict whether bowling balls will float or sink in a container of water, then watch as one bowling ball floats and a second one sinks. Students will then calculate the densities of each ball to help determine the density of water.

Materials

Large, transparent container of water (a 10-gallon aquarium works well)

Two bowling balls (one weighing less than 12 pounds and one weighing more than 12 pounds)

Scale

String

Rulers or meter stick (one per student or group)

Calculator (one per student or group)

Student worksheet

- 1) Fill the aquarium about two-thirds full of water. Note: Before conducting the demonstration, check to make sure that you did not fill the tank too full of water. If you are going to have both bowling balls in the tank at the same time, ensure that they will both fit in the tank with the water.
- 2) Ask students whether the bowling ball will sink or float in water. Have them write their response on their student worksheet.
- 3) Carefully place one of the bowling balls in the water (decide whether you first want to confirm most students' initial thoughts—that it will sink—or first show them the floating bowling ball). **Do not drop the bowling ball into the tank—you will break the glass!**
- 4) Now ask students what they think should happen to the next bowling ball. Again, carefully place the second ball in the tank of water. One will sink and the other will float.
- 5) Have students hypothesize about the reason one ball sank and the other ball floated.
- 6) Place each bowling ball on a scale. Students should be able to see that the bowling ball that weighed less than 12 pounds floated and the one that weighed more than 12 pounds sank. They should also be able to assume that the density of water is somewhere between the densities of the two balls.
- 7) Have students calculate the densities of the bowling balls.

Activity Two: Burning Candle Activity

Objective

Students will learn about the properties of matter and how those properties can change as they watch the changes in air density as a candle burns itself out in a jar.

Lesson Overview

By placing a burning candle in an inverted jar over a trough of water, students can observe, through the change in water level, the increase in air density as the air in the jar heats up, then watch as air contracts once the air cools down. This extension on a classic candle-in-a-jar demonstration adds temperature and density components to this activity.

Materials

Candle

Matches

Clear jar

Trough of water

Spacers such as coins to place jar on in the trough

Food coloring (optional)

Safety note: Adults should light the candle and handle the glass jar during the activity.

Introduction

Many students and adults have seen the demonstration of burning a candle in a sealed jar. In a relatively short time, the flame inside the jar is extinguished. This activity shows that fire needs three basic ingredients: oxygen, fuel, and heat. As the oxygen inside the jar is lowered enough, the flame is extinguished. However, there is also more going on inside the jar. The density of the air is changing as the air is first heated with the flame, then cools once the flame is extinguished. This can be observed by inverting the jar into a trough of water. As the air inside the jar heats up and expands, several air bubbles can be seen in the water as the air inside the jar moves from a high-pressure area to an area with lower pressure. Once the candle is extinguished, the air begins to cool and condense. As a result, the water level begins to rise inside the jar.

Some students may argue that the water level is rising inside the jar because the oxygen is being used up. However, if that were the case, then the water level would have risen steadily while the candle was burning and the oxygen was being depleted. Instead, the water level rises after the candle flame is extinguished and the air inside the jar begins to cool.



Candle, jar, and trough setup.



Burning candle.



Water level after candle has been extinguished.

Procedure

- 1) Fill a trough larger than the clear jar with water that is deep enough to allow the jar to sit in the trough, with several small spacers (coins work well) that will allow water to flow in and out of the inverted jar. Adding a couple drops of food coloring will allow students to see the water level change more easily.
- 2) Place the candle in the water, securing the candle so that it doesn't tip over.
- 3) Light the candle and place the jar on the spacers, making sure the jar is sealed with the water.
- 4) Ask students to observe both the candle burning and the water level as the candle burns, then extinguishes. Have students note the water bubbles that appear as the water in the jar heats up.
- 5) This demonstration can be repeated several times, if necessary, in order for students to have a chance to develop hypotheses about the rising water level, bubbles, etc.

c) For each bowling ball, calculate the circumference. An easy way to calculate the circumference of a ball is to take a piece of string and wrap it around the ball. Lay the string on a meter stick to determine the string's length. Calculate the circumference in centimeters.

d) In order to determine the volume of each bowling ball, use the following formulas:

$$\text{Volume} = \frac{4}{3} \times \pi \times r^3$$

$$\text{Circumference} = 2 \times \pi \times r$$

e) To calculate the density of the bowling ball, divide the mass of the ball by the volume. Be sure to use kilograms for the ball's mass and cubic centimeters for the volume. Complete these calculations for each bowling ball.

f) Using the densities of each bowling ball, what can you infer about the density of water? Explain your answer.

Activity Two Worksheet: Burning Candle Activity

In the following demonstration, you will watch as a burning candle is placed inside a jar, which is sealed with a pan of water.

Pre-Lab Question

What do you think is going to happen? Why?

Observation

Write and/or draw a picture to show what is happening during this demonstration. Add as many details as possible about the candle, the flame, and the water.

Followup Questions

- 1) Explain what happened during the demonstration.
- 2) Based on your instructor's explanation, why did that occur?
- 3) Did that support or contradict your pre-lab explanation? How so?
- 4) Think of another demonstration or experiment you would like to try that would test the results of this experiment. What would you do? How would that test and/or challenge the results of the experiment you just took part in?

Lesson: How To See Density Worksheets

Answer Key

Activity One Worksheet: Sinking and Floating Bowling Balls

Pre-Lab Question

What do you think will happen when you place a bowling ball in a tank of water? Why?

Answers will vary, but most students will probably assume that the bowling ball will sink in the water because it's heavy.

Activity

- 1) Describe what happened when the first bowling ball was placed in the tank of water.

Depending on which ball is placed in the water first, one will sink and the other will float.

- 2) Describe what happened when the second bowling ball was placed in the tank of water.

- 3) Why did this happen?

The density of water is 1.0 gram per cubic centimeter, so a bowling ball that weighs less than or equal to 10 pounds will float and a bowling ball that weighs greater than or equal to 12 pounds will sink because of the difference in densities.

- 4) Using the results of the two bowling balls in water and the density calculations you will complete for the bowling balls, you are going to determine the approximate density of water. Show your work for each step.

- a) Use a scale to weigh the first bowling ball. If your scale measures in pounds, convert from pounds to kilograms.

Answers will vary. For purposes of this example problem, we will use an 8-pound ball for calculations.

- b) Repeat for the second bowling ball.

Answers will vary. For purposes of this example problem, we will use a 13-pound bowling ball for calculations.

- c) For each bowling ball, calculate the circumference. An easy way to calculate the circumference of a ball is to take a piece of string and wrap it around the ball. Lay the string on a meter stick to determine the string's length. Calculate the circumference in centimeters.

Regulation bowling balls are the same size, so students should figure the circumference for each ball to be 68.6 centimeters.

- d) In order to determine the volume of each bowling ball, use the following formulas:

$$\text{Volume} = \frac{4}{3} \times \pi \times r^3$$

$$\text{Circumference} = 2 \times \pi \times r$$

$$\text{Circumference}/(2 \times \pi) = r$$

$$68.6 \text{ cm}/(2 \times 3.14) = r$$

$$r = 10.9 \text{ cm}$$

$$\text{Volume} = \frac{4}{3} \times \pi \times r^3$$

$$\text{Volume} = \frac{4}{3} \times 3.14 \times (10.9 \text{ cm})^3$$

$$\text{Volume} = 5,422 \text{ cm}^3$$

Note: Each bowling ball has three holes that affect the ball's volume and density slightly. However, for the purposes of this activity, these will not be calculated. They have a minimal effect on this activity.

e) To calculate the density of the bowling ball, divide the mass of the ball by the volume. Be sure to use kilograms for the ball's mass and cubic centimeters for the volume. Complete these calculations for each bowling ball.

$$8 \text{ lb} = 3,629 \text{ g}$$

$$3,632 \text{ g}/5,422 \text{ cm}^3 = 0.67 \text{ g/cm}^3$$

$$13 \text{ lb} = 5,897 \text{ g}$$

$$5,902 \text{ g}/5,422 \text{ cm}^3 = 1.09 \text{ g/cm}^3$$

f) Using the densities of each bowling ball, what can you infer about the density of water? Explain your answer.

Based on the densities of the two bowling balls, students should be able to infer that water has a density that is between that of the less dense bowling ball and that of the denser bowling ball. Water's density is 1.0 g/cm^3 , and although student calculations will not be able to make that precise of an answer, they should be able to see that water's density is close to that. In the example above, which used an 8-pound ball and a 13-pound ball, they would be able to calculate that water has a density that is more than 0.67 g/cm^3 and less than 1.09 g/cm^3 .

Activity Two Worksheet: Burning Candle Activity

In the following demonstration, you will watch as a burning candle is placed inside a jar, which is sealed with a pan of water.

Pre-Lab Question

What do you think is going to happen? Why?

Answers will vary. Most students will probably say that the candle will burn out. Some students may suggest that the oxygen is being used up in the jar, which is causing the water level to rise (see introduction for an explanation about why that is not the reason).

Observation

Write and/or draw a picture to show what is happening during this demonstration. Add as many details as possible about the candle, the flame, and the water.

Answers will vary, but students should be able to show that outside pressure pushes down on the water in the trough with more pressure once the candle has been extinguished than while the candle is burning and heating the air inside the jar.

Followup Questions

- 1) Explain what happened during the demonstration.

Students should focus on what is physically happening during the demonstration, not the reasons behind it.

- 2) Based on your instructor's explanation, why did that occur?

Students should be able to recount the explanation given in the introduction, that the density of the air in the jar is decreasing as the air expands when the flame is burning in the jar. As the candle is extinguished, the air will cool and condense, allowing the water level in the jar to rise.

- 3) Did that support or contradict your pre-lab explanation? How so?

Answers will vary.

- 4) Think of another demonstration or experiment you would like to try that would test the results of this experiment. What would you do? How would that test and/or challenge the results of the experiment you just took part in?

Answers will vary, but students may want to test jars of different sizes or shapes or candles of different sizes. Existing experiments have also been conducted about the cause of the candle's extinguishing. Some have tested whether it was the elimination of oxygen in the jar vs. creating carbon dioxide that extinguishes the flame. Others may want to test the idea of air density by trying to heat the air in the jar without depleting oxygen levels. (This can be done by heating the glass jar in a hot water bath and adding very warm water into the jar, then pouring out the water and removing the jar from the water bath. The jar can then be inverted over the water trough as was done with the candle and jar, and the same result, although slower, will occur.)

NATIONAL SCIENCE STANDARDS

5–8

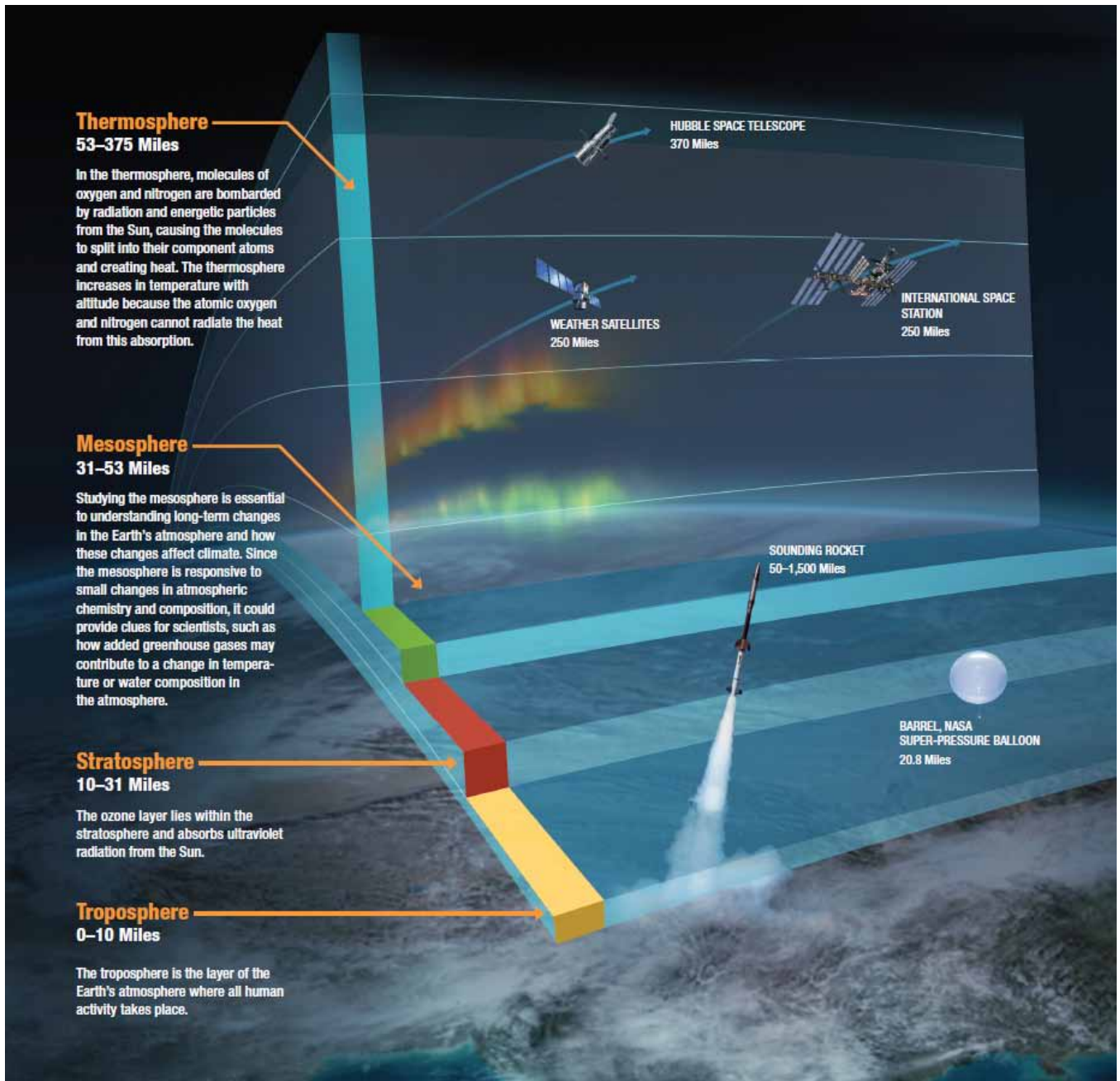
Abilities necessary to do scientific inquiry
Understanding about scientific inquiry
Properties and changes of properties in matter

9–12

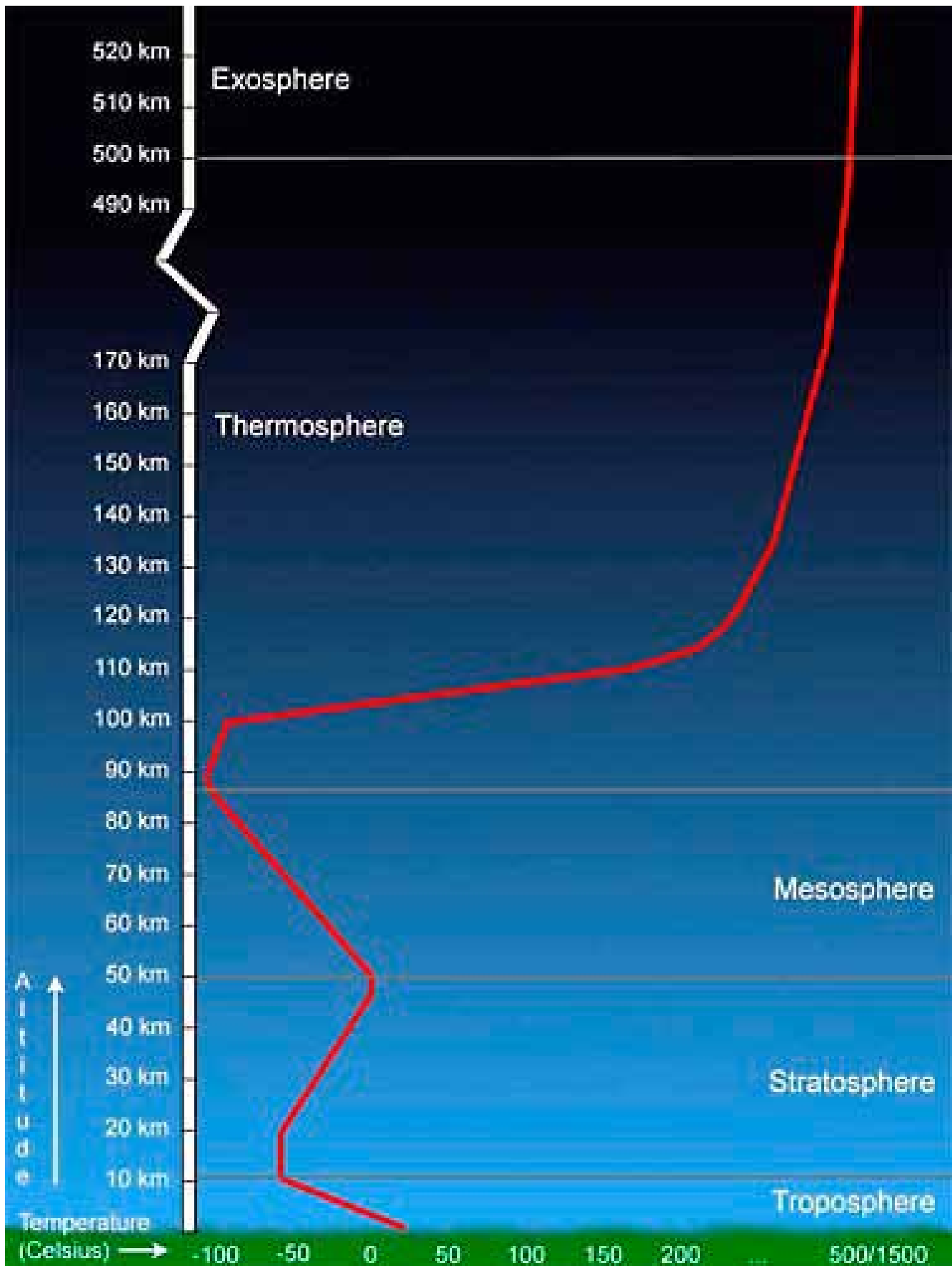
Abilities necessary to do scientific inquiry
Understanding about scientific inquiry
Structure and properties of matter
Chemical reactions
Interactions of energy and matter

A thick, curved orange line starts at the top center and curves downwards and to the left, ending near the bottom left corner. The line is smooth and has a consistent thickness.

Images



The structure of the upper atmosphere.



This graphic illustrates the atmosphere's structure, starting with the troposphere at Earth's surface. (Image Credit: NASA, <http://www.nasa.gov/centers/langley/news/factsheets/DIAL.html>)



Research engineer Marta Bohn-Meyer stands in front of an SR-71. (Image Credit: NASA, <http://www.dtic.mil/dtic/handle/document/108888>)



A WB-57 high-altitude aircraft. (Image Credit: NASA, http://www.jpl.nasa.gov/images/earth/wb57_browse.jpg)



STS-104 mission specialists Michael Gerhardt (dark shirt) and James Reilly (white shirt) are photographed wearing oxygen masks during their pre-breath before an Extravehicular Activity (EVA) in the Quest airlock of the International Space Station (ISS). (Image Credit: NASA, <http://archive.org/details/STS104e5146>)



A life-support technician assists a pressure-suited pilot into the cockpit of NASA's ER-2 earth resources aircraft. (Image Credit: NASA, <http://www.dfrc.nasa.gov/Gallery/Photo/ER-2/Small/EC00-0037-27.jpg>)



Astronaut Rick Mastracchio, STS-118 mission specialist, on the mission's first planned session of extravehicular activity (EVA). (Image Credit: NASA, <http://archive.org/details/HSF-photo-s118e06305>)



The deep sea submarine Ben Franklin made space exploration history in 1969 by studying the behavior of aquanauts in a sealed, self-contained, self-sufficient capsule. (Image Credit: NASA, <http://www.nasa.gov/mission/spacelab/prepare/travel/px15.html>)



Marshmallow Peeps before the vacuum pump was turned on.



Marshmallow Peeps during air evacuation from pump.



Marshmallow Peeps at full vacuum.



Marshmallow Peeps after repressurization.



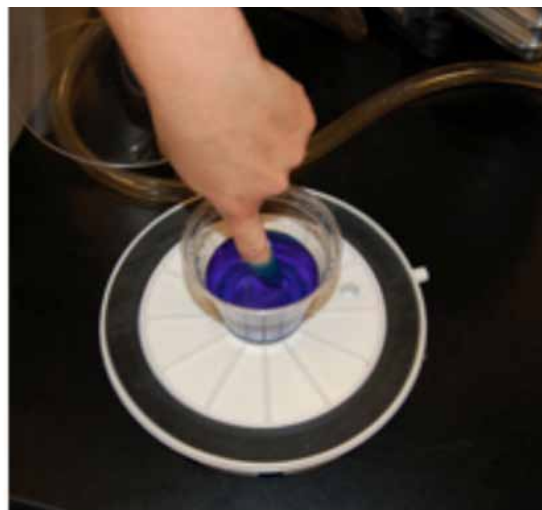
Crew members for Space Shuttle Endeavour's STS-126 mission depart for Launch Pad 39A. The sleeves of their tube-lined thermal suits are visible beneath their orange launch-and-entry suits. (Image Credit: NASA, http://www.nasa.gov/images/content/298053main_126_walkout_lg.jpg)



Water before pump is activated.



Water boiling in a vacuum.



Testing water temperature immediately after the water leaves the vacuum environment.



Candle, jar, and trough setup.



Burning candle.



Water level after candle has been extinguished.

Resources

NASA Resources

Special thanks to James Sokolik, Operations Manager, Dryden Flight Research Center.

“A Brief History of the Pressure Suit”:

<http://www.nasa.gov/centers/dryden/research/AirSci/ER-2/pshis.html>

Jenkins, D.R. *Dressing for Altitude: U.S. Aviation Pressure Suits—Wiley Post to Space Shuttle*. NASA SP-2011-595. 2012.

Parker, James F., and Vita R. West, eds. *Bioastronautics Data Book*, 2nd ed. NASA SP-3006. 1973.

Roth, Emanuel M. “Rapid (Explosive) Decompression Emergencies in Pressure-Suited Subjects,” prepared by the Lovelace Foundation for Medical Education and Research for NASA. NASA CR-1223. Albuquerque, NM. 1968. <http://www.ncbi.nlm.nih.gov/pubmed/5305515>.

NASA Education Links

“Spacesuits and Spacewalks.” NASA Web site (provides many links and activities to learn about both spacesuits and spacewalks):
<http://www.nasa.gov/audience/foreducators/spacesuits/home/index.html>

“Suited for Spacewalking.” Educators’ guide:

http://www.nasa.gov/pdf/143159main_Suited_for_Spacewalking.pdf

“AtmosModeler Simulator.” Temperature and pressure simulator:

<http://www.grc.nasa.gov/WWW/k-12/airplane/atmosi.html>

“The Atmosphere”:

<http://www.grc.nasa.gov/WWW/k-12/airplane/atmosphere.html>

“Astro-Venture Geology Educator Guide, Lesson 2: Temperature, Pressure, and the Earth”:

<http://astroventure.arc.nasa.gov/teachers/pdf/AV-Geolesson-2.pdf>

“What Is the Temperature of Space?” Activity Guide:

http://www.nasa.gov/pdf/379068main_Temperature_of_Space.pdf

“The Layers of Earth’s Atmosphere”:

http://airs.jpl.nasa.gov/maps/satellite_feed/atmosphere_layers/

“Spacesuits: Pressurized Protection from Thermal Effects.” Activity Guide:

http://www.nasa.gov/pdf/379066main_Spacesuits_Pressurized_Protection.pdf

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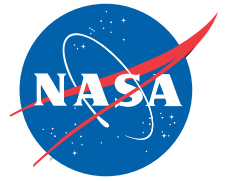
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Aeronautics
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A photograph of an astronaut in a white space suit and helmet, shown in profile against a black background. The astronaut is wearing a white helmet with a clear visor and a white space suit with various straps and equipment. The lighting is dramatic, highlighting the contours of the helmet and suit.

Physical Science Lessons on Temperature, Pressure, Density, and Human Survival at High Altitudes



GRADES

5-12

If These Airplanes Could Talk



history of flight t

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(Photo courtesy of Courtesy of The National Museum of the United States Air Force)

If These Airplanes Could Talk

Lesson Overview

Through observation and information gathering skills, students will learn the proper way to read and interpret artifacts or museum exhibits. When gathering information, students must ask six questions - "who?", "what?", "when?", "where?", "why?" and "how?" - to get the information needed to fully understand what they are viewing. Though this lesson is tailored to aviation, the concepts can be applied to any type of exhibit or artifact that is on display.

Note: We have provided photos and fact sheets in the [Reference Materials](#) section of four aircraft that are currently on display in a museum. These may be used if no museum exhibits are available.

Objectives

1. Students will gain a better understanding of the history of an artifact or museum exhibit. Through practice, students will also learn how to interpret other exhibits or artifacts they encounter in the future.

Materials:

Museum exhibits or the aircraft photos and fact sheets located in the [Reference Materials](#) section

GRADES

5-12

Time Requirements: 20 minutes per artifact

Background

History of Aviation

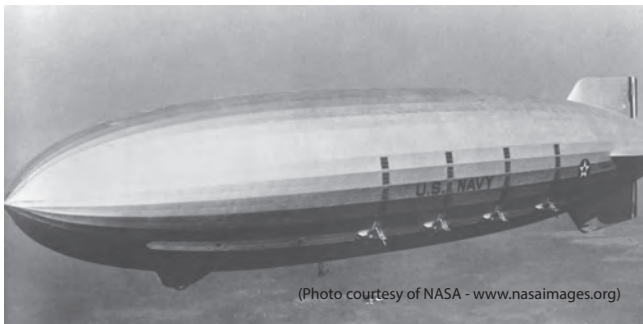
For many thousands of years, man has looked at the sky and dreamt of flying. Evidence of this can be found in stories such as “Daedalus” from Greek mythology and “Pushpaka Vimana of Ravana” in Hindu mythology. The earliest known attempts to fly were made by fashioning wings, modeled after birds’ wings and strapping them to human arms. This method was unsuccessful but it did not deter people from continuing to attempt to fly.



Img. 1 Kongming lantern

The kite was the first successful unmanned flying device and was invented in China around 400 BC. Kites work by generating lift, just as today’s modern airplanes do. Devices that use this type of technology are referred to as “heavier-than-air” aircraft.

About 100 years later in 300 BC, the Chinese invented the Kongming lantern (Img. 1). Kongming lanterns (also called paper lanterns) were constructed of a thin paper shell with a lamp or candle burning underneath. The heat from the lamp warmed the air in the bag which caused the lantern to rise. The Montgolfier brothers expanded on this discovery in 1782 and built the world’s first hot air balloon, which works according to the same principles only on a larger scale.



Img. 2 Macon Airship

Kongming lanterns and hot air balloons both fly because gases, including air, become less dense when heated. The heated air in the balloon is lighter than the cooler, denser air outside of the balloon, and is therefore able to rise. Devices that use this technology are classified as “lighter-than-air” aircraft.



Img. 3 Reenactors in front of a replica Fokker Dr. I triplane

Throughout the centuries, people around the world studied flight and developed many different kinds of flying devices, including gliders made of lightweight wood, and airships, such as the Macon Airship (Img. 2). In 1485, Leonardo da Vinci designed a hang glider, called The Ornithopter, with fixed wings and some movable control surfaces. Although he never built the device, his design provided the basis for the modern day helicopter. During the early 19th century, several men made “flying machines” which used various technologies to power their aircraft, including electricity and steam.

It wasn’t until the early 20th Century that flight as we know it today emerged. Aircraft began to be made of

aluminum instead of wood and fabric. Aviators experimented with several types of wing structures, including monoplane, which means “one set of wings”, biplane, and triplane (Img.3). As they refined their designs, monoplanes were made with various wing designs and many control surfaces (ailerons, elevator, rudder, etc.; see Figure 1) were added and modified.

In the years since the Wright Brothers’ first flight in a controlled, engine-powered aircraft, the distances we have been able to fly have increased dramatically, from the 120 feet of Orville and Wilbur’s Wright Flyer, to several thousand miles. By 1969 aircraft were taking man to the moon and today’s longest-range passenger airplanes can fly halfway around the world non-stop.

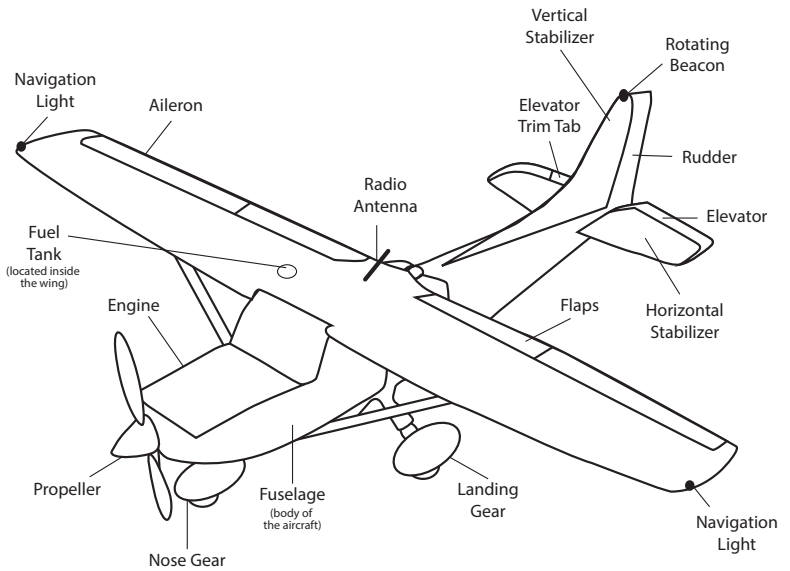


Fig. 1 Parts of an airplane



Img. 4 Civilian aircraft registration number

the underside of the wing so they could be read by someone on the ground whilst the aircraft was in flight.

Military aircraft also have insignia on the fuselage, wings, or tail. This insignia identifies the nation or air force to which the aircraft belongs (Img. 5). Many military planes also have identification numbers similar to civilian aircraft. The first of such markings appeared in 1913.

Aircraft Identification

Every aircraft has a story. You can tell a lot about an aircraft by looking at the markings and inscriptions located on the fuselage and wings. Civilian aircraft have an alphanumeric registration number (Img. 4), which is similar to the license plate on an automobile. The alphanumeric markings for aircraft registered in the United States begin with the letter “N”. They are referred to as “tail numbers” because they are usually displayed on the tail of the aircraft, although older aircraft had them displayed on



Img. 5 Military aircraft insignia

Activity 1

Interpreting an Artifact

GRADES 5-12

Time Requirement: 20 minutes per artifact

Materials:

Museum exhibits or the aircraft photos and fact sheets located in the [Reference Materials](#) section

Worksheets

Artifacts
(Worksheet 1)

Reference Materials

1903 Wright Flyer
(Fact Sheet 1)

Fokker Dr. 1
(Fact Sheet 2)

SR-71
(Fact Sheet 3)

Boeing VC-137C
(Fact Sheet 4)

Key Terms:

Biplane
Fuselage
High Wing
Jet Engine
Low Wing
Monoplane
Triplane

Objective:

Students will gain a better understanding of the history of an artifact or museum exhibit. Students will also learn how to interpret other exhibits or artifacts that they encounter in the future.

Activity Overview:

While at an aviation museum, students will view various aircraft and ask the questions “who?”, “what?”, “when?”, “where?”, “why?” and “how?” to gain a better understanding of each aircraft’s history.

Activity:

Prior to beginning this activity, provide the students with an oral summary of the [Background](#) information or have the students read it themselves.

While at a museum, have the students view various aircraft and ask the questions “who?”, “what?”, “when?”, “where?”, “why?” and “how?” about each exhibit.

Encourage the students to use their background knowledge and the context clues in the exhibit to infer what the answers to these questions might be before looking at the information provided by the museum. (Ex: If the plane has guns attached, it was probably used by a military.) If a museum is not available, have the students look at the photos and fact sheets provided in the [Reference Materials](#) section. Discuss the answers to each of the questions provided with your students. Be sure to check the validity of any deduced answers; this can be done by asking your museum guide, reviewing the information provided about the exhibit, or by performing additional independent research.

The provided answers reference the aircraft included in the [Reference Materials](#) section. Your answers will differ by exhibit.



Discussion Points:**Who:**

Who developed the aircraft?

Who used the aircraft?

Who is associated with this aircraft? (country, group, or individual)

What:

What was the function of the aircraft? (note any markings or inscriptions)

What materials are used? (wood, fabric, metal)

What style of wing design is used? (monoplane, biplane or triplane)

What type of wing placement does the aircraft have? (high wing, low wing)

What propulsion system does this aircraft use? (propeller or jet; single or multiple engines)

When:

When was the aircraft produced?

When was the aircraft flown?

When was the aircraft retired?

Where:

Where was the aircraft produced?

Where was the aircraft registered?

Where was the aircraft used?

Why:

Why would a museum keep this airplane?

Why is this airplane important to local, regional, national or international history?

How:

How was it used?

Answers for 1903 Wright Flyer

Who:

Who developed the aircraft?

The Wright Brothers, Orville and Wilbur Wright

Who used the aircraft?

The Wright Brothers, Orville and Wilbur Wright

Who is associated with this aircraft?

(country, group, or individual)

Orville and Wilbur Wright, from the United States of America; further research indicates they were from Dayton, Ohio

What:

What was the function of the aircraft?

(note any markings or inscriptions)

To become the world's first successful powered heavier-than-air flying machine; to contribute to furthering the science of aviation

What materials are used? (wood, fabric, metal)

The airframe was made of wood with muslin fabric covering the wings; the engine crankcase was aluminum

What style of wing design is used?

(monoplane, biplane or triplane)

Biplane

What type of wing placement does the aircraft have? (high wing, low wing)

N/A

What propulsion system does this aircraft use?

(propeller or jet; single or multiple engines)

Single combustion engine; 12-horsepower Wright horizontal four cylinder engine with twin propellers

When:

When was the aircraft produced?

1903

When was the aircraft used?

1903

When was the aircraft retired?

Unknown from the data provided; further research shows it was damaged beyond repair on the same day of its inaugural flight, Dec 17, 1903

Where:

Where was the aircraft produced?

Unknown from the data provided; further research indicates it was built in the Wright Brothers' bicycle shop in Dayton, OH

Where was the aircraft registered?

This aircraft was never registered; it was built before the registration system was established

Where was the aircraft flown?

Kittyhawk, NC

Why:

Why would a museum keep this airplane?

It was the first powered airplane to fly

Why is this airplane important to local, regional, national or international history?

It was used for the first flight in the world

How:

How was it used?

It was used as a test plane, flown in a dirt field several times over the course of one day (December 17, 1903)

Answers for Fokker Dr. 1

Who:

Who developed the aircraft?

Fokker; further research indicates Fokker was a Dutch aircraft manufacturer named after its founder, Anthony Fokker

Who used the aircraft?

The German army during WWI

Who is associated with this aircraft?

(country, group, or individual)

Manfred von Richthofen (the "Red Baron") is well known for winning many dogfights using this plane during WWI

What:

What was the function of the aircraft?

(note any markings or inscriptions)

It was a fighter plane in WWI; the Iron Cross symbols indicate that it is a German plane

What materials are used? (wood, fabric, metal)

Unable to determine based on information provided; further research indicates it was made from fabric covered steel tubes

What style of wing design is used?

(monoplane, biplane or triplane)

Triplane

What type of wing placement does the aircraft have? (high wing, low wing)

N/A

What propulsion system does this aircraft use?

(propeller or jet; single or multiple engines)

Single combustion engine with a propeller

When:

When was the aircraft produced?

The first of these planes were produced in 1917

When was the aircraft used?

1917 - 1918

When was the aircraft retired?

Circa 1918

Where:

Where was the aircraft produced?

Unknown from the data provided; further research indicates the company that built it, Fokker, started in Schwerin, Germany in 1912, and moved to the Netherlands in 1919

Where was the aircraft registered?

This aircraft was never registered; it was built before the registration system was established

Where was the aircraft flown?

On the Western Front and elsewhere during WWI

Why:

Why would a museum keep this airplane?

It is a replica of a very famous type of plane used in World War I and one of a very few types of biplane ever built

Why is this airplane important to local, regional, national or international history?

It helped the Germans fight in WWI

How:

How was it used?

In military battles

Answer for Lockheed SR-71A

Who:

Who developed the aircraft?

Lockheed Aircraft Corporation

Who used the aircraft?

The U.S. Air Force

Who is associated with this aircraft?

(country, group, or individual)

Maj. Jerome F. O'Malley and

Maj. Edward D. Payne

What:

What was the function of the aircraft?

(note any markings or inscriptions)

To fly long-range, advanced, strategic reconnaissance missions (reconnaissance flights are flown for information-gathering and surveying purposes)

What materials are used? (wood, fabric, metal)

Unable to determine based on information provided, though the photo indicates it is made mostly of metal

What style of wing design is used?

(monoplane, biplane or triplane)

Monoplane

What type of wing placement does the aircraft have? (high wing, low wing)

Low wing

What propulsion system does this aircraft use?

(propeller or jet; single or multiple engines)

Multiple jet engines; Two Pratt & Whitney J58s with 32,500lbs. of thrust each with afterburner

When:

When was the aircraft produced?

Unknown from the data provided; these aircraft first entered service in 1966

When was the aircraft used?

1966 - 1998

When was the aircraft retired?

U.S. Air Force retired its fleet of SR-71s on Jan. 26, 1990

Where:

Where was the aircraft produced?

Unknown from the data provided; further research indicates it was built by Lockheed Aircraft Corporation at The "Skunkworks" in Palmdale, California

Where was the aircraft registered?

The United States of America

Where was the aircraft flown?

The aircraft was used world-wide

Why:

Why would a museum keep this airplane?

"Throughout its nearly 24-year career, the SR-71 remained the world's fastest and highest-flying operational aircraft."; it also set records for speed and altitude

Why is this airplane important to local, regional, national or international history?

It helped the U.S. military gather information about their enemies

How:

How was it used?

In military reconnaissance missions

Answer for Boeing VC-137C (Boeing 707)

Who:

Who developed the aircraft?

Boeing Aircraft Corporation

Who used the aircraft?

Several U.S. Presidents, diplomats and other dignitaries and officials

Who is associated with this aircraft?

(country, group, or individual)

The United States, specifically the President of the United States and the U.S. Airforce

What:

What was the function of the aircraft?

(note any markings or inscriptions)

To fly the President of the United States and other government officials

What materials are used? (wood, fabric, metal)

Unable to determine based on information provided, though the photos indicate it is made mostly of metal

What style of wing design is used?

(monoplane, biplane or triplane)

Monoplane

What type of wing placement does the aircraft have? (high wing, low wing)

Low wing

What propulsion system does this aircraft use?

(propeller or jet; single or multiple engines)

Multiple jet engines; Four Pratt & Whitney TF33 (JT3D-3B) turbofans with 18,000 lbs. thrust each

When:

When was the aircraft produced?

1962

When was the aircraft used?

1962 - 1998

When was the aircraft retired?

1998

Where:

Where was the aircraft produced?

At the Boeing factory in Renton, Washington

Where was the aircraft registered?

The United States of America

Where was the aircraft flown?

World-wide

Why:

Why would a museum keep this airplane?

It was the first airplane made specifically for use by the President of the United States

Why is this airplane important to local, regional, national or international history?

It was the first airplane built specifically for Presidential use and it was flown on many historic journeys, such as returning John F. Kennedy's body to Washington after his assassination in 1963

How:

How was it used?

It was used to transport the President, diplomats and other dignitaries and officials

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Properties and changes of properties in matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Structure and properties of matter
- Interactions of energy and matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology



Reference Materials

Fact Sheet 1 1903 Wright Flyer



(Photo courtesy of Wikipedia, GNU Free Documentation License)

Img. 6 The Wright Brothers' First Flight; December 17, 1903

Summary:

The Wright brothers inaugurated the aerial age with the world's first successful flights of a powered heavier-than-air flying machine. The Wright Flyer was the product of a sophisticated four-year program of research and development conducted by Wilbur and Orville Wright beginning in 1899. After building and testing three full-sized gliders, the Wrights' first powered airplane flew at Kitty Hawk, North Carolina, on December 17, 1903, making a 12-second flight, traveling 36 m (120 ft), with Orville piloting. The best flight of the day, with Wilbur at the controls, covered 255.6 m (852 ft) in 59 seconds.

The Wrights pioneered many of the basic tenets and techniques of modern aeronautical engineering, such as the use of a wind tunnel and flight testing as design tools. Their seminal accomplishment encompassed not only the breakthrough first flight of an airplane, but

also the equally important achievement of establishing the foundation of aeronautical engineering.

Date: 1903

Country of Origin: United States of America

Dimensions:

Wingspan: 12.3 m (40 ft 4 in)

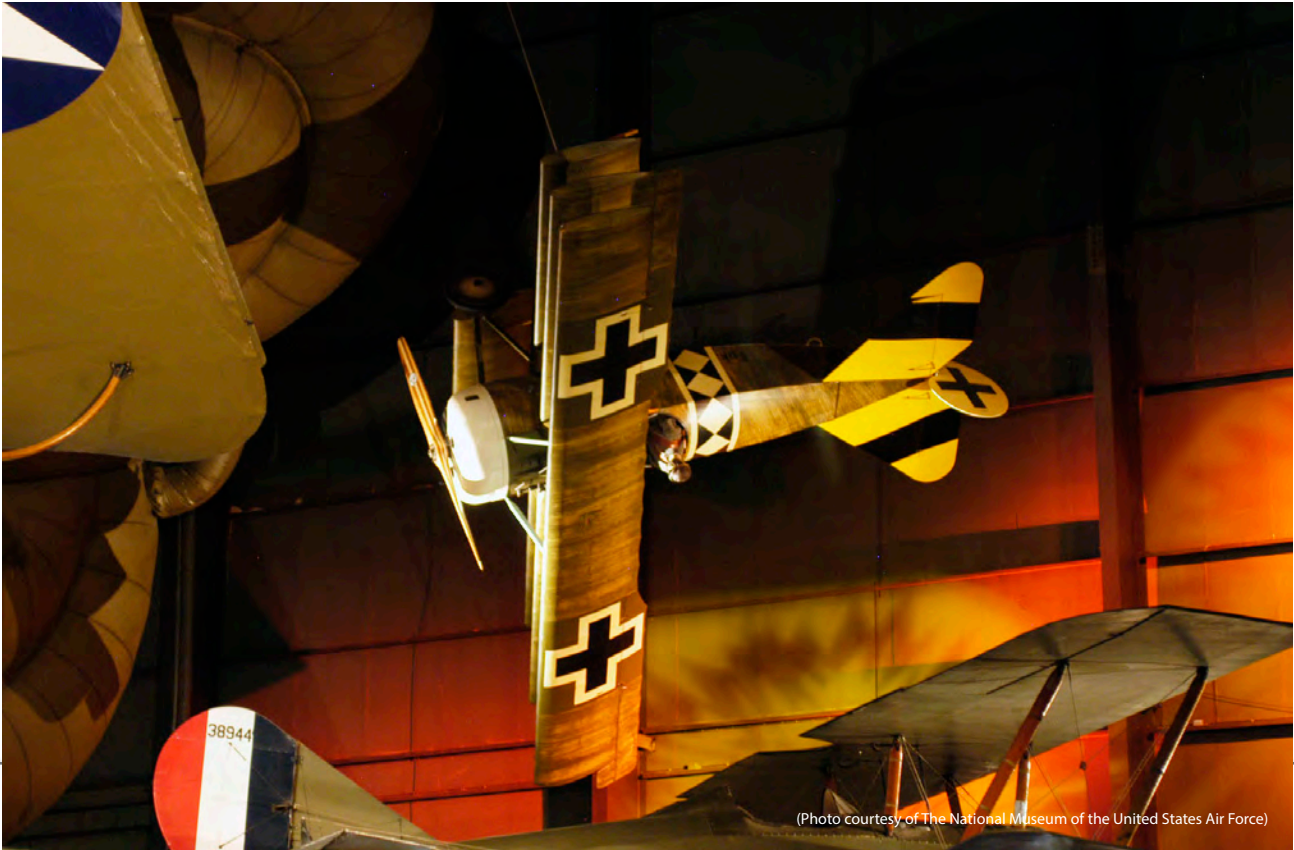
Length: 6.4 m (21 ft 1 in)

Height: 2.8 m (9 ft 4 in)

Weight: Empty, 274 kg (605 lb) / Gross, 341 kg (750 lb)

Materials: Airframe: Wood / Fabric Covering: Muslin
Engine Crankcase: Aluminum

Physical Description: Canard biplane with one 12-horsepower Wright horizontal four-cylinder engine driving two pusher propellers via sprocket-and-chain transmission system. No wheels; skids for landing gear. Natural fabric finish; no sealant or paint of any kind.



(Photo courtesy of The National Museum of the United States Air Force)

Img. 10 1917 Fokker Dr. 1

Summary:

Few aircraft have received the attention given the Fokker Dr. I triplane. Often linked with the career of World War I's highest scoring ace, Germany's Rittmeister Manfred von Richthofen (the "Red Baron"), the nimble Dr. I earned a reputation as one of the best dogfighters of the war.

The German air force ordered the Fokker Dr. I in the summer of 1917, after the earlier success of the British Sopwith triplane. The first D. I planes appeared over the Western Front in August 1917. Pilots were impressed with its agility, and several scored victories with the highly maneuverable triplane. Von Richthofen score 19 of his last 21 victories were achieved while he was flying the D. I. By May 1918, however, the Dr. I was being replaced by the newer and faster Fokker D. VII.

Although Fokker built a total of 320 of these aircraft, none have survived. This reproduction is painted to

represent the aircraft flown by Lt. Arthur Rahn in April 1918 when he served with Jagdstaffel 19. Lt. Rahn is credited with six confirmed victories. The aircraft was placed on display in April 1994.

Armament: Two 7.92mm Spandau LMG 08/15 machine guns

Engine: Oberursel Ur II of 110 hp or LeRhône of 110 hp

Maximum speed: 103 mph

Range: 185 miles

Ceiling: 19,685 ft.

Span: 23 ft. 7 in.

Length: 18 ft. 11 in.

Height: 9 ft. 8 in.

Weight: 891 lbs. empty; 1,291 lbs. loaded

Fact Sheet 3 Lockheed SR-71A



(Photo courtesy of Wikipedia, GNU Free Documentation License)

Img. 11 Lockheed SR-71A

Summary:

The SR-71, unofficially known as the “Blackbird,” is a long-range, advanced, strategic reconnaissance aircraft developed from the Lockheed A-12 and YF-12A aircraft. The first flight of an SR-71 took place on Dec. 22, 1964, and the first SR-71 to enter service was delivered to the 4200th (later 9th) Strategic Reconnaissance Wing at Beale Air Force Base, Calif., in January 1966. The U.S. Air Force retired its fleet of SR-71s on Jan. 26, 1990, because of a decreasing defense budget and high costs of operation.

Throughout its nearly 24-year career, the SR-71 remained the world’s fastest and highest-flying operational aircraft. From 80,000 feet, it could survey 100,000 square miles of Earth’s surface per hour. On July 28, 1976, an SR-71 set two world records for its class -- an absolute speed record of 2,193.167 mph and an absolute altitude record of 85,068.997 feet.

On March 21, 1968, in the aircraft on display, Maj. (later Gen.) Jerome F. O’Malley and Maj. Edward D. Payne made the first operational SR-71 sortie. During its career, this

aircraft accumulated 2,981 flying hours and flew 94 total sorties (more than any other SR-71), including 257 operational missions, from Beale Air Force Base, Calif., Palmdale, Calif., Kadena Air Base, Okinawa, and RAF (Base), Mildenhall, England. The aircraft was flown to the museum in March 1990.

Armament: None

Engines: Two Pratt & Whitney J58s of 32,500 lbs. thrust each with afterburner

Crew: Two

Maximum speed: Mach 3+ (three times the speed of sound) or over 2,000 mph

Range: More than 2,900 statute miles

Ceiling: Over 85,000 ft.

Span: 55 ft. 7 in.

Length: 107 ft. 5 in.

Height: 18 ft. 6 in.

Weight: 140,000 lbs. loaded

Serial number: 61-7976



(Photo courtesy of The National Museum of the United States Air Force)

Img. 12 SAM 26000, a Boeing VC-137C landing at the National Museum of the United States Air Force in Dayton, OH

Summary:

This U.S. Air Force Boeing VC-137C aircraft (civilian designation 707-320B) was the first jet made specifically for use by the President of the United States. Built in 1962, it served many presidents over three decades, carrying heads of state, diplomats and other dignitaries and officials on many historic journeys.

Popularly known as "SAM 26000" (Special Air Mission; tail number 26000), the aircraft has also been called "Air Force One" -- though this designation was used officially only when the president was aboard. During the 1950s, the call sign of the presidential aircraft was the prefix SAM followed by the aircraft's tail number, and the name "Air Force One" was later chosen to ensure there was no question as to where the president's aircraft was and whether the president was aboard. Because President Kennedy did not name his aircraft as had former presidents, the news media popularized the call sign "Air Force One" as this aircraft's name.

On Oct. 10, 1962, VC-137C number 26000 entered USAF service directly from the Boeing assembly line in

Renton, Wash. President Kennedy had the aircraft painted in striking blue and white instead of the usual military colors to give it a distinctive look. The title "United States of America" was emblazoned on the fuselage and an American flag was painted on the tail. This aircraft carried eight presidents: Kennedy, Johnson, Nixon, Ford, Carter, Reagan, George H.W. Bush and Clinton.

In December 1972 another Boeing 707-320, aircraft 27000, became the primary presidential aircraft and 26000 became a back-up, flying vice presidents and other high-ranking government officials. In 1990 SAM 26000 left the presidential fleet, but it continued to fly government officials, including Secretary of State James Baker. Prior to the 1991 Gulf War, he went abroad in 26000 for talks with Iraqi leaders about removing their troops from Kuwait.

SAM 26000 flew President Kennedy to Berlin in 1963, where he declared to West Berliners, "Ich bin ein Berliner," assuring them of continuing United States support in

Continued >>

Fact Sheet 4 Continued

<< *Continued*

the face of Communist threats and the construction of the Berlin Wall. Kennedy also flew aboard SAM 26000 to Dallas, Texas, where he was assassinated on Nov. 22, 1963 -- and it was on this airplane that Vice President Lyndon B. Johnson was sworn in as the new president. SAM 26000 then carried John F. Kennedy's body and President Johnson back to Washington, D.C. Johnson also used 26000 to visit U.S. troops in Vietnam during the Southeast Asia War.

Beginning in 1970, President Nixon's national security advisor, Dr. Henry Kissinger, used the aircraft for 13 trips to Paris, France, for secret meetings with the North Vietnamese. In February 1972 President Nixon flew aboard SAM 26000 on his historic "Journey for Peace" to the People's Republic of China (the first visit by an American president to China). In May 1972 SAM 26000 carried Nixon to the Soviet Union.

In October 1981 the aircraft flew residents Nixon, Ford and Carter, and former Secretary of State Dr. Kissinger to the funeral of the slain Egyptian president Anwar Sadat. In March 1983 Queen Elizabeth II of the United Kingdom flew on SAM 26000 during her trip to the United States when she visited the West Coast.

At a nationally televised event in May 1998, the USAF retired SAM 26000 at the museum. This aircraft provided 36 years of service and accumulated more than 13,000 flying hours.



(Photo courtesy of The National Museum of the United States Air Force)

Img. 13 SAM 26000 on display at the National Museum of the United States Air Force in Dayton, OH

Maximum speed: 604 mph

Ceiling: Above 43,000 ft.

Range: 6,000+ miles

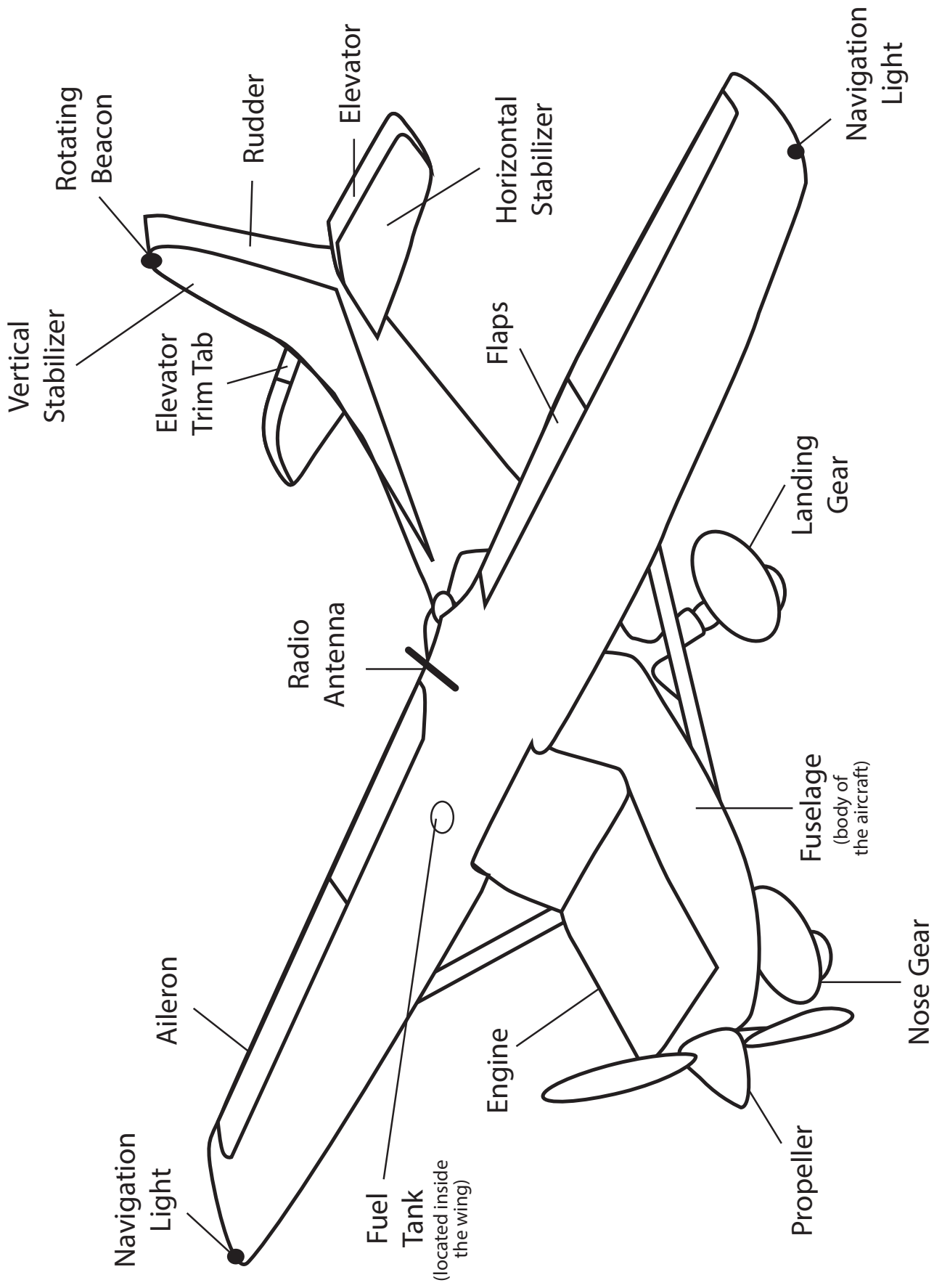
Engines: Four Pratt & Whitney TF33 (JT3D-3B) turbofans of 18,000 lbs. thrust each

Load: 40 passengers or 26,200 lbs. of cargo

Crew: 7 or 8

Content from The National Museum of the United States Air Force

Fig. 1 Parts of an airplane



Glossary

Biplane:

An airplane with two pairs of wings stacked vertically on top of each other

Control Surface:

Attached to the wings and tail, these moveable parts are used for steering or controlling an aircraft (example: ailerons, elevator, rudder)

Fuselage:

The main body of an aircraft where the wings and tail are attached

High Wing:

The design of an airplane where the wings are level with or above the top of the fuselage

Jet Engine:

An engine design which use turbines to create thrust

Low Wing:

The design of an airplane where the wings are attached to the center or bottom half of the fuselage

Monoplane:

An airplane with one main set of wings

Triplane:

An airplane with three vertically stacked wings



Student Worksheets

Worksheet 1 Artifacts

Artifact Name: _____

Who:

Who developed the aircraft?

Who used the aircraft?

Who is associated with this aircraft? (country, group, or individual)

What:

What was the function of the aircraft? (note any markings or inscriptions)

What materials are used? (wood, fabric, metal)

What style of wing design is used? (monoplane, biplane or triplane)

What type of wing placement does the aircraft have? (high wing, low wing)

What propulsion system does this aircraft use? (propeller or jet; single or multiple engines)

Worksheet 1 Continued

When:

When was the aircraft produced?

When was the aircraft used?

When was the aircraft retired?

Where:

Where was the aircraft produced?

Where was the aircraft registered?

Where was the aircraft flown?

Why:

Why would a museum keep this airplane?

Why is this airplane important to local, regional, national or international history?

How:

How was it used?



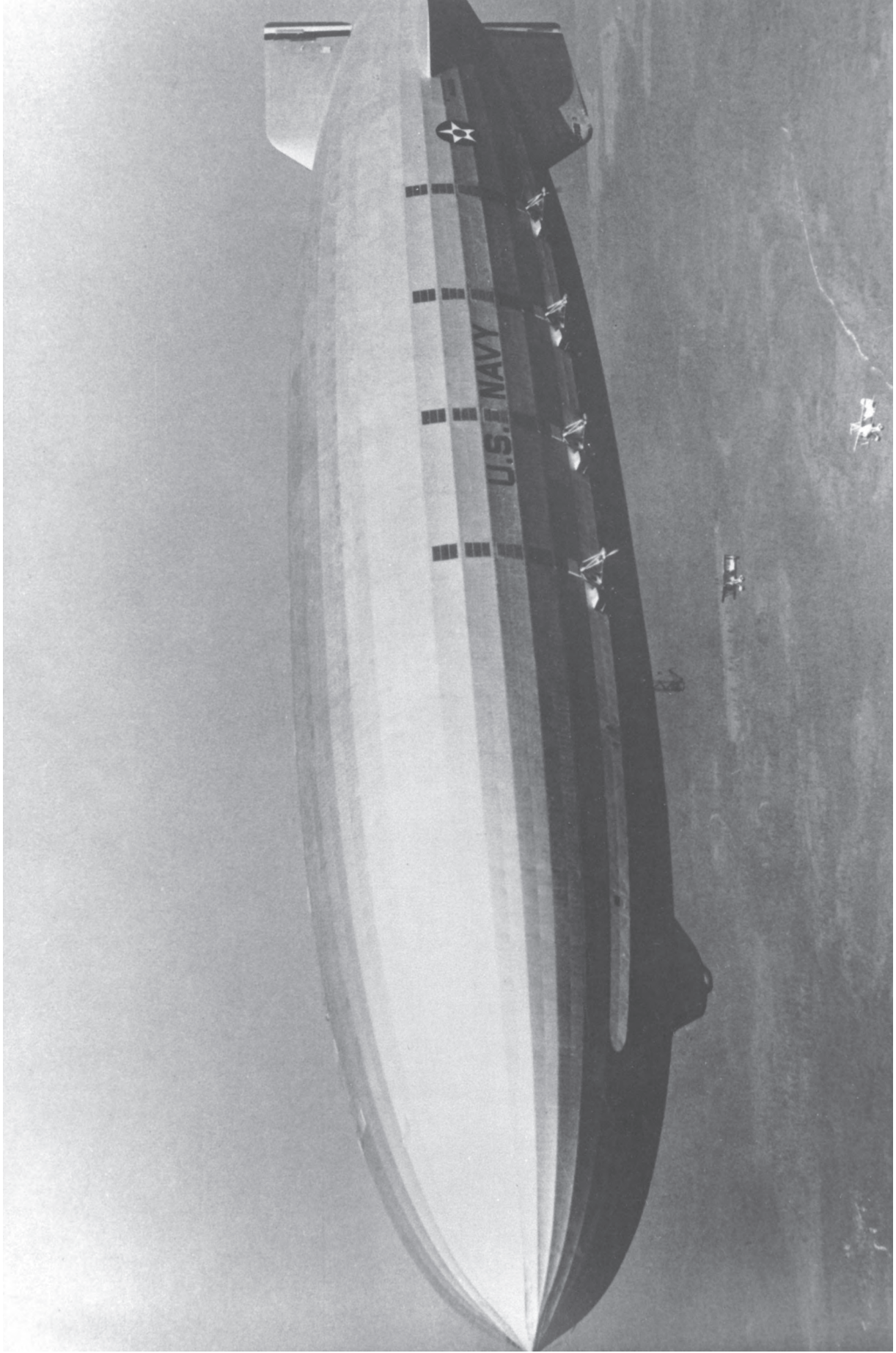
Images

Img. 1 Kongming lantern



(Photo courtesy of Wikipedia, GNU Free Documentation License)

Img. 2 Macon Airship



(Photo courtesy of NASA - www.nasaimages.org)

Img. 3 Reenactors in front of a replica Fokker Dr. I triplane



(Photo courtesy of The National Museum of the United States Air Force)

Img. 4 Civilian aircraft registration number



(Photo courtesy of NASA - www.nasaimages.org)

Img. 5 Military aircraft insignia



(Photo courtesy of NASA - www.nasaimages.org)

Img. 6 The Wright Brothers' First Flight; December 17, 1903



(Photo courtesy of Wikipedia, GNU Free Documentation License)

Img. 7 The Wright Brothers' 1903 aircraft, the Wright Flyer, in the Smithsonian National Air and Space Museum



(Photo courtesy of Smithsonian National Air and Space Museum)

Img. 8 The Wright Brothers' 1903 aircraft, the Wright Flyer, in the Smithsonian National Air and Space Museum



(Photo courtesy of Wikipedia, GNU Free Documentation License)

Img. 9 The 1903 Wright Flyer in the Smithsonian National Air and Space Museum, May 1982



(Photo courtesy of Wikipedia, GNU Free Documentation License)

Img. 10 1917 Fokker Dr. 1



(Photo courtesy of The National Museum of the United States Air Force)

Img. 11 Lockheed SR-71A



(Photo courtesy of Wikipedia, GNU Free Documentation License)

Img. 12 SAM 26000, a Boeing VC-137C landing at the National Museum of the United States Air Force in Dayton, OH



(Photo courtesy of The National Museum of the United States Air Force)

Img. 13 SAM 26000 on display at the National Museum of the United States Air Force in Dayton, OH

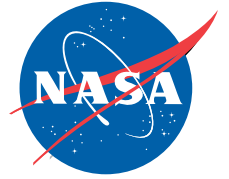


(Photo courtesy of Courtesy of The National Museum of the United States Air Force)

Aeronautics
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history of flight



GRADES

K-4

First Flyers



history of flight

Aeronautics
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First Flyers

Lesson Overview

In this lesson, divided into five activities, students will learn about the abilities of technological design, science as a human endeavor, and the position and motion of objects as they explore the history of American aviation.

More specifically students will learn about famous aviators and important discoveries in flight. In addition, they will experiment with kite design, propulsion and drag as they seek to understand some of the challenges involved in the development of aviation technology.

Each activity is structured around an important discovery in flight and how that discovery affected science and technology as well as society. Hands-on activities and history about a famous aviator who lived at the time of the discovery is also attached to each activity.

Objectives

Students will:

1. Identify five discoveries about flight.
2. Create a series of stories written by the class (called Choral Writing) of one of America's first flyers from a list including Wilbur and Orville Wright, Amelia Earhart, the Tuskegee Airmen, Chuck Yeager, and Neil Armstrong.
3. Experiment with sled kites with different tail lengths, flown in varying amounts of wind to determine optimal design much like the Wright brothers did in 1899 with their famous Wright kite.
4. Experiment with shape and drag using modeling clay dropped in liquid.
5. Experiment with a simple paper helicopter to compare how the lift of rotary wings (in the form of a propeller) in a helicopter differs from the lift of an airplane with fixed wings.
6. Experiment with balloon rockets to learn about propulsion.

Materials:

In the Box

Two straight drinking straws	Maple seed "helicopters" (optional)
Tape	Paper Helicopter Template (Worksheet 2)
Scissors	Paper
Two 45cm lengths of string	Measuring tape
One 1m length of string	Paper
Ruler	Balloon rockets kit
Single-hole punch	Large long balloons
Paper clip	Fishing line
Markers, crayons, pencils (optional)	Straight straws
Selection of ribbons	Clothes pins or binder clips
Painted canvas to show the material that covered the aircraft	
A piece of aluminum from pop can, siding, air duct, etc.	
Tall, clear 10-12 oz. plastic cups	
Modeling clay	
Stopwatch	
Clear, syrupy liquid	
Ruler/Yardstick	
Gallon-sized container(s)	
3/8 fasteners (optional)	

Provided by User

Chart paper

GRADES

K-4

Time Requirements: 5 Hours

Background

Discoveries in American Aviation

Airplanes are such an important part of our everyday lives that it is hard to believe that they did not exist until a little over a century ago.

America's progress in aviation has grown out of the belief that better technology improves life for people.

The airplanes included in this timeline represent five significant achievements in the history of flight. These technological advances not only transformed aviation, but society as well by reinventing travel, advancing commerce, changing the way people engage in warfare, creating entirely new industries, and bringing people around the globe together like never before.

Discovery One: The First Successful Powered Airplane

Airplane: 1903 Wright Flyer

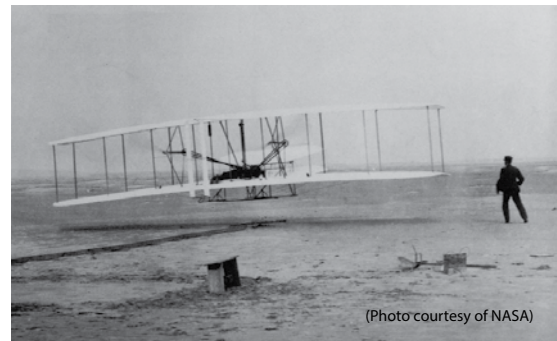
Date: First flight on December 17, 1903

SCIENCE AND TECHNOLOGY

The first powered, controlled, heavier than air flight lasted only 12 seconds, covered just 120 feet, and traveled at a mere 30mph, but Wilbur and Orville Wright came up with the basic solutions for powered, controlled flight. Their contributions included an innovative propeller design that provided thrust, and a system for controlling movement in three directions—vertical (pitch), horizontal (yaw), and lateral (roll). These same basic principles have been applied to every airplane that has been built since.

SOCIAL IMPACT

The Wright Flyer's first successful flight launched the aerial age and thrilled people around the world about the possibilities of flight. Writers and artists incorporated flight in their work while images of airplanes appeared on clocks, cigarette cases, plates, and other everyday items. Soon airplanes were used to deliver mail and freight, dust crops, map the Earth, and carry passengers.



Img. 1 1903 Wright Flyer

Discovery Two: The First Airplane to Fly Across the Atlantic Ocean Nonstop With a Single Pilot

Airplane: Spirit of St. Louis (Ryan NYP)

Departed New York, USA on May 20, 1927

Arrived Paris, France 33 1/2 hours later

SCIENCE AND TECHNOLOGY

At the time Charles Lindbergh made his historic transatlantic flight, the airplane had become a much more dependable machine. Larger and more powerful engines allowed airplanes to travel faster, higher, and farther. The Spirit of St. Louis was built for maximum distance with wings built to carry the 450 gallons of fuel needed to fly from New York to Paris 4,000 miles and 33 1/2 hours away.

SOCIAL IMPACT

Lindbergh's flight astonished the world because it demonstrated the safety of airplanes, which led to a rapid advancement in the aviation industry. Within the few years following Lindbergh's flight, airplanes were crossing the United States in 48 hours (compared to 72 hours by train). Soon songs, novels, comic books, and movies made aviation their theme.



(Photo courtesy of NASA)

Img. 2 Charles Lindbergh

Discovery Three: The First Profitable Passenger Airplane

Airplane: Douglas DC-3

Date: First flown in 1935

SCIENCE AND TECHNOLOGY

The DC-3 was built of aluminum, making it stronger and more durable than earlier aircraft, which used modified fabrics like painted canvas. The DC-3 also had a larger fuselage (body) and wings, and it could carry more weight. The DC-3 transported as many as 21 passengers at a time at speeds of up to 212 mph. The design of the DC-3 was streamlined with its bullet-shaped fuselage, two powerful engines enclosed by cowlings (hoods), and its retractable landing gear.

SOCIAL IMPACT

The DC-3 was the first modern airliner. It was the fastest commercial form of transportation in its day, and the first airplane to make a profit carrying passengers. The DC-3 made air travel popular and affordable. Its sleek, streamlined shape influenced the design of everything from automobiles to toasters. Military airplane technology also had advanced by this time, resulting in the remarkable airpower that was demonstrated in World War II. The DC-3 used by Americans to move troops and supplies during the war was nicknamed the Gooney Bird because of its awkward appearance.



(Public Domain)

Img. 3 Douglas DC-3

Milestone Four: The Invention of the Helicopter

Aircraft: Sikorsky R-4

Date: Made its initial flight on January 13, 1942

SCIENCE AND TECHNOLOGY:

The Sikorsky R-4 as designed by Igor Sikorsky had a single, three-bladed main rotor (engine). The R-4 was the world's first large-scale, mass-produced helicopter and the first helicopter to enter service with the United States Army Air Forces, Navy, and Coast Guard. The R-4 became the model for all modern single-rotor helicopters produced thereafter.

SOCIAL IMPACT:

Because helicopters have the ability to fly forwards, backwards, up, down and sideways, as well as remaining stationary over a single spot, they are used to complete tasks that are not possible with airplanes. For example, helicopters are often more useful than airplanes in fighting fires, rescuing people stuck in otherwise inaccessible places, transporting the sick and injured, moving and removing large objects, and gathering news and scientific data.



Img. 4 Sikorsky R-4

Milestone Five: The First Plane to Fly Faster than the Speed of Sound

Airplane: Bell X-1 "Glamorous Glennis"

Date: First broke the sound barrier on October 14, 1947

SCIENCE AND TECHNOLOGY

The Bell X-1 became the first airplane to fly faster than the speed of sound. Until then, no one knew what would happen to objects in flight at the speed of sound. There was fear of the effects of compressibility or a collection of several aerodynamic effects that "struck airplanes" like a wall keeping them from further acceleration. U.S. Air Force Captain Charles E. "Chuck" Yeager piloted the X-1 as it reached Mach 1.01 at an altitude of 43,000 feet. Yeager nicknamed the airplane the "Glamorous Glennis" in honor of his wife.

The X-1 used its rocket engine to climb to its test altitude after launching from the bay of a large Boeing B-29 airplane at an altitude of 23,000 feet. The airplane flew a total of 78 times, and on March 26, 1948, with Yeager as its pilot, the X-1 reached a speed of 957 miles per hour at an altitude of 71,900 feet. It was the highest speed and altitude ever reached by any manned airplane up to that time.



Img. 5 Bell X-1 "Glamorous Glennis"

SOCIAL IMPACT

The Bell X-1 laid the foundation for America's space program in the 1960s because the personnel associated with the development of X-1 technology went on to assume key leadership positions in the program. The project also forged the post-war relationship between the U.S. military, private industry, and research facilities. The flight data collected by the X-1 was invaluable for the remainder of the 20th century in furthering U.S. fighter jet design.

Famous American Aviators

In addition to these great achievements in the science and technology of aviation, the history of aviation would not be complete without the ingenuity and tenacity of many great pilots. The people included in this part of the lesson are only a few of the many Americans who changed aviation history forever.

Wilbur and Orville Wright

Wilbur Wright, the third child of Milton and Susan Wright, was born on April 16, 1867. Wilbur was the oldest child of the brother-partners who would eventually give humankind the capacity for flight.

The other half of that partnership, Orville, was born four years later, on August 19, 1871, in the family's newly built house in Dayton, Ohio.

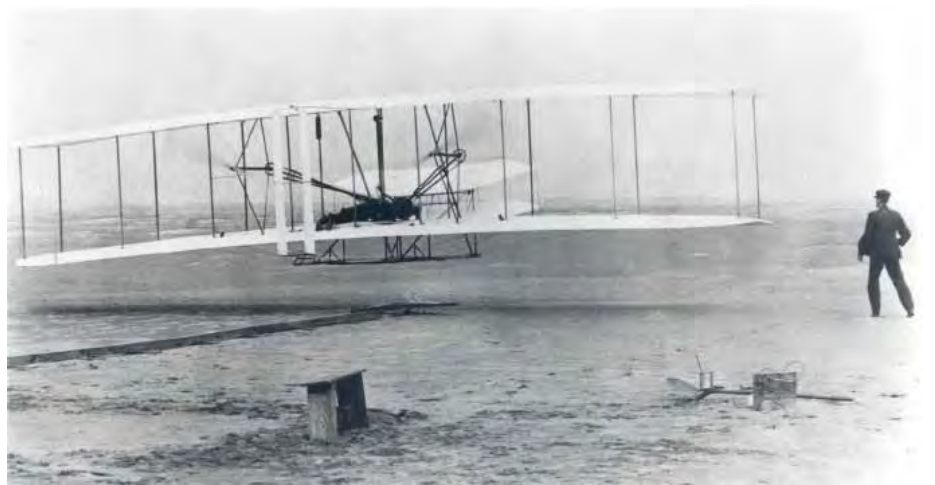
As boys, Wilbur and Orville were inspired by their mother's mechanical abilities and their father's intellectual curiosity. Milton brought his boys various souvenirs and trinkets he found during his travels as a minister for the Church of the United Brethren in Christ. One such trinket, a helicopter-like top, inspired the boys' interest in flight. In school,

Wilbur was an excellent student who would have graduated from high school if his family had not moved during his senior year. Then his mother's illness and death kept Wilbur from attending college. Orville, on the other hand, was merely an average student, known for being mischievous. Thus Orville quit school before his senior year to open a printing business. It was common for people to not graduate from high school back then.

The first time Wilbur and Orville called themselves "The Wright Brothers" was when they opened their own printing firm. At the time, Wilbur was 22 and Orville was 18.

In 1892, the brothers began repairing bicycles for friends, and soon started their own repair business. In 1893, the brothers opened a bicycle shop in Dayton, Ohio, and three years later, even made their own bicycle models.

In 1896, while nursing Orville, who was sick with typhoid, Wilbur read about the death of the famous German glider pilot Otto Lilienthal, the first man to make a heavier-than-air flight using a glider. Lilienthal died when his glider lost lift. The news of Lilienthal's work led Wilbur to take a keen interest in flying. On May 30, 1899, he wrote to the Smithsonian Institution for information on aeronautical research.



Img. 1 The Wright brothers

Within a few months, Wilbur read all that had ever been written about flying. From his reading, he was able to identify the necessary elements for the success of any flying machine: **wings to provide lift, a power source for propulsion, and a system of control.**

Of all of the early aviators, Wilbur especially recognized the need for controlling a flying machine in all three of its axes: pitch, roll and yaw. Wilbur's solution to the problem of control was 'wing warping.' He came up with this revolutionary system by twisting a long rectangular box which had its ends removed. Twisting the surface of each "wing" changed its position in relation to the oncoming wind. Such changes in position would result in changes in the direction of flight. Wilbur tested his theory using a small kite, and it worked.

In August of 1900, Wilbur and Orville built their first glider and chose a lonely beach on the coast of North Carolina called Kitty Hawk to test their new invention.

The following year, the brothers tested a new, improved glider with a 22-foot wingspan; however, after a disappointing performance they returned to Dayton to construct a wind tunnel in which to test a variety of more effective wing designs. Using the results of the wind tunnel, the brothers constructed their 1902 glider. In October, they returned to Kitty Hawk to test this glider, which succeeded in flying 620 feet, a new record. Following this success Wilbur and Orville returned once again to Dayton to begin working on a propeller and engine for the first ever manned, powered flying machine.

After they designed a propeller based on the same principles used to design their wings, Wilbur and Orville built a 4-cylinder, 12-horsepower engine to power their 1903 Flyer, which was built in sections in the back room of their bicycle shop and shipped to Kitty Hawk where it was to be assembled.

On December 14, 1903, Wilbur won the coin toss and made his first attempt to fly the machine, but the machine stalled on take-off, causing minor damage. Once the plane was repaired three days later, Orville made his second attempt.

At 10:35 a.m., on December 17, 1903, Orville Wright completed the world's first heavier-than-air, machine powered flight. The flight lasted 12 seconds and covered a mere 120 feet, but Orville did what humans had been yearning to do – he flew.

Amelia Earhart

Amelia Mary Earhart was the daughter of Samuel "Edwin" Stanton Earhart and Amelia "Amy" Otis Earhart. Amelia was born in Atchison, Kansas, on July 24, 1897. Amelia's upbringing was unconventional. Her mother, Amy, did not believe in molding her children, Amelia and her sister Muriel (nicknamed Pidge), into "nice little girls."

As a child, Amelia spent long hours playing with Pidge, climbing trees, hunting rats with a rifle and "belly-slamming" her sled downhill. In 1904, Amelia and her uncle pieced together a homemade ramp modeled after a roller coaster. They attached the ramp to the family's tool shed and Amelia rode the ramp in a wooden box. Though the wooden box was shattered and Amelia's lip bruised, she exclaimed, "Oh, Pidge, it's just like flying!"



(Photo courtesy of NASA)

Img. 6 Amelia Earhart

By the time Amelia was in high school, her family had moved to Chicago. There, Amelia searched for a school that had a strong science program. She discovered one in Hyde Park High School. After graduating from Hyde Park, Amelia continued to research her future career, keeping a scrapbook of newspaper clippings about successful women in male-dominated fields including film production, law, advertising, management and engineering.

In 1920, Amelia and her father visited an airfield where Amelia took her first ride in an airplane. That ride would change her life forever. She said, "By the time I had got two or three hundred feet off the ground I knew I had to fly."

Six months after her first flight, Amelia purchased a used bright yellow airplane, which she nicknamed "The Canary." On October 22, 1922, Amelia flew her plane to an altitude of 14,000 feet, setting a world record for female pilots.

A year after Charles Lindbergh's solo flight across the Atlantic in 1927, Amelia got a phone call from Captain Hilton H. Railey, who asked, "Would you like to fly the Atlantic?" Amelia enthusiastically took this opportunity, though she flew only as a passenger, with the added duty of keeping up the flight log. After the flight, Amelia said, "I was just baggage, like a sack of potatoes." She added, "...maybe someday I'll try it alone."

Because of her resemblance to Lindbergh, whom the press nicknamed "Lucky Lindy," some reporters began referring to Amelia as "Lady Lindy" or the "Queen of the Air."

Although Amelia gained some fame from her transatlantic flight, she wanted to set a record of her own. So, Amelia set off on her first extended solo flight, in August of 1928, becoming the first woman to fly solo across North America and back. In 1931, she set a world altitude record of 18,415 feet.

At the age of 34, on the morning of May 20, 1932, Earhart set off from Harbour Grace, Newfoundland with the latest copy of a local newspaper to confirm the date of her flight. She intended to fly to Paris in her single engine plane just like Charles Lindbergh, but after a flight lasting 14 hours, 56 minutes during which she battled strong winds, icy conditions and mechanical problems, Amelia landed in a pasture in Northern Ireland. When a farm hand asked, "Have you flown far?" Amelia replied, "From America." Amelia Earhart had become the first woman to fly solo non-stop across the Atlantic.

In 1935, Amelia became the first person to fly solo from Hawaii to California. In the same year, flying her beloved Vega airplane, which she called "Old Bessie," Amelia soloed from Los Angeles to Mexico City.

Between 1930 and 1935, Amelia Earhart set seven records in aviation for speed and distance, but by 1935, Amelia began to think about a new adventure, a flight she most wanted to attempt – a circumnavigation of the globe at the equator.

In order to prepare for her flight, Amelia contacted Hollywood "stunt" pilot Paul Mantz to help her improve her long distance flying. As well, she joined the faculty of Purdue University in 1935 as a visiting professor in order to counsel women on aviation careers, serve as technical advisor to the Department of Aeronautics and garner support for her around-the-world flight.

Though not the first pilot to circle the globe, Amelia would choose the longest course at 29,000 miles, following a difficult equatorial path. With funding from Purdue, a Lockheed Electra 10E was built to her specifications to include among other things, an especially large fuel tank.

Soon, Amelia contacted Fred Noonan to be her navigator since he had plenty of experience in marine as well as airplane navigation.

On March 17, 1937, Amelia and her crew flew the first leg of the trip from Oakland, California to Honolulu, Hawaii. In addition to Amelia and Fred Noonan, Harry Manning and Paul Mantz were on board; however, the flight could not continue due to technical failures.

While the Electra was being repaired Amelia and her husband, George P. Putnam, a publisher, got additional funds for a second try. This time Amelia would fly from Oakland, California to Miami, Florida. Once she got there would she publicly announce her plans to circumnavigate the globe. The flight's opposite direction, from west to east instead of east to west, was due in part to changes in wind and weather patterns. Fred Noonan would be Amelia's only crewmember on this flight. The two departed Miami on June 1 and after many stops in South America, Africa, India and Southeast Asia, they arrived at Lae, Papua New Guinea on June 29, 1937. At this stage in the journey, Amelia and Fred Noonan had about 22,000 miles behind them. The remaining 7,000 miles would be over the Pacific Ocean.

On July 2, 1937, Amelia and Fred Noonan took off from Lae, Papua New Guinea in a heavily loaded Electra. They were heading for Howland Island, a flat sliver of land 2,556 miles away. Amelia's last known position was taken about 800 miles into her flight by the United States Coast Guard ship Itasca, which had been assigned to communicate with Amelia's airplane and guide them to the island once they got overhead.

Through a series of misunderstandings or errors, Amelia's final approach to Howland Island using radio failed and beginning one hour after Amelia's last recorded message, the Itasca began its search north and west of Howland Island. The United States Navy soon joined in the search, and over a period of about three days all of the area around Howland Island was investigated, but no sign of the flier was ever found. Airplanes also flew over the area to the north, west and southwest of Howland Island, based on a possibility that the Electra had crashed in the ocean, perhaps leaving the aviators in an emergency raft, but the search yielded nothing.

On July 19, 1937, the official search for Amelia Earhart and Fred Noonan was called off, and no physical evidence of Earhart, Noonan or the Electra 10E has ever been found. Amelia Earhart was declared legally dead on January 5, 1939.

Although Ms. Earhart was not the only female aviator of her time, she was the most famous. She had her own clothing and luggage line, and endorsed multiple products.

Other prominent female aviators included Willa Brown, who was the first African American to earn a commercial flight license in the United States. In addition, she helped train more than 200 students who eventually became Tuskegee Airmen. At age 16, Elinor Smith was the youngest pilot to earn a license which was signed by Orville Wright. Another notable pilot was Jacqueline Cochran, the first woman to exceed Mach 1 (the sound barrier).

Tuskegee Airmen

Although formally they were known as the 332nd Fighter Group of the U.S. Army Air Corps, the Tuskegee Airmen Corps, was the popular name for a group of African American pilots who fought with distinction in World War II. The pilots were nicknamed the Red-tailed Devils because airplane tails were painted red.

The Tuskegee Airmen were the first African American military pilots in the history of the United States armed forces. During World War II, African Americans in many states were still subject to Jim Crow laws, which meant they were required to have separate training schools and facilities and were kept separate from white members of the military. As such, the Tuskegee Airmen experienced racial discrimination, both within and outside of the army. Despite these challenges, the Tuskegee Airmen flew successful missions as bomber escorts throughout Europe.

Before the Tuskegee Airmen, no American military pilots had been African American, but in 1941 when the United States Congress forced the Army Air Corps to form an all-black combat unit, the War Department disagreed. In an effort to eliminate the unit before it could form, the War Department set up a system to accept only those with an uncommonly high level of flight experience or with a higher education, setting up standards they thought would be difficult for African American pilots to achieve. The policy failed dramatically when the Air Corps received an abundance of applications from African American men who qualified, many of whom already participated in the Civilian Pilot Training Program through the historically black Tuskegee Institute.

Strict racial segregation in the U.S. Army required the development of a separate group of African American flight surgeons to support the Tuskegee Airmen. Before the development of this unit, no U.S. Army flight surgeons were Black. The training of African American men as medical examiners was conducted through separate classes until 1943, when two Black doctors were admitted to the U.S. Army School of Aviation Medicine at Randolph Field, Texas. This was one of the earliest racially integrated courses in the U.S. Army. Seventeen flight surgeons served with the Tuskegee Airmen from 1941 through 1949. The chief flight surgeon of the Tuskegee Airmen was Dr. Vance H. Marchbanks, a boyhood friend of Benjamin O. Davis, Jr., who would become the commander of the fighter group.

It was not easy overcoming racism in the military, but by the end of the war, the Tuskegee Airmen shot down 112 German aircraft, sunk a German-operated Italian destroyer, and destroyed numerous enemy trucks and trains. Their squadrons completed more than 15,000 attacks during 1,500 missions. The Tuskegee Airmen were awarded a Distinguished Unit Citation (DUC) for the mission to escort B-17s on their way to bombing the Daimler-Benz tank factory in Berlin, Germany. During this flight, pilots destroyed three enemy jets.

By the end of the war, the Tuskegee Airmen were awarded several Silver Stars, 150 Distinguished Flying Crosses, 8 Purple Hearts, 14 Bronze Stars, 744 Air Medals and earned the distinction of never losing any bombers to enemy fighters.

Chuck Yeager

Charles Elwood "Chuck" Yeager was born on February 13, 1923. Yeager is a famous test pilot and retired major general in the United States Air Force. He was also the first pilot to travel faster than the speed of sound. Yeager's career began in World War II as a private in the United States Army Air Forces. After serving as an aircraft mechanic, Yeager entered a pilot training in September of 1942. Upon graduating, Yeager was promoted to the rank of flight officer, after which he became a North American P-51 Mustang fighter pilot. After the war, Yeager became a test pilot for many kinds of aircraft and rocket planes.



Img. 7 The Tuskegee Airmen

(Photo courtesy of NASA)



Img. 8 Chuck Yeager

(Photo courtesy of NASA)

On October 14, 1947, Yeager became the first man to break the sound barrier. Flying the experimental Bell X-1, Yeager reached Mach 1 at an altitude of 45,000 feet. Yeager later commanded fighter squadrons in Southeast Asia during the Vietnam War. In recognition of his outstanding performance ratings for the units he commanded, Yeager was promoted to brigadier general. Yeager's flying career spans more than 60 years and has taken him to every corner of the globe, including the Soviet Union during the height of the Cold War.

Neil Armstrong

Neil Alden Armstrong was born on August 5, 1930. A United States Naval Aviator, astronaut, test pilot, aerospace engineer and university professor, Armstrong is both a distinguished pilot and scientist. Armstrong was the first person to set foot on the Moon. His first spaceflight was aboard Gemini 8 in 1966, on which he was the command pilot, becoming one of the first U.S. civilians to fly in space. On this mission, Armstrong performed the first manned docking of two spacecraft. Armstrong's second and last spaceflight was as mission commander of the Apollo 11 moon-landing mission on July 20, 1969. It was on this mission, that Armstrong and Buzz Aldrin climbed down to the lunar surface for 2½ hours while Michael Collins remained in orbit in the Command Module. For this mission, Armstrong received the Congressional Space Medal of Honor.

Before becoming an astronaut, Armstrong was in the United States Navy, and he fought in the Korean War. After the war, Armstrong served as a test pilot at the National Advisory Committee for Aeronautics (NACA) High-Speed Flight Station, now known as the Dryden Flight Research Center, where he flew over 900 flights in a variety of aircraft.

After flying a number of NASA missions, including the first space docking mission ever, Armstrong was appointed commander for the Apollo 11 mission, which would land him on the Moon. As part of his preparation for lunar module control, Armstrong spent time in a helicopter, though he had previously received helicopter training during his time in the Navy. Armstrong thought the helicopter was good for training the astronauts when it came to determining flight paths for the lunar module, but otherwise, Armstrong thought there were too many differences between the controls of the two vehicles to make it the best training experience.

Armstrong and his crew of Buzz Aldrin and Michael Collins completed a successful mission to walk on the Moon on July 21, 1969. It was upon stepping off the Eagle spacecraft that Armstrong uttered his now famous words, "That's one small step for man, one giant leap for mankind."

After his Apollo mission, Armstrong retired as an astronaut, served as the NASA Deputy Associate Administrator for Aeronautics and went on to teach in the aerospace engineering program at the University of Cincinnati. Later Armstrong became a spokesman and served as a board member for many leading American corporations.



(Photo courtesy of NASA)

Img. 9 Neil Armstrong

Activity 1

Introducing Discovery One in American Aviation

GRADES**K-4****Time Requirements: 1 Hour****Materials:**In the Box

None

Provided by User

Chart paper

A map of the United States
with Kitty Hawk, North
Carolina marked

Stopwatch

Two straight drinking straws

Tape

Scissors

Two 45cm lengths of string

One 1m length of string

Ruler

Single-hole punch

Paper clip

Markers, crayons, pencils
(optional)

Selection of ribbons

WorksheetsSled Kite Template
(Worksheet 1)Reference MaterialsDiscovery One mini-poster
(Figure 1)**Objective:**

In this activity, students will learn about position and motion of objects, properties of objects and materials, abilities of technological design, and science as a human endeavor through the first discovery in American aviation, the Wright Flyer. After learning about the Flyer, students will experiment with kite design and lift. Students will learn more about the Wright brothers as they engage in Choral Writing about Wilbur and Orville Wright.

Activity Overview:

Students will first learn about the significance of the Wright Flyer in aviation history. Following this, students will create their own sled kites to experiment, like the Wrights, with design and lift.

Activity:

1. **Introduce students to the idea of a “Discovery in Flight” as an event marking a significant change in what had been previously known about airplanes and flight.** Ask the students to name different discoveries in flight. Ask: “Who invented the airplane?” or “When did humans first fly?”
2. **Tell students that with each of the discoveries in flight, they will be learning about the ways the discovery impacted science and society.** Explain that a scientific impact includes the way newly acquired scientific knowledge is used for practical purposes. Societal impacts involve the way the discovery is used to improve the lives of people living together in various communities.
3. **Tell students: “Listen carefully to these two names – Wilbur Wright and Orville Wright.** Then ask: “Who has heard these names before?”
4. **Go on to introduce December 17, 1903 as the day the Wright Flyer flew successfully for the first time over the sandy shores of Kitty Hawk, North Carolina.** Show students this location on a map.

Key Terms:

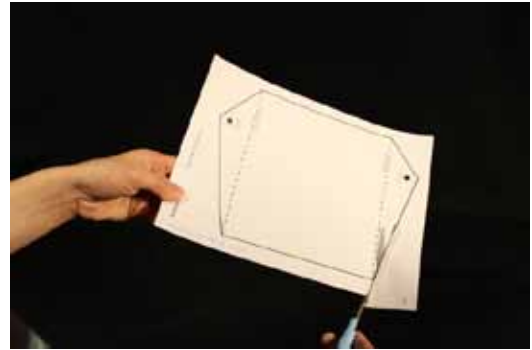
Airfoil
 Heavier-than-air
 Lift
 Pitch
 Propeller
 Propulsion
 Roll
 Yaw

5. **Ask students: “How long do you think Wilbur and Orville’s first flight lasted?”**
 After the students respond, tell them the flight lasted for all of 12 seconds. Tell the students to stand on one foot for 12 seconds while you watch a clock or stopwatch. Afterward, ask students if this seemed like a very long time for an airplane to stay in the air.
6. **Next, ask students: “How far do you think the Wright flyer flew in 12 seconds?”**
 After some general discussion, tell students that the flyer traveled 120 feet. Have some point of reference to demonstrate this distance for your students (the length of the gym, the playground, the parking lot, etc.).
7. **Now, tell the students that, like the Wrights, who started with kites, the students will make a “sled kite” using a template already made for them.** The teacher will explain the directions and provide a set of written, illustrated instructions for students to follow.

It is recommended that, for younger students, the templates and straws be cut in advance and there are enough adult helpers present to assist the students as they assemble their kites. Alternatively, kite kits could be assembled in advance and sent home for students to make and then bring back to school.

Sled kite directions to follow:

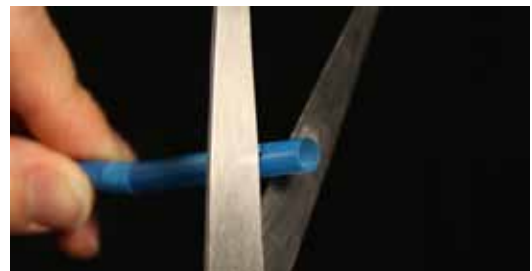
- a. Make a copy of the Sled Kite Template.



- b. Carefully cut out the kite.



- c. Trim the length of the two drinking straws so they will fit in the area marked on the template for the straws.



d. Tape the straws in place.



e. As shown, place two or three pieces of tape over the marked areas, covering the black circles where string holes will be punched.



f. Using a single-hole paper puncher, carefully punch the two holes marked by the black circles you just taped.



g. Cut two pieces of kite string each 45 centimeters long and one piece one meter long, which will be used in Step K.

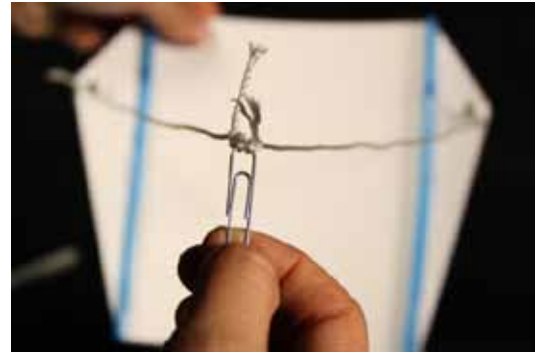


- h. Tie one string through each hole.

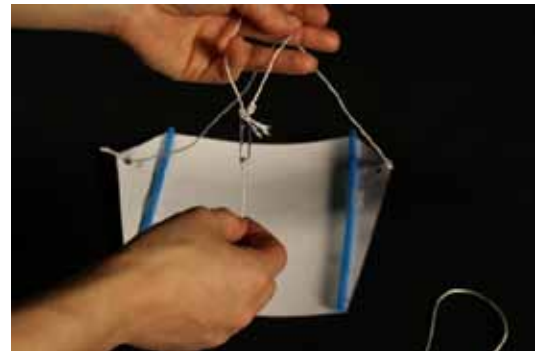


- i. Tie the string tight enough, but do not tear the paper.

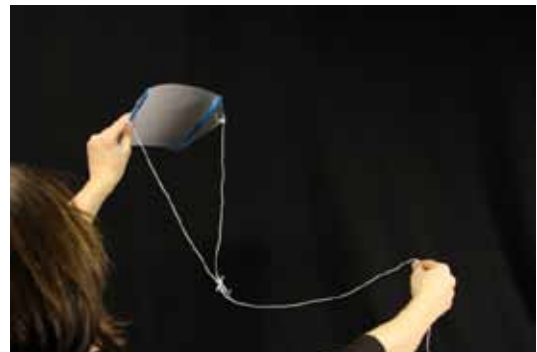
- j. Tie the loose end of each string to a paper clip as shown.



- k. Pick up the 1m long piece of string and tie the end of this string to the paper clip, opposite the kite.



- l. Your sled kite is ready to fly!



8. **To fly the kite, take students outside to a clear area.** If you do not have access to the outside, find a large indoor space. Instruct students to hold the end of the 1 m length of string and run with the kite to make it fly. Ask the students to run fast and then slow to observe how their speed affects the kite's flight.
9. **If there is time, students can add a strip of ribbon or crêpe paper as tails for their kites.** To do this, begin with a long tail, then progressively shorten it to see how the tail design affects flight.
10. **After kite trials, which may last from 10 – 20 minutes, students will return to the classroom and discuss their results, with the teacher recording student observations for all to see.** To guide the discussion, teachers may ask: How did the effect of running compare to walking when you were flying your kite? (Running created the effect of wind; more wind equals more lift). Relate this finding to Wilbur's choice of Kitty Hawk for a test site for the Wright Flyer.
11. **Then, if you had time to add a kite tail, ask the students how the tail affected the kite's motion.** (Tails add stability, keeping the nose pointed upward to provide lift.)

Show students the photograph of the Wright brothers and the 1903 Wright Flyer (Imgs. 1 and 6, found in the Image section of this lesson). Then read all or some of the lesson's Background Information about the Wright brothers. The students will listen for facts and generate ideas that may be used for the Choral Writing activity to follow. It is a good idea to use chart paper for this activity since all of the students will be able to see the story as it is being written, and it can be easily displayed for others to read as well.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Properties of objects and materials
- Position and motion of objects

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

HISTORY AND NATURE OF SCIENCE

- Science as a human endeavor

Activity 2

Introducing Discovery Two in American Aviation

GRADES**K-4****Time Requirements: 1 Hour****Materials:**In the Box

None

Provided by User

Map with flight path from New York to Paris, and from New York to Ireland marked

Chart paper

Painted canvas to show the material that covered the aircraft

A piece of aluminum

Tall clear container

Modeling clay

Stopwatch

Clear, syrupy liquid

Worksheets

None

Reference Materials

Discovery Two mini-poster

Key Terms:

Aerodynamic

Drag

Resistance

Transatlantic

Objective:

In this activity, students will learn about properties of objects and materials, science as a human endeavor, and abilities of technological design through the second discovery of flight in American aviation history, Charles Lindbergh's transatlantic flight in the airplane, the Spirit of St. Louis, on May 20, 1927. After learning about Lindbergh's flight, students will experiment with drag and how drag affects motion. (This activity may be done in small groups, or for younger students, as a demonstration.) Students will learn about Amelia Earhart and respond through Choral Writing.

Activity Overview:

Students will first learn about the significance of Charles' Lindbergh's flight from New York to Paris in the Spirit of St. Louis on May 20, 1927. Following this, students will experiment with drag and aerodynamic design. Finally, students will create a story through Choral Writing about Amelia Earhart.

Activity:

1. **Review what students learned in the previous activity about the Wright Flyer, kite design and lift, and the Wright brothers.**

You may wish to post the Discovery One mini-poster (Figs. 1 and 6 found in the Reference Materials section of this lesson) before your review in order to help prompt the students to recall what they learned in the previous activity. If not, post the Discovery mini-poster after the students review. Use the mini posters as part of your daily review and to create a timeline of significant, game-changing discoveries in aviation.

2. **Ask students to look at the map you posted. Point to New York and then to Paris.**

Ask students: "What stands between New York and Paris?" A big ocean of water, they will say. Ask them what that ocean is called. If no one is able to name the ocean, tell students it's the Atlantic.

3. **Ask: Can airplanes cross over the Atlantic?** Follow this question by asking: Who was the first person to cross the Atlantic in an airplane and when? Introduce Charles Lindbergh (Fig. 2) and his airplane, the Spirit of St. Louis, by showing students photos. Mention that shortly after Lindbergh, the first man to fly across the ocean from New York to Paris, Amelia Earhart took to the skies to be the first woman to cross the Atlantic, flying from New York to Ireland.
4. **As an option, search the Internet for and play a song or two about Lindbergh's flight across the Atlantic.**
5. **Ask students what problems pilots might face during such a flight, especially on windy days.** Explain how drag is a key issue in flight. Provide an example of drag by discussing how a parachute or sail is designed to increase drag and use drag as a benefit, but airplanes do not want to increase drag. Drag makes aircraft less maneuverable and slows them down.
6. **Introduce the What a Drag activity with the following introduction: "Let's see how shape affects drag."** We are going to use modeling clay to make different shapes. Then we are going to drop each shape into a glass filled with a thick clear liquid. Next, we will time the shape to see how long it takes to get to the bottom of the glass. Once we time each shape, we will determine which shape made it to the bottom of the glass fastest. That shape will win because it will be the most aerodynamically designed shape. In other words, it will be the shape with the least amount of drag."

A note about safety: Warn students not to taste the liquid or get it in their eyes. If safety goggles are available, you may wish to use them.

After gathering data about each shape (and you may wish to have 4-6 different shapes, some bullet-shaped, some cube-shaped, some flat and wide, some round, and so on), generalize about which shapes sunk fastest and what design elements they have in common (rounded, narrow shapes will sink faster). Discuss how these shapes are more aerodynamic (resist fluid less; explain that air is a form of fluid). Relate the aerodynamic designs of clay to other objects in life (cars, airplanes, a football, speed boats, bicycle racing helmets, etc.)

7. **Close by showing the students a photograph of Amelia Earhart (Fig. 7) and reading some or all of the Background Information with your students.** Then complete a story about Amelia Earhart using the Choral Writing Activity. *If space allows, post this choral writing product next to the choral writing product completed at the end of the previous activity. You may also choose to associate the Discovery mini poster with each related choral writing product by posting them together as a pair.*

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Properties of objects and materials
- Position and motion of objects

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

HISTORY AND NATURE OF SCIENCE

- Science as a human endeavor

Activity 3

Introducing Discovery Three in American Aviation

GRADES**K-4****Time Requirements: 1 Hour****Materials:**In the Box

None

Provided by User

Chart paper

Ruler/Yardstick

Gallon sized container(s)

3/8 fasteners (optional)

Worksheets

None

Reference Materials

Discovery Three mini-poster

Key Terms:

Gas mileage

Square feet

Volume

Objective:

In this activity, students will learn about science as a human endeavor, abilities of technological design, and position and motion of objects through the third discovery in American aviation history, the invention of the DC-3, which made air transportation accessible and affordable, and played a vital role in WWII. After learning about the DC-3, students will explore some math related to the DC-3. Students then will create a story through Choral Writing about the Tuskegee Airmen, an elite corps of African American pilots who gained fame during World War II.

Activity Overview:

Students will learn about the DC-3, the airplane that made air travel accessible and affordable for passengers as well as profitable for airlines. Students will use math to understand the size, construction and fuel limitations of the DC-3. Students will learn about the Tuskegee Airmen and their contributions to military aviation during World War II, the war in which the DC-3 proved to be of exceptional value.

Activity:

1. **Review the information your students have learned thus far, including details about the Wright brothers and Amelia Earhart as well as details related to Discoveries 1 and 2.** Refer to the Discovery mini-posters and choral writings as needed.
2. **Ask students to recall the date on which the Wright brothers flew their flying machine successfully for 12 seconds. (December 17, 1903)**
3. **Tell students that on December 17, 1935, exactly 32 years after the first successful flight of the Wright brothers, a new kind of airplane was introduced to the world.** It was an airplane with a specially designed tail to give the plane better stability and reduce the tendency to fishtail (show how fishtailing looks by moving your hand, palm parallel to the floor, left then right, on a horizontal axis (yaw)). It had longer and stronger wings, a rounder nose and sides for more aerodynamic design, which means less drag, and two newly designed, especially powerful engines.

4. **Tell the students that today's activity will focus on the math of the DC-3 (Fig. 3).** Included in procedure 5 are a number of ways to look at the math of the DC-3. Teachers may choose to explore all or some of this math.
5. **Say to the students: Here are some fun facts about the DC-3 that have some really big numbers in them!**
 - - Five hundred thousand rivets (Write this number on board while saying it) were used in the manufacture of the Douglas DC-3 airplane. The average size used in the manufacture was approximately $\frac{3}{8}$ of an inch long (Give students an everyday reference for that size such as the length of a thumbnail or show them on a ruler, or show them an actual fastener that is $\frac{3}{8}$ of an inch long), and if those rivets were laid end-to-end, they would cover a distance of 15,625 feet or more than three miles (Again, give students a reference point for that such as the distance from the school to the grocery store, etc.).
 - - Approximately 13,300 square feet of sheet metal were used in the construction of each DC-3. (Show the students what 1 square foot looks like, or have the students show what 1 square foot looks like. Tell students 13,300 square feet is about 2.5 miles of metal when stretched out 1 foot wide.
 - - The engines powering the DC-3 weigh 1,275 pounds each or a total of 2,550 pounds. That weight is approximately as heavy as a mid-size car.
 - - At a cruising speed of 180 mph and 10,000 feet up in the sky, ninety-one gallons of fuel are used each hour giving the plane an approximate gas mileage of 2 miles per gallon. (Show students a gallon-sized container so they can see what one gallon looks like; compare 2 miles per gallon for the DC-3 to a modern car – hybrid and conventional. Also have them imagine how much space 91 gallons might take up. For older students, ask them to calculate how many gallons would be used for flights of varying lengths. If you are able to collect 9 one-gallon containers of the same shape, show the students how much room those nine containers take up. For example, place 9 one-gallon containers on or under one student's desk and surround that desk with 9 other desks each having 9 gallons on or under them. This illustrates the amount of fuel needed for one hour of flight in the DC-3. Do the same to see how much space the fuel will take up for two hours of flight.
6. **Complete the lesson by reading all or some of the Tuskegee Airmen (Img. 8) Background Information included in the lesson.** Follow the reading with a Choral Writing activity. Note: At this point, your students have written three stories, two about famous individual aviators and one about the famous group of aviators, the Tuskegee Airmen.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Properties of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

HISTORY AND NATURE OF SCIENCE

- Science as a human endeavor

Activity 4

Introducing Discovery Four in American Aviation

GRADES**K-4****Time Requirements: 1 Hour****Materials:**In the Box

None

Provided by UserMaple seed “helicopters”
(optional)

Paper

Scissors

Measuring tape

3 meters of ribbon (optional)

WorksheetsHelicopter Template
(Worksheet 2)Reference Materials

Discovery Four mini-poster

Key Terms:

Gravity

Lift

Rotary wing aircraft

Seed dispersal

Surface area

Objective:

In this activity, students will learn about position and motion of object, properties of objects and materials, and abilities of technological design as they learn about the evolution of the helicopter from its earliest designs created by Leonardo Da Vinci to the modern helicopter invented by Igor Sikorsky, the father of the helicopter, as we know it today. Students will create a simple paper model of a helicopter and experiment with design and lift. Students will learn about how, as part of Neil Armstrong’s training to land the Lunar Module on the moon, he used a helicopter.

Activity Overview:

Students will learn about the history of the helicopter from Da Vinci’s drawings of the 1500s to the helicopters of today. Students will also discover how helicopters produce lift by the pressure differences caused by the shape of its rotating blades. To do this, students will make their own paper helicopters to experiment with design and lift. Finally, students will be introduced to Astronaut Neil Armstrong, the first man to walk on the moon, who learned to operate the Lunar module in part by training on a helicopter.

Activity:

1. **Review, as you have done at the beginning of each of the previous activities, the information your students have learned thus far.** Refer to the Discovery mini-posters (Fig. 4) and choral writings as needed.
2. **Ask the students if they ever have seen a helicopter before (other than on media device).** Ask those students to describe a helicopter and how they compare to airplanes.
3. **Introduce the helicopter by sharing the following with the students:** *During the mid 1500s, the Italian inventor Leonardo Da Vinci made drawings of a flying machine he called the ornithopter, which some scientist believe was the inspiration for the modern day helicopter. Then, in 1784, French inventors created a toy with a rotary-wing that could lift and fly. This toy proved the principle of helicopter flight. It was another Frenchman who came up with the name, “helicopter,” from the two words “helico” for spiral and “pter” for wings. Then in 1910, a Russian born scientist began working on a full-sized helicopter, and by 1940, he designed one that worked!*

4. **Ask the students if helicopters are more useful than airplanes.** Discuss how helicopters can go up and down while remaining stationary over one spot. This allows them better access to people in need of rescue or operating as an ambulance in the air.
5. **Show students a model of the paper helicopter they will be making in this activity (you will need to make this in advance).** Also, show students the materials they will use to make their own helicopters. For younger students, helicopters may be made in advance or in the interest of time the teacher may simply demonstrate this activity.
6. **The directions for the paper helicopter are as follows:**
 - a. Cut along the solid lines of the template.



- b. Fold along the dotted lines. The propeller blades should be folded in opposite directions. X and Y fold toward the center, and Z is folded up to give the body support and a lower center of gravity as shown.

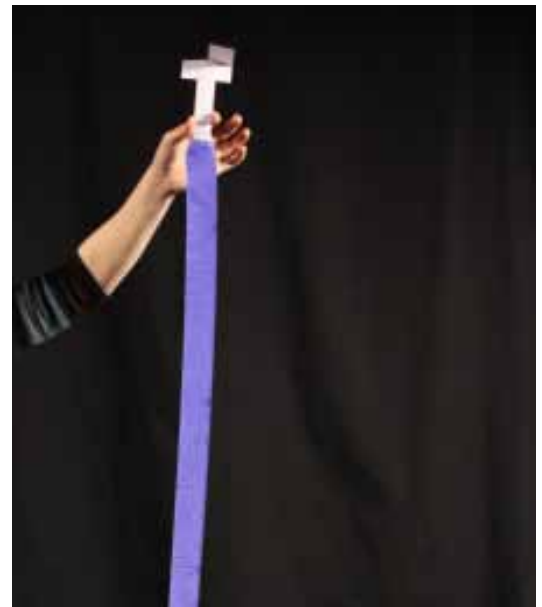


- c. Stand up and drop the helicopter.

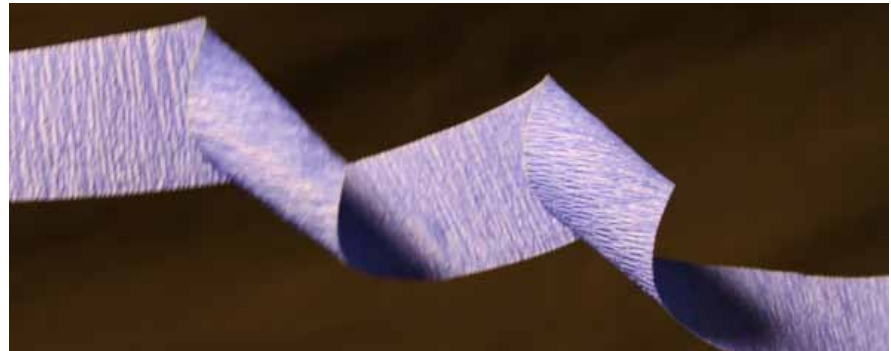


- d. Discuss what the students observed after doing this several times.
- e. Now, have students drop an unfolded piece of paper and the helicopter. Ask: Which one fell faster? Students will observe that the paper falls faster because it did not generate lift, whereas the spinning helicopter reduced the rate of its fall by producing lift and resisting the pull of gravity.
- f. Have the students predict what will happen if they wadded up the paper and drop it. (The wadded up paper will drop faster than the sheet of paper and the helicopter. The sheet of paper falls slower mainly because its larger surface area offers greater resistance to the air than the compact, wadded up ball of paper.)

- g. Have students add a piece of ribbon to their helicopter as shown in the directions. Tell the students that this ribbon will help them determine the number of rotations because they will be counting ribbon twists instead of trying to count each spin of the paper helicopter.



- h. Explain this procedure:
Students will stand on the loose end of the ribbon, and pull the helicopter up so there are no twists in the ribbon. Then students will drop the helicopter, counting twists in the ribbon once the helicopter lands. (Caution students to keep their foot on the ribbon as they count.)



- i. Experiment with the angle of the “wings” to see if a change in the wing angle affects the helicopter’s flight.
- j. Explain that the quickly moving air over the top of the blade creates low pressure, but the air beneath the blade is moving slower, so it creates higher pressure and high pressure under the rotor blades creates lift, which causes the helicopter to rise.
7. **Close the activity by discussing the person and career of Neil Armstrong (Img. 9).** Once again, students will add to their Choral Writing collection of aviation heroes by using the Choral Writing activity to write about Neil Armstrong after the teacher reads some or all of the Background Information located in this lesson.
8. **If time or the season allows, show the students maple seed “helicopters” or other seeds that disperse by wind and compare how plants spread their seeds by wind using their own kind of rotary blades.**

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Properties of objects and materials
- Position and motion of objects

SCIENCE AND TECHNOLOGY

- Abilities to distinguish between natural objects and objects made by humans
- Abilities of technological design
- Understanding about science and technology

HISTORY AND NATURE OF SCIENCE

- Science as a human endeavor

Activity 5

Introducing Discovery Five in American Aviation

GRADES**K-4****Time Requirements:** 1 Hour**Materials:**In the Box

None

Provided by User

Paper

Balloon rockets kit

Large long balloons

Fishing line

Straight straws

Tape

Clothes pins or binder clips

WorksheetsPaper Airplane Instructions
(Worksheet 3)Reference Materials

Discovery Five mini-poster

Key Terms:

Altitude

Drag

Mach

Newton's Laws

Propulsion

Rocket Engine

Velocity

Objective:

In this activity, students will learn about properties of objects and materials, position of motion and object, abilities of technological design, and science as a human endeavor through the fifth discovery in American aviation history, the first rocket powered airplane to travel faster than the speed of sound, the X-1. After learning about the X-1, students will experiment with propulsion by making a balloon rocket. Students will learn about Chuck Yeager, the first pilot to fly the X-1 and write about what they learned through Choral Writing.

Activity Overview:

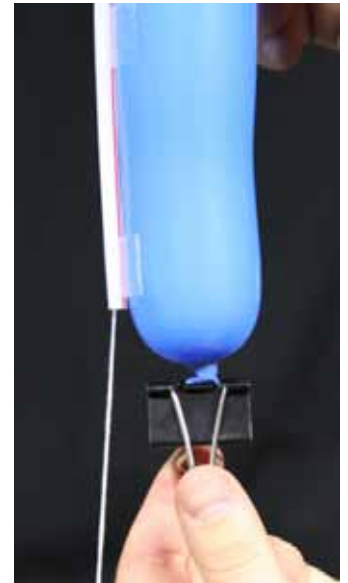
Students will first learn about the significance of the flight of the X-1 airplane, the first airplane to fly faster than the speed of sound. While the X-1 used a rocket engine to propel it forward, students will make a balloon rocket to simulate the flight of a rocket-propelled airplane such as the X-1. Finally, students will learn about Chuck Yeager, the first man to fly faster than the speed of sound while piloting the X-1 and write about him as they have the other famous aviators introduced in this lesson.

Activity:

1. **Review, as you have done at the beginning of each of the previous activities, the information your students have learned thus far.** Refer to the Discovery mini-posters and choral writings as needed.
2. **First introduce the X-1 airplane by showing the students a photograph (Fig. 5) and describing the feats of the X-1, the highest and fastest flying airplane of its time.**
3. **Explain that the measurement for the speed of sound is called Mach.** At sea level, the speed of sound is 761.2 mph in the Earth's atmosphere. The speed represented by Mach 1 is not a constant. It is mostly dependent on temperature and altitude. Since the speed of sound increases as the air temperature increases, the actual speed of an object traveling at Mach 1 will depend on the air temperature and pressure of the air around it.

4. **Explain that besides the rocket engine, the bullet-shaped fuselage of the X-1 allowed it to cut through the atmosphere with little air resistance.** To demonstrate this concept, compare the shape of a wad of paper to a standard paper airplane of simple design (See Paper Airplane Template - Worksheet 3). Throw each one in the same direction and see which one goes the farthest. Explain how the shape of the paper airplane decreases air resistance (drag).
5. **Attach a length of fishing line to the ceiling.** Tape the fishing line or attach a paper clip to the fishing line and hook it to the light or ceiling tile braces. The fishing line should hang from the ceiling to the floor or table top.
It is a good idea to do this in advance if the space is available.

6. **Blow up one of the balloons and hold it shut with a clothes pin or clip.** You will remove the clothes pin or clip before launch.
7. **Attach the straw to the side of your rocket using the tape.** Be sure the straw runs lengthwise along the balloon.
This will be your guide and method for attaching your balloon rocket to your fishing line.



8. **Thread the fishing line through the straws with the balloon nozzle pointed toward the floor.** Launch is now possible simply by removing the clothes pin or clip.
The fishing line should be taut in order for the rocket to travel successfully up the line, and the clipped balloon nozzle must be untwisted just before release.
9. **Discuss how the exhaust of the balloon rocket and the exhaust of the X-1 rocket engine push against the ground, sending them in the opposite direction of the exhaust because of Newton's law— for every action there is an equal and opposite reaction.**



10. **Read about Chuck Yeager (Img. 10).** Engage in the Choral Writing activity about his life and his career.

11. **Say:** “Let’s review all of the things we have learned so far by walking past our aviation discoveries time line, which includes important events in aviation history as well as important aviators.”
12. **Allow students time to walk by the display you have made that includes the Discovery mini-posters and the choral writing products.** Allow students time to discuss what they have learned and to ask any questions about what they have learned before completing the “Discussion Points” part of the lesson.

Discussion Points:

Have 4 pieces of chart paper taped to the wall or to the chalk or white board. Write each reflection question on the top of its own paper. List student responses under each question.

1. **Say:** Reflect on the timeline we created. After exploring these five important discoveries in American aviation, how have airplanes evolved, or changed, since 1903 when the Wright brothers first experienced flight?
2. **Ask:** What have we learned about flight since then?
3. **Ask:** Which aircraft impressed you most? Why?
4. **Ask:** In your opinion which aviators did the most to advance the field of aviation? Why?

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Properties of objects and materials
- Position and motion of objects

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

HISTORY AND NATURE OF SCIENCE

- Science as a human endeavor



Reference Materials

Glossary

Aerodynamic:

A design that reduces air resistance

Airfoil:

A structure with curved surfaces designed to give the most favorable ratio of lift to weight; used as the basic form of an aircraft wing

Altitude:

Height above sea level

Drag:

Resistance to motion

Gas mileage:

The ratio of the number of miles traveled to the number of gallons of gasoline burned

Gravity:

The force that attracts a body toward the center of the earth, or toward any other physical body having mass

Heavier-than-air:

The aircraft weighs more than air

Lift:

The force that opposes the weight of an airplane and holds the airplane in the air

Mach:

The speed of sound. Mach 1 is the speed of sound, Mach 2 is twice the speed of sound, etc

Newton's Third Law:

States that for every action there is an equal and opposite reaction

Pitch:

The up and down movement of an aircraft's nose

Propeller:

A revolving shaft on an aircraft that helps create thrust (forward motion)

Propulsion:

A force driving forward

Resistance:

A force opposing another force

Rocket engine:

An engine that produces thrust by the expulsion of high-speed exhaust created by the combustion of solid or liquid propellants

Roll:

The tilt of the wings on an aircraft toward or away from the ground, on the vertical axis

Rotary wing aircraft:

An aircraft that achieves lift through the rotation of its wings' surfaces

Seed dispersal:

The movement or transport of seeds away from the parent plant

Square feet:

A unit of area equal to one foot by one foot square

Surface area:

The total area of the surface of a two- or three-dimensional object

Transatlantic:

Crossing from one side of the Atlantic Ocean to the other

Velocity:

Speed

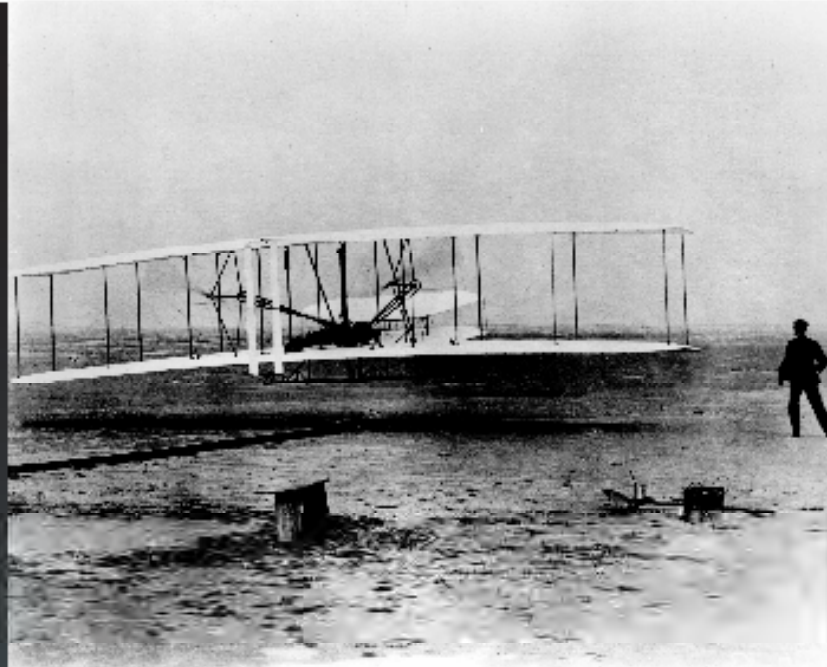
Volume:

A measurement of the space inside an object

Yaw:

The side-to-side motion of the nose of an airplane on the horizontal axis

DISCOVERY ONE: THE FIRST SUCCESSFUL AIRPLANE



Airplane: 1903 Wright Flyer

Date: First flight on December 17, 1903

SCIENCE AND TECHNOLOGY

The first airplane flight lasted only 12 seconds, covered just 120 feet, and traveled at a mere 30 mph, but Wilbur and Orville Wright came up with the basic solutions for powered, controlled flight. Their contributions included an innovative propeller design that provided thrust, and a system for controlling movement in three directions—vertical (pitch), horizontal (yaw), and lateral (roll). These same basic principles have been applied to nearly every airplane that has been built since.

SOCIAL IMPACT

The Wright Flyer's first successful powered flight brought attention to the aerial age and thrilled people around the world about the possibilities of flight. Writers and artists incorporated flight in their work while images of airplanes appeared on clocks, cigarette cases, plates, and other everyday items. Soon airplanes were used to deliver mail and freight, dust crops, map the Earth, and carry passengers.

DISCOVERY TWO: THE FIRST AIRPLANE TO FLY ACROSS THE ATLANTIC OCEAN NONSTOP WITH A SINGLE PILOT



Airplane: Spirit of St. Louis (Ryan NYP)
Departed New York, USA on May 20, 1927
Arrived Paris, France 33 1/2 hours later

SCIENCE AND TECHNOLOGY

At the time Charles Lindbergh made his historic transatlantic flight, the airplane had become a much more dependable machine. Larger and more powerful engines allowed airplanes to travel faster, higher, and farther. The plane he flew, the *Spirit of St. Louis* was built for maximum distance with wings built to carry the 450 gallons of fuel needed to fly from New York to Paris 4,000 miles and 331 ½ hours away.

SOCIAL IMPACT

Lindbergh's flight astonished the world because it demonstrated the safety of airplanes, which led to a rapid advancement in the aviation industry. Within the few years following Lindbergh's flight, airplanes were crossing the United States in 48 hours (compared to 72 hours by train). Soon songs, novels, comic books, and movies made aviation their theme.

DISCOVERY THREE: THE FIRST PROFITABLE PASSENGER AIRPLANE



Airplane: Douglas DC-3
Date: First flown in 1935

SCIENCE AND TECHNOLOGY

The DC-3 was built of aluminum, making it stronger and more durable than earlier aircraft, which used modified fabrics like painted canvas. The DC-3 also had a larger fuselage (body) and wings, and it could carry more weight. The DC-3 transported as many as 21 passengers at a time at speeds of up to 212 mph. The design of the DC-3 was streamlined with its bullet-shaped fuselage, two powerful engines enclosed by cowlings (hoods), and its retractable landing gear.

SOCIAL IMPACT

The DC-3 was the first modern airliner. It was the fastest commercial form of transportation in its day, and the first airplane to make a profit carrying passengers. The DC-3 made air travel popular and affordable. Its sleek, streamlined shape influenced the design of everything from automobiles to toasters. Military airplane technology also had advanced by this time, resulting in the remarkable airpower that was demonstrated in World War II. The DC-3 used by American troops during the war was nicknamed the Gooney Bird, and it was used to move troops and supplies.

MILESTONE FOUR: THE INVENTION OF THE HELICOPTER



Airplane: Sikorsky R-4

Date: Made its initial flight on January 13, 1942

SCIENCE AND TECHNOLOGY

The Sikorsky R-4 as designed by Igor Sikorsky had a single, three-bladed main rotor (engine). The R-4 was the world's first large-scale, mass-produced helicopter and the first helicopter to enter service with the United States Army Air Forces, Navy, and Coast Guard. The R-4 became the model for all modern single-rotor helicopters produced thereafter.

SOCIAL IMPACT

Because helicopters have the ability to fly forwards, backwards, up, down and sideways, as well as remaining stationary over a single spot, they are used to complete tasks that are not possible with airplanes. For example, helicopters are often more useful than airplanes in fighting fires, rescuing people stuck in otherwise inaccessible places, transporting the sick and injured, moving and removing large objects, and gathering news and scientific data.

MILESTONE FIVE: THE FIRST PLANE TO FLY FASTER THAN THE SPEED OF SOUND



Airplane: Bell X-1 "Glamorous Glennis"

Date: First broke the sound barrier on October 14, 1947

SCIENCE AND TECHNOLOGY

The Bell X-1 became the first airplane to fly faster than the speed of sound. U.S. Air Force Captain Charles E. "Chuck" Yeager piloted the X-1 as it reached a speed of Mach 1.01 at an altitude of 43,000 feet. Yeager nicknamed the airplane the "Glamorous Glennis" in honor of his wife.

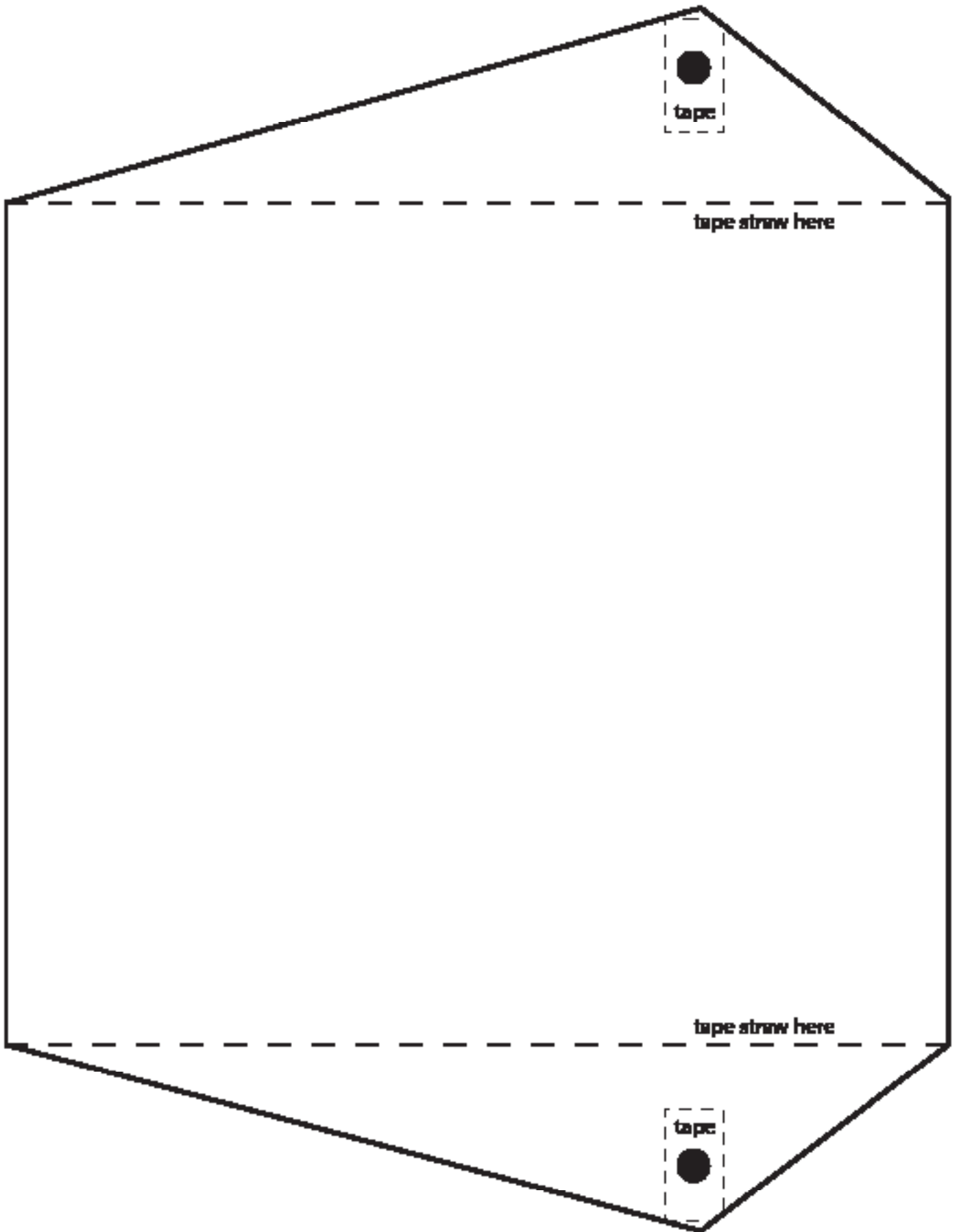
The X-1 used its rocket engine to climb to its test altitude after launching from the bay of a large Boeing B-29 airplane at an altitude of 23,000 feet. The airplane flew a total of 78 times, and on March 26, 1948, with Yeager as its pilot, the X-1 reached a speed of 957 miles per hour at an altitude of 71,900 feet. It was the highest speed and altitude ever reached by any manned airplane up to that time.

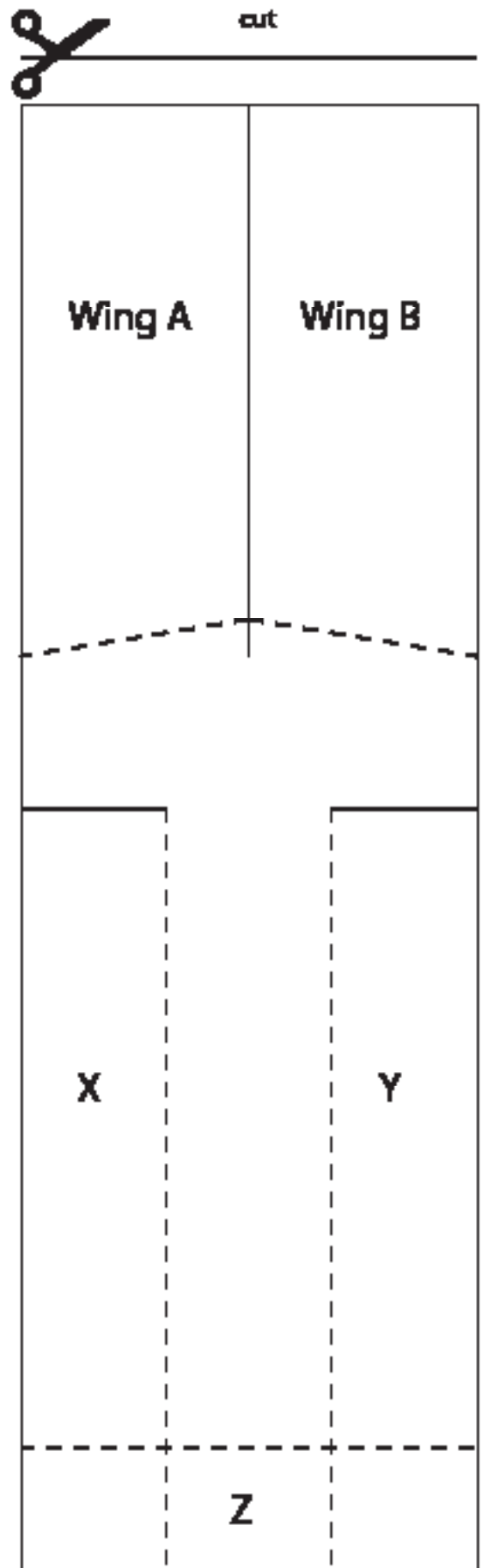
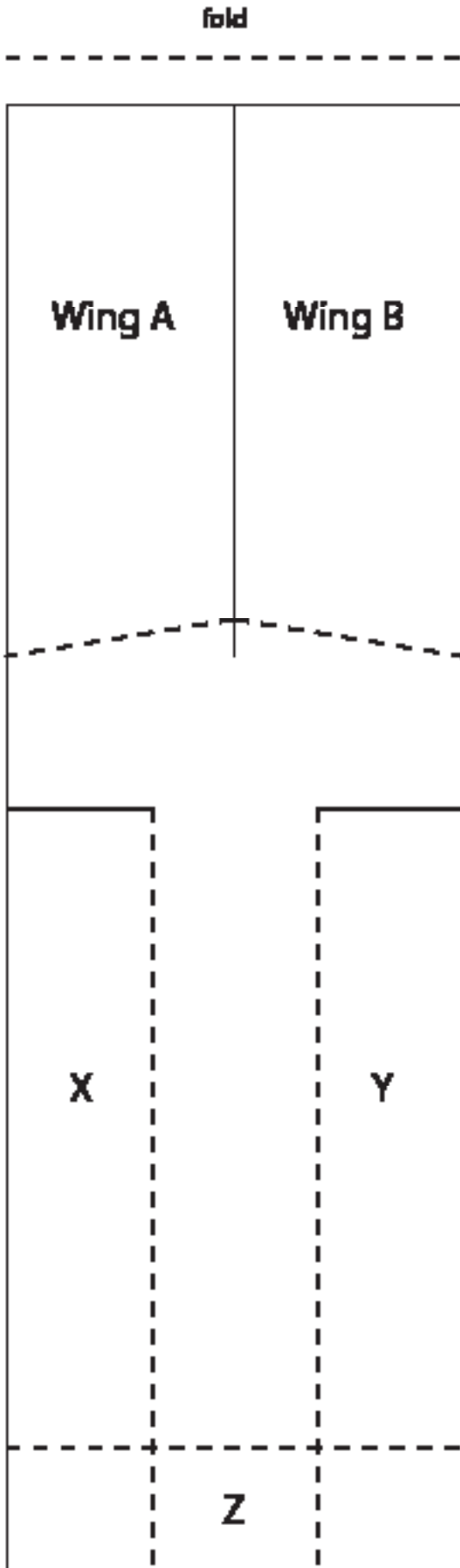
SOCIAL IMPACT

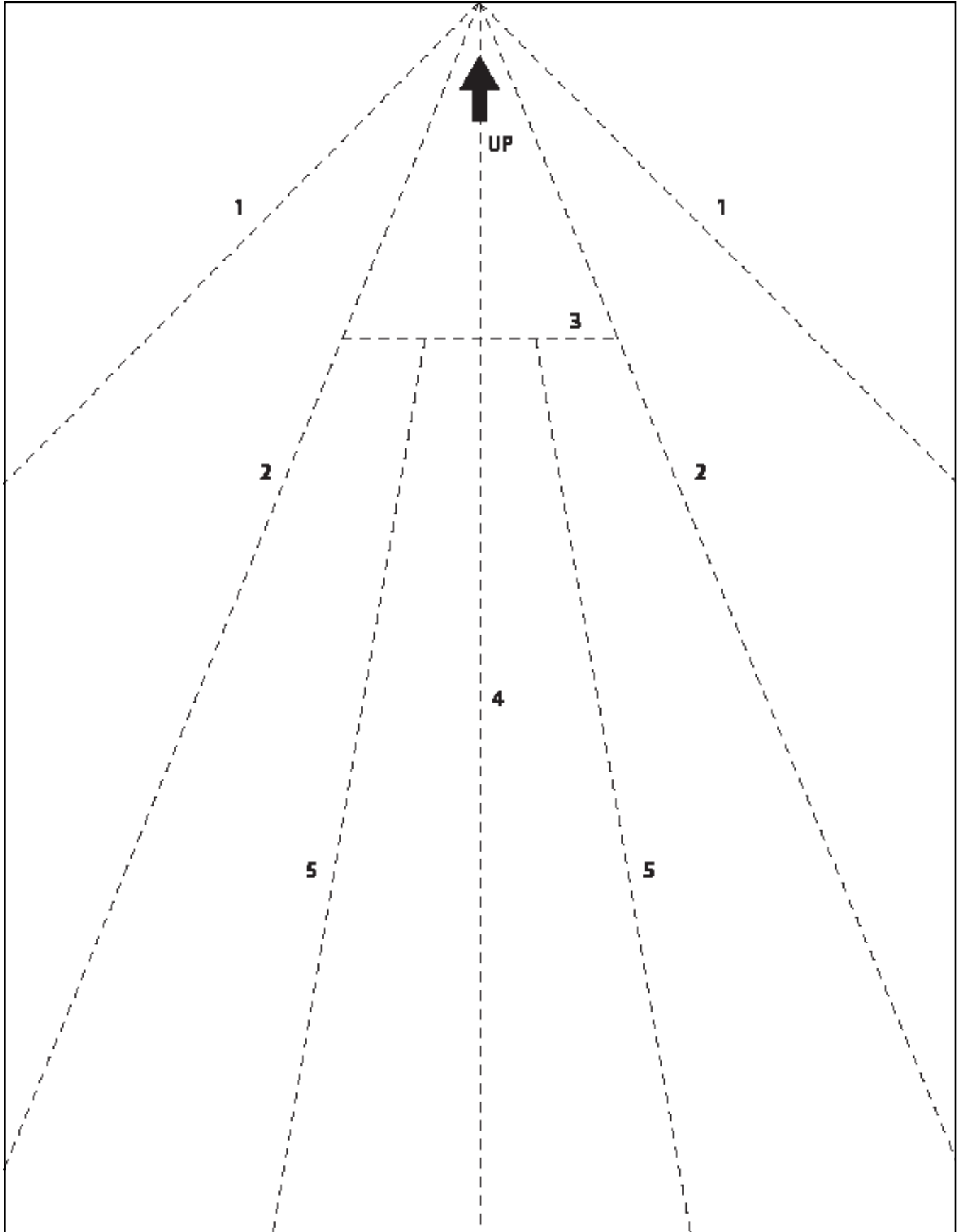
The Bell X-1 laid the foundation for America's space program in the 1960s because the personnel associated with the development of X-1 technology went on to assume key leadership positions in the program. The project also forged the post-war relationship between the U.S. military, private industry, and research facilities. The flight data collected by the X-1 was invaluable for the remainder of the 20th century in furthering U.S. fighter jet design.



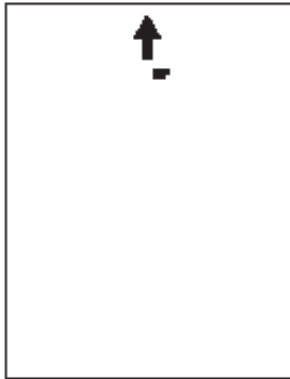
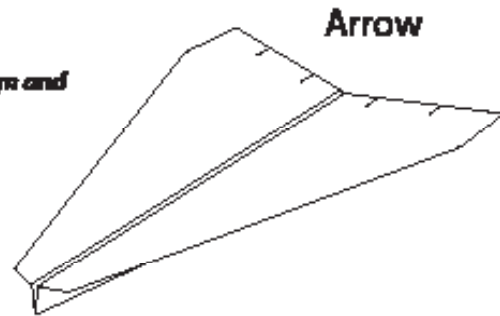
Worksheets



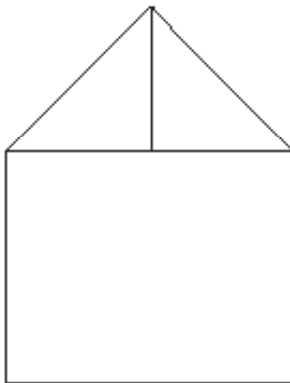




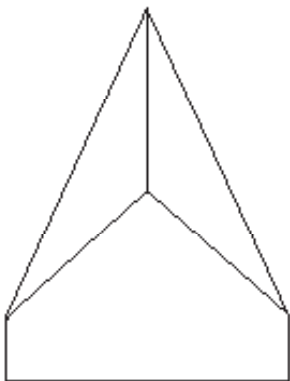
The arrow design paper airplane has an easy to fold design and flies straight and smooth.



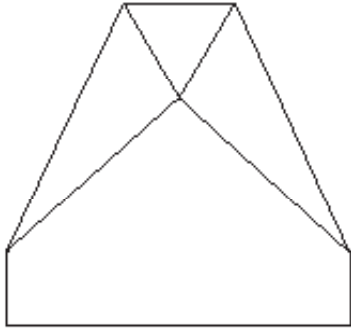
Place the template with the "UP" arrow at the top of the paper. Flip the template over so that none of the fold lines are visible.



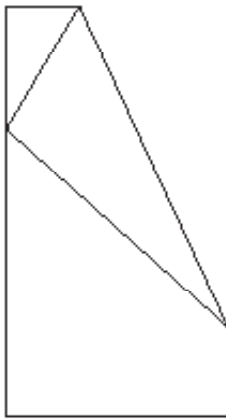
Pull the top right corner towards you until you can see fold line 1. Once visible, crease the paper along the dotted line. Repeat with the top left corner.



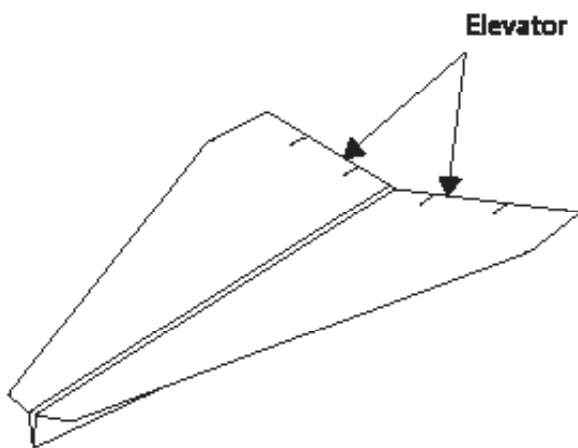
Fold the right side towards you again and crease along fold line 2. Repeat for the left side.



Fold the tip towards you and crease along fold line 3.



Flip the template over. Fold the left side onto the right side and crease along fold line 4. Make sure that the outsides of the wings line up correctly.



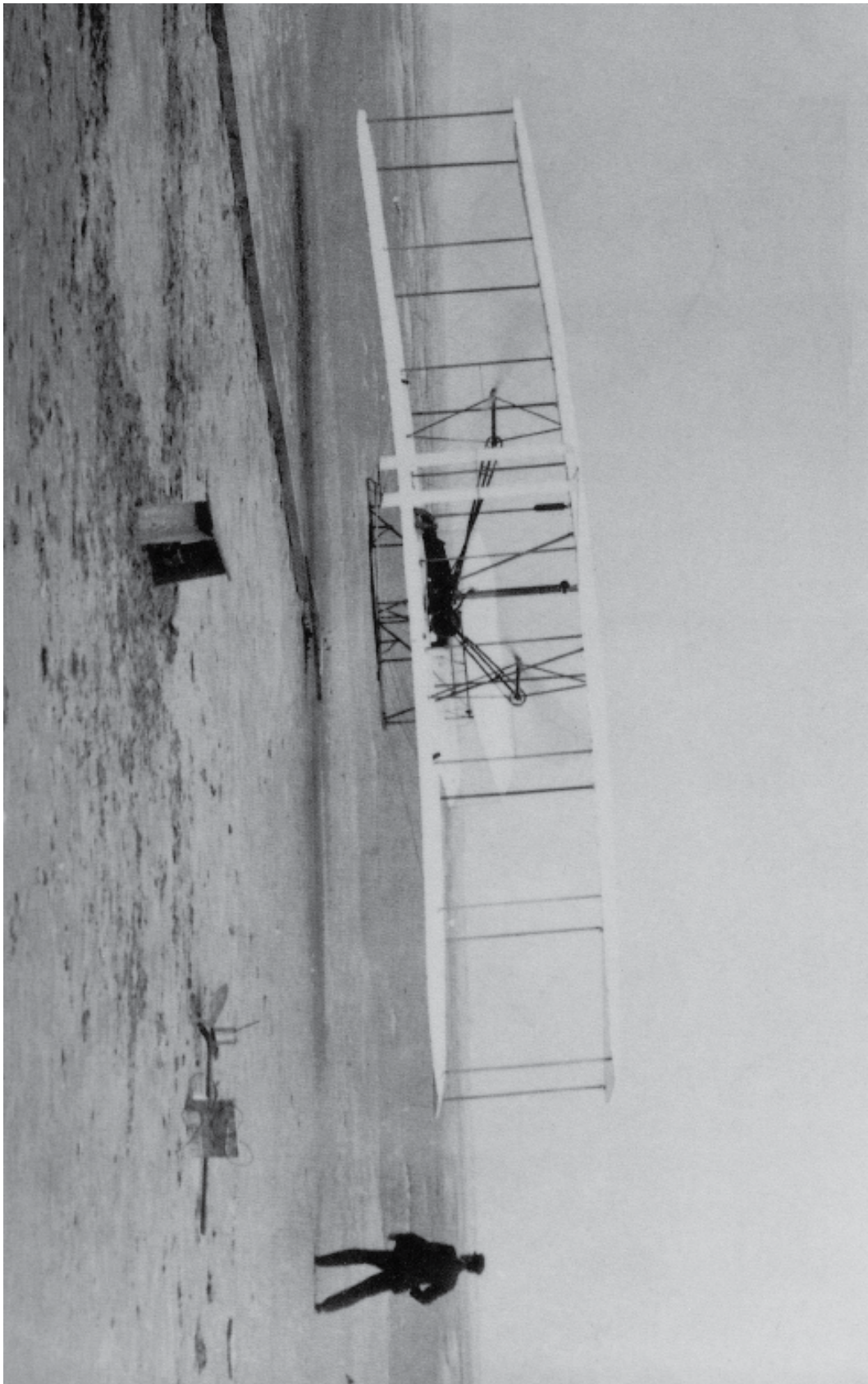
Finally, fold the wings down along fold line 5. Open the fold that you just made so that the wings stick out straight. Cut two one inch slits along the back edge of each of the wings. These are the elevator adjustments. They can be adjusted for flight. You can also adjust the wings by tilting them up slightly away from the fuselage.

Now you are ready to fly!



Images

Img. 1 1903 Wright Flyer



(Photo courtesy of NASA)

Img. 2 Charles Lindbergh



(Photo courtesy of the NASA)

Img. 3 Douglas DC-3



(Public Domain)

Img. 4 Skiorsky R-4



(Photo courtesy of NASA)

Img. 5 Bell X-1 "Glamorous Glennis"



(Photo courtesy of NASA)

Img. 6 Amelia Earhart



(Photo courtesy of NASA)

Img. 7 The Tuskegee Airmen



(photo courtesy of NASA)

Img. 8 Chuck Yeager



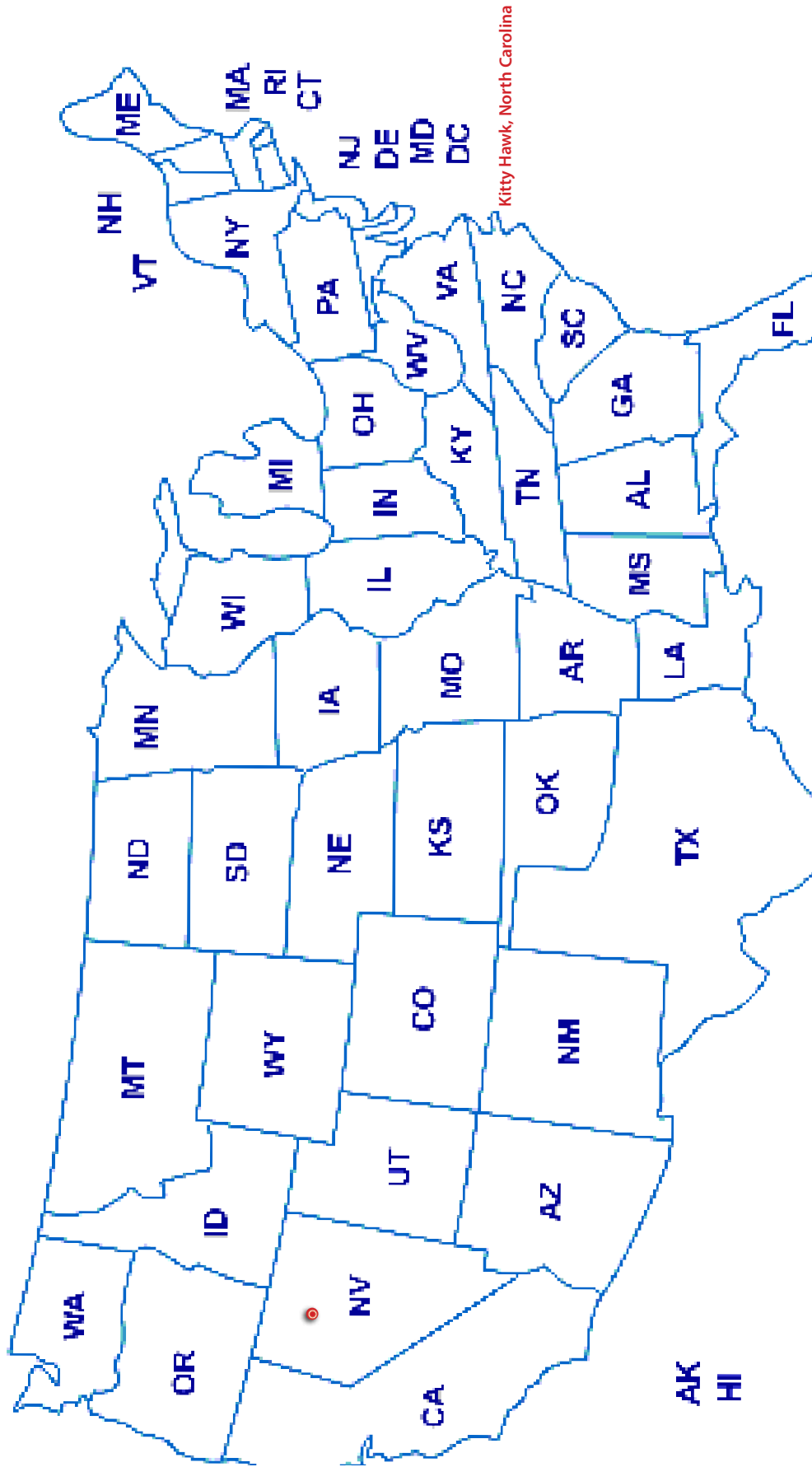
(Photo courtesy of NASA)

Img. 9 Neil Armstrong



(Photo courtesy of NASA)

Img. 11 Kitty Hawk, North Carolina



(Photo courtesy of NASA)

Img. 12 The flight path from New York, USA to Paris, France



(Map courtesy of the Central Intelligence Agency)

Img. 13 The flight path from New York, USA to Dublin, Ireland

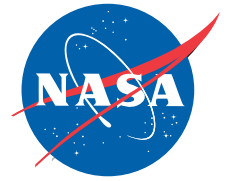


(Map courtesy of the Central Intelligence Agency)

Aeronautics
Research
Mission
Directorate



history of flight



GRADES

5-12

Designing an Aeronautics Museum Gallery



Aeronautics
Research
Mission
Directorate



history of flight

Designing an Aeronautics Museum Gallery

Lesson Overview

In this lesson, students will learn about science as human endeavor, the importance of aviation museums in telling the story of the history of flight, the history of science, historical perspectives, and the abilities of technological design through the story of the history of flight. In addition, students will gain an understanding of museum careers such as curator, exhibit staff member and museum educator through modeling those roles. Students will work in teams to design a museum gallery with a NASA aeronautics theme. Using graph paper, each team will lay out their gallery to scale with its artifacts and displays. Team members will create a map of their gallery that details the layout of the exhibits. Lastly, the teams will plan programs and activities that will enhance the visitor experience of their aviation gallery.

Objectives

Students will:

1. Comprehend the importance of aviation museums in telling the story of the history of flight.
2. Learn about museum careers.
3. Design an aeronautics museum gallery to scale using NASA's contributions to aeronautics as a theme.
4. Select appropriate artifacts and displays to include in the gallery.
5. Create a map that details the gallery.
6. Plan programs and activities to enhance the visitor experience to the gallery.

Materials:

In the Box

NASA's Contributions to Aviation PowerPoint presentation

Graph paper

Provided by User

Index cards

Scissors

Glue

Pencils/pens

Rulers

GRADES

5-12

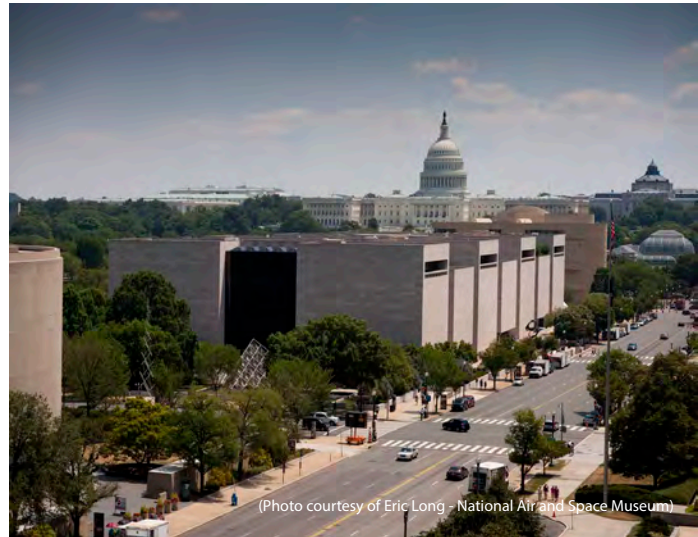
Time Requirements: 8 Hours

Background

Aeronautics Museums

Each year, millions of visitors of all ages visit informal educational institutions which include museums and science centers. Many of the museums have a specialty to showcase, for example, art or natural history. Aviation is no exception. In the United States, there are over 250 museums that focus on aviation. Visitors to these aviation museums can catch a glimpse of aviation history through varied artifacts and displays.

NASA realizes the importance of the informal education community in telling the NASA aeronautics story. Through educational partnerships with numerous informal community institutions, NASA provides artifacts as well as professional development opportunities for its members. The goal is to enhance the informal education community members' capabilities by providing access to NASA staff, research, technology and information.



(Photo courtesy of Eric Long - National Air and Space Museum)

Img. 1 National Air and Space Museum

The two museums in the United States with the largest collection of famous airplanes are 1) the National Air and Space Museum (NASM) in Washington D.C. along with its companion facility the Steven F. Udvar-Hazy Center near Washington Dulles International Airport, and 2) the National Museum of the United States Air Force (NMUSAF) in Dayton, Ohio.

The National Air and Space Museum has almost 9 million visitors each year. NASM's collection includes many of the most significant aircraft and spacecraft in our nation's history. There are over 30,000 aviation objects in the collection. In addition, NASM's archival collection contains numerous photographs, manuscripts, technical drawings, documents, films and oral histories.



(Photo courtesy of the National Museum of the United States Air Force)

Img. 2 National Museum of the United States Air Force

The National Museum of the United States Air Force is the oldest and largest military aviation museum in the world. The museum's collection includes more than 300 aircraft and missiles. Aviation history from the Wright brothers to the present can be seen during a visit. Over 1 million visitors a year visit the NMUSAF.

A museum must be organized in a way that programs and exhibits draw in visitors to educate and tell a compelling story. Museum organization, however,

largely depends upon the size of the museum with the larger museums having a greater number of individuals with different roles and responsibilities. The following is a list of several key museum-related job titles that help a museum to operate smoothly. (The list does not include additional personnel whose roles are not unique museum's operations, i.e., the staff or the gift shop, food service, security, maintenance or technicians.)

Museum Jobs Important to the Creation of an Exhibit

Museum Director: The individual responsible for the overall operations of the museum. The director is often the spokesperson to the media and other community organizations. The director generally signs off on new exhibits.

Curator: A subject matter expert in the museum. He or she uses this specialized knowledge to incorporate the artifacts or collections in their museum to create exhibits or displays.

Exhibits Staff: Individuals who design and fabricate large exhibitions. The designers work closely with the curator and education staff at the museum to define and organize the content, develop the narrative, and then build the exhibit.

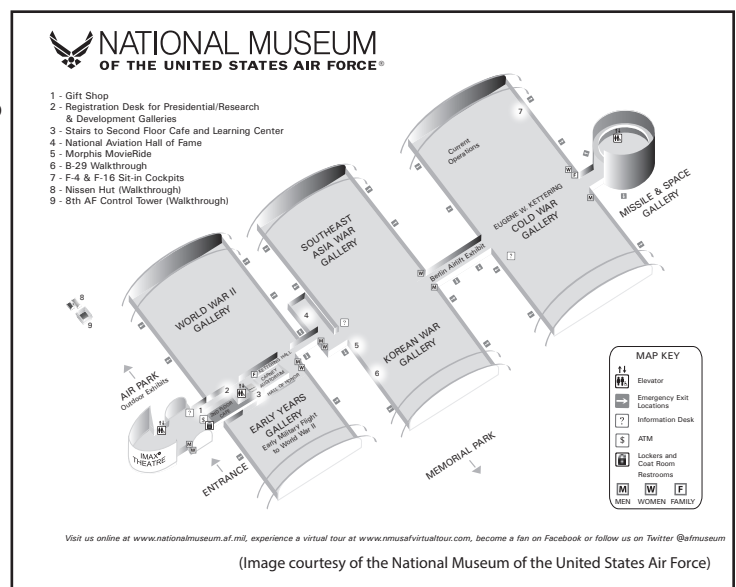
Museum Educator: A trained educator who uses his or her skills to create school programs, classes, tours, lectures, special events, etc. that focus on the exhibits, artifacts and displays in the museum. The museum educator works with the curator and exhibit designers to create visitor friendly exhibits.

Development and Membership Staff: Individuals who often meet with potential donors and write grants to help fund the operations of the museum. They also often oversee membership programs.

Volunteer Coordinator: Individual responsible for the training and recruitment of volunteers to assist the museum staff in various roles such as staffing the information desk or giving tours to students.

Marketing and Public Relations Staff: Individuals responsible for promoting the museum to the community. They serve as media liaisons to publicize museum programs, events and special exhibits. In addition, they are responsible for the museum's membership programs.

The exhibits and displays are included in galleries, which have specific theme. Note in the gallery map for the Museum of the United States Air Force each gallery has a theme. What is included in each gallery is limited by size of the gallery and what is in the collection. On occasion, a museum may borrow an artifact from another museum to use in the exhibit.



Img. 3 Gallery Map National Museum of the USAF

Museums often conduct educational and special programs to highlight a gallery or the museum. Educational programs at a museum can include:

Educational Programs

Guided School Group Tours: Guided school group tours allow students to make meaningful connections to the museum’s collection by having a specially trained docent, museum teacher; lead them on a guided tour through the museum. During the tour students often have the opportunity to ask questions, participate in discussions, and participate in “hands on” activities.

Self-Guided Tours: On a self-guided tour a visitor is provided a museum map or gallery guide that will enable the visitor to tour without an escort. Sometimes museums have audio tours available where you can listen to a recording at various spots throughout the museum.

Demonstrations: Demonstrations are conducted by museum staff to explain scientific principles or concepts that often relate to a specific gallery in the museum. Note Image 4 of the “How Things Fly Exhibit” at the National Air and Space Museum. In this exhibit visitors engage in activities that demonstrate the principles of flight.



Img. 4 Photo of How Things Fly Exhibit at the National Air and Space Museum

Discovery Stations: Discovery stations at a museum are sites where visitors can do “hands on” activities on an informal basis with museum artifacts and other appropriate materials that relate to a certain theme.

Story Time: Story Time programs are more likely to be offered to pre-school children as well as students in the first through third grade. After a story, students are involved in “hands on” activities that relate to the story. Sometimes the students get to role play different parts of the story.

Special Programs

Special programs and activities at a museum can include many things. The following are a few examples:

Films: Some museums offer a film series related to the artifacts in the museum.

Presentations: Experts are invited to give presentations at a museum for members as well as guests.

Special Exhibit: A museum has permanent exhibits as well as special exhibits. A special exhibit stays at a museum for a short time. The exhibit might be an aircraft on loan from another museum or an artifact or exhibit from NASA.

Receptions: Receptions at a museum can be formal or informal. Sometimes when there is a special exhibit receptions are hosted for different groups. One group might be for members of the museum, while another might be for potential donors.

Family Days: During Family Days at a museum the entire family is involved all sorts of activities that might include building kites, learning about the physics of a baseball, watching movies, and of course eating.

Summer Camps: Summer camps, usually for 5 days, connect students to science and other subjects through fun-filled activities.

Activity 1

Designing an Aeronautics Museum Gallery

GRADES 5-12**Time Requirements:** 8 Hours**Materials:**In the Box

“NASA’s Contributions to Aviation” PowerPoint presentation

Graph Paper

Provided by User

Index cards

Scissors

Glue

Pencils/pens

Rulers

Worksheets

Design an Aeronautics Gallery (Worksheet 1)

Gallery Programs (Worksheet 2)

Aeronautics Gallery Guide (Worksheet 3)

Reference Materials

Figure 1

Figure 2

The First Century of Flight: NACA/NASA Contributions to Aeronautics

Objective:

Students will learn about science as a human endeavor, the history of science, and the abilities of technological design as they work in teams to design a gallery for an aviation museum based on the theme of NASA’s contributions to aviation.

Activity Overview:

While working in teams, students will experience what it is like to design a museum gallery based on NASA’s contributions to aeronautics. In addition, students will learn about different careers associated with working in a museum. Each team will create a scale model of their gallery. Once the teams have completed their scale model, they will prepare a gallery guide of the gallery they have designed. In addition, the teams will plan several educational activities or special programs for their gallery.

Activity:1. **Introduction**

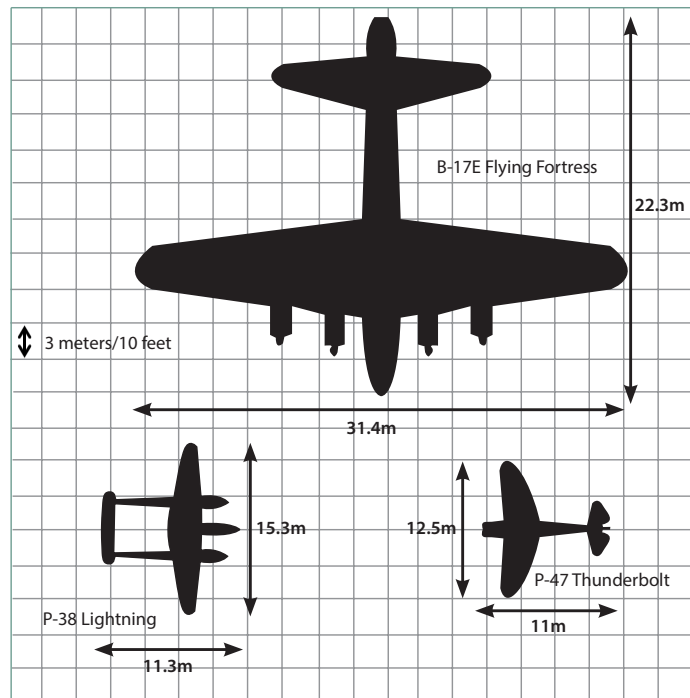
- a. Have a discussion with the students about what a museum is. *Ask the students to describe any experiences they have had in visiting a museum. Emphasize that it is a place where artifacts of a historical, scientific, or artistic nature are displayed.*
- b. Discuss the organization of a museum by highlighting the different roles of staff at the museum. *(See list in [Reference Materials](#).)*
- c. Ask the students how museum objects are arranged in museums overall. *They are usually located in different galleries with each gallery having a different theme.*
- d. Inform the students that they are to work in teams to create a gallery with a NASA aeronautics theme.
- e. Divide the class into teams of 4-6 students.
- f. Distribute a copy of Figure 1 that depicts 20 of NASA’s contributions to general aviation. Also, provide each team with a description of each of the contributions, found in the [Reference Materials](#) section. *Suggestion: Ask each team to write down the name of every contribution they understand, and then circle their favorites. Report out to tell why they are their favorite. Be sure to discuss the ones the teams did not circle.*

Key Terms:

- Curator
- Development and membership staff
- Exhibits staff
- Marketing and public relations staff
- Museum artifact
- Museum gallery
- Museum director
- Museum educator
- Volunteer coordinator

- g. Show the PowerPoint, "NASA's Contributions to Aviation;" it can be downloaded from the MIB website:
<http://www.aeronautics.nasa.gov/mib.htm>
- h. If possible, download Richard Hallion's book, "NASA's Contributions to Aeronautics Vol 1 and Vol 2" for the students to use as a resource.
(See list in Reference Materials.)

2. **Distribute graph paper to each team.** Inform the students that they are to use the graph paper to create a scale drawing of their gallery. The graph paper on Worksheet 3 can be duplicated and distributed for the scale drawing. For this activity the students will not include labeled exhibits. *Show students figure 2 and explain that this is a sample drawing of the beginnings of an aero gallery. This particular gallery is 61 meters (200 feet) by 61 meters (200 feet). It has a WWII theme and three aircraft have been placed in the gallery. The B-17E has a wing space of 31.4 meters (103 feet) and the plane is 22.3 meters (73 feet) long; the P-38 Lightning has a wingspan of 15.3 meters (52 feet) and a length of 11.3 meters (37 feet); the P-47 Thunderbolt has a wing span of 12.5 meters (41 feet) and is 11 meters (36 feet) long. Inform the students that they do not necessarily need to use silhouettes of any aircraft, or other artifacts they might put in their gallery. They can cut out squares, rectangles, triangles, or circles with appropriate dimensions using index cards to put on their graph paper. In the example, the B-17E would be 10.3 spaces wide and 7.3 spaces long. The students can write the name of the artifact or display on the index card.*



(Each square is 3 meters x 3 meters)

Fig. 2 Scale drawing of Aero Gallery

3. **Working as teams, the students are to use the Design an Aeronautics Gallery Worksheet to plan their gallery.** Walk the students through the worksheet highlighting each area. Ask the students if they have any questions.
4. **Using the information on the Design an Aeronautics Gallery Worksheet, the teams are to create a scale drawing of their gallery.** Remind the students they are to use the graph paper to create a scale drawing of their gallery.
Inform the students that besides the artifacts and displays they must consider such things as lighting in the gallery; whether they are going to hang any of the aircraft from the ceiling or have all of the aircraft on the floor. Remind the students that they also should consider in their gallery design if anything needs to be protected either in a display case or behind plexiglass. Lastly, have the students think about the type of floor they will have in their gallery--will your gallery floor support the weight of all of the artifacts and displays in the gallery? What kinds of "hands on" displays will they have for the visitors to interact with.
5. **Next the teams are to use the Gallery Programs Worksheet to plan educational programs or special events for the gallery.** When you get to this section ask the students what kinds of programs they have attended at a museum or science center. Have the class to offer ideas for different kinds of programs. Teams can use this information to plan their gallery programs.
6. **Lastly, each team creates a one-page gallery guide to highlight their gallery.** Use the Aeronautics Guide Worksheet and scale drawing to assist in the design of the team's gallery guide.
Ask the students to think about the kinds of information they would like to know about before visiting a museum gallery and use this information to help them plan their gallery guide. You may want each team to prepare a 2 slide power point that shows their museum guide with slide 1 being the front side of the guide and slide 2 the back side of the guide.
7. **Have an all teams meeting in which each team shares information about their galleries.** After all the teams have shown their gallery guides, ask them to compare and contrast all of the guides.

Discussion Points:

1. **Why are aviation museums a great resource for NASA to use to inform the public about their contributions to aeronautics?**

Millions of visitors go to aviation museums each year. Museum staffs have a way of taking very technical information and making it understandable by the general public. NASA provides access to scientists and engineers who can provide guidance in the creation of very specific exhibits or displays. NASA also has a traveling exhibits program that institutions and museums can borrow to exhibit.

2. **Compare and contrast the advantages and disadvantages of learning science in a museum verses learning it in the classroom.**

The advantage or disadvantage is often associated with the amount of time spent learning the subject. Museums often have classes or summer programs where students can participate for longer periods of time to gain a better understanding of science, technology, and/or the universe. Museums have resources that classrooms do not, such as exhibits, demonstrations, programs, and collections.

3. **Why is it important to develop an aeronautics or aviation gallery based on a theme?**

A theme provides a focus for the gallery. A WWII gallery for example can have many aircraft from WWII on exhibit and have many displays to support the different artifacts.

4. **Why is it important to work as a team in the creation of a gallery?**

No one person has all of the skills necessary to create a gallery. The curator has the subject matter expertise, while the exhibits staff can create the exhibits or displays to explain the science or technology. The education staff can develop special programs for students or teachers where they can learn the subject first hand.

5. **What was the most difficult task or your team in order to design your gallery?**

The responses to this question will vary with the students. However, one of the most difficult tasks for the students to do is to decide what to put in the gallery since they are not subject matter experts. Also, students have a tendency to want to put too much in the gallery space.

6. **Why is it important to have educational programs and special activities to compliment the artifacts and displays in an aeronautics gallery?**

They generate more interest and they help to keep visitors coming back to the museum and galleries.

7. **What were each team's cost estimates to construct and operate their gallery?**

Answers will vary for each of the teams.

8. **In addition to admissions, what are some of the ways that museums seek additional funding?**

Some examples that museums use to acquire additional funds is , for example, they seek out private donors, have membership programs, seek grants, host special events, and form partnerships.

9. **Would you like to work in a museum?**

Responses will vary with students.

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

HISTORY AND SCIENCE OF NATURE

- Science as a human endeavor
- Nature of scientific knowledge
- Historical perspectives

NATIONAL MATH STANDARDS 9-12

NUMBERS AND OPERATIONS

- Understand numbers, ways of representing numbers, relationships among numbers, and number systems
- Understand meanings of operations and how they relate to one another
- Compute fluently and make reasonable estimates

MEASUREMENT

- Understand measurable attributes of objects and the units, systems, and processes of measurements
- Apply appropriate techniques, tools, and formulas to determine measurements

PROCESS

- Problem solving
- Communication
- Connections
- Representation



Reference Materials

Glossary

Airbag Systems:

In the 1950s, NASA explored a variety of crew protection systems including airbags. They were later adapted to protect robotic spacecraft during landings. They have now been further tested by NASA and adapted for use as an airbag system on passenger aircraft (as seen on the ATI RT-700, a twin-engine business aircraft).

Airborne Wind Shear Detection:

During the 1980s and 1990s, NASA led a comprehensive research program to identify the characteristics of dangerous wind shear, and validated technologies that can predict its severity while in flight. Today, aircraft are equipped with forward-looking sensors that alert pilots to wind shear hazards.

Area Rule:

In the 1950s, NASA scientist, Richard Whitcomb, discovered several fundamental solutions to key aerodynamics challenges. One of the most revolutionary solutions was the "area rule," a concept that helped aircraft designers avoid the disruption in airflow and resulting drag caused by the attachment of the wings to the fuselage. For decades, aircraft designers have been able to make aircraft fly more efficiently at high speeds by using the area rule.

Artifact:

Pertains to the things in the museum created by humankind whether it be an aircraft or an important document.

Aviation Museum:

This type of museum uses displays and artifacts to highlight the history of aviation.

Composite Structures:

NASA first partnered with industry during the 1970s to conduct research on how to develop high-strength, nonmetallic materials that could replace heavier metals on aircraft. Gradually, composite structures were used to replace metals on parts of aircraft tails, wings, engines, cowlings and parts of the fuselage. Composites reduce overall aircraft weight and improve operational efficiency.

Computational Fluid Dynamics (CFD):

Starting in the 1970s, NASA began developing sophisticated computer codes that accurately could predict the flow of fluid, such as the flow of air over an aircraft's wing or fuel through a space shuttle's main engine. Those ideas and codes became CFD, which today is considered a vital tool for the study of fluid dynamics and the development of new aircraft. CFD greatly reduces the time and cost required for designing and testing nearly any type of aircraft.

Curator:

Museums have subject matter experts also called curators. They use their specialized knowledge to take the artifacts or collections in their museum to create exhibits or displays.

Deicing Systems :

As early as the 1940s through NASA's predecessor, the National Advisory Committee on Aeronautics, or NACA, research on the causes and prevention of icing on the ground or in the air has been a focus. Using icing research tunnels, wind tunnels and flight tests, NASA research has contributed to the development of icing protection systems and operational methods for icing conditions.

Development and Membership staff:

Individual(s) in the museum who often meet with potential donors and write grants to raise funds to help fund the operations of the museum. They also often oversee membership programs.

Digital Fly-By-Wire:

During the 1960s and 1970s, NASA helped develop and flight test a digital “fly-by-wire” (DFBW) system to replace heavier, less reliable hydraulics systems and control linkages with a lighter system using a digital computer and electric wires. The system sends signals from the pilot to the control surfaces of the aircraft, adding redundancy and improving control. DFBW is used today on the Gulfstream G350/G450.

Exhibits staff:

Individuals who design and fabricate large exhibitions. The designers work closely with the curator and education staff at the museum to define and organize the content, develop the narrative, and then build the exhibit.

Glass Cockpit:

During the 1970s and 1980s, NASA created and tested the concept of an advanced cockpit configuration that replaced dial and gauge instruments with flight panel digital displays. The digital displays presented information more efficiently and provided the flight crew with a more integrated, easily understood picture of the vehicle situation. Glass cockpits are in use on general aviation, commercial and military aircraft, and on NASA’s space shuttle fleet.

Highway-in-the-Sky (HITS):

During the 1990s, a NASA research program contributed to the development of advanced electronic displays that deliver point-to-point, on-demand communication, navigation and weather data to pilots. The system was commonly referred to as a “highway-in-the-sky”.

Lightning Protection Standards:

During the 1970s and 1980s, NASA conducted extensive research and flight tests to identify the conditions that cause lightning strikes and the effects of in-flight strikes on aircraft. NASA’s knowledge base was used to improve lightning protection standards for aircraft electrical and avionics systems.

Marketing and Public Relations staff:

Individuals who are responsible for promoting the museum to the community. They work with the media to provide stories for newspapers, television or radio. In addition, they are responsible for the museum’s membership programs.

Museum Director:

This individual is responsible for the overall operations of the museum. The director interfaces with their museum boards and are often the spokesperson to the media and other community organizations. The museum director generally signs off on new exhibits.

Museum Educator:

This person is a trained educator who uses his or her skills to create school programs, classes, tours, lectures, special events, etc., focusing on the exhibits, artifacts, and displays in the museum. The museum educator works with the curators and exhibit designers to make the exhibits more “visitor” friendly.

Museum Gallery:

A room or area in a museum that exhibits artifacts or displays.

NASA Structural Analysis (NASTRAN):

In the 1960s, NASA partnered with industry to develop a common generic software program that engineers could use to model and analyze different aerospace structures, including any kind of spacecraft or aircraft. Today, NASTRAN is an “industry-standard” tool for computer-aided engineering of all types of structures.

Natural Laminar Flow (NLF) Airfoil:

From the 1970s to the 2000s, NASA researchers have worked to develop airfoil (wing) designs that allow smooth air flow for maximum lift and minimum drag at low and medium cruise speeds. The application of NLF techniques has helped reduce fuel consumption and landing speeds, and increase aircraft speed and range.

Quiet Jets:

During the 1990s and 2000s, tests were conducted in NASA flight research facilities to validate technologies to dramatically reduce the level of noise generated by turbofan engines typically used on small business jets.

Real-Time Graphical Weather:

During the 1990s and 2000s, NASA research drove the development of cockpit displays that provide real-time ground or in-flight weather information to the flight crew. Since not all small aircraft can fly “above the weather,” the data is of particular help to pilots in avoiding weather related accidents.

Small Aircraft Transportation System (SATS):

During the first few years of the 21st century, NASA and the FAA partnered on a project targeting technologies that could increase small aircraft travel between small airports. There are many more small airports in the United States than traditional airports, but they can be under-utilized due to lack of control towers or radar. Ultimately, the SATS project enabled the application of beneficial technologies to help overcome that challenge, including Synthetic Vision Systems and Highway-in-the-Sky.

Stall/Spin Research:

From the 1960s through the 1990s, NASA wind tunnels, flight tests, and a special facility constructed to study aircraft stall and spin characteristics were used to identify the causes of small aircraft stalls and spins and ways to recover from them. NASA research led to solutions for general aviation aircraft including spin resistant wings and leading-edge devices for unswept wings.

Supercritical Airfoil :

During the 1960s and 1970s, NASA scientist Richard Whitcomb led a team of researchers to develop and test a series of unique geometric shapes of airfoils or wing sections that could be applied to subsonic transports to improve lift and reduce drag. The resulting “supercritical airfoil” shape, when integrated with the aircraft wing, significantly improves the aircraft’s cruise efficiency.

Synthetic Vision Systems (SVS):

From the 1970s to the 2000s, NASA researchers developed and flight tested a class of computer database-derived systems that include head-up displays and other new pictorial format avionics that can aid pilots in low visibility conditions. The most recent design concepts for SVS can create three-dimensional pictures of the world outside the aircraft, day or night, using GPS, terrain models, sensors and a runway incursion warning system.

TURBO-AE Code:

During the 1990s, NASA developed a computer code that generates two-dimensional simulations of potential aeroelastic (AE) problems that can occur in jet engine blades. Such problems include flutter or fatigue that can eventually cause engine fan blades to stall or fail. With TURBO-AE, engineers can more efficiently design thinner, lighter, faster rotating blades for today's jet engines built for higher performance, lower emissions and lower noise.

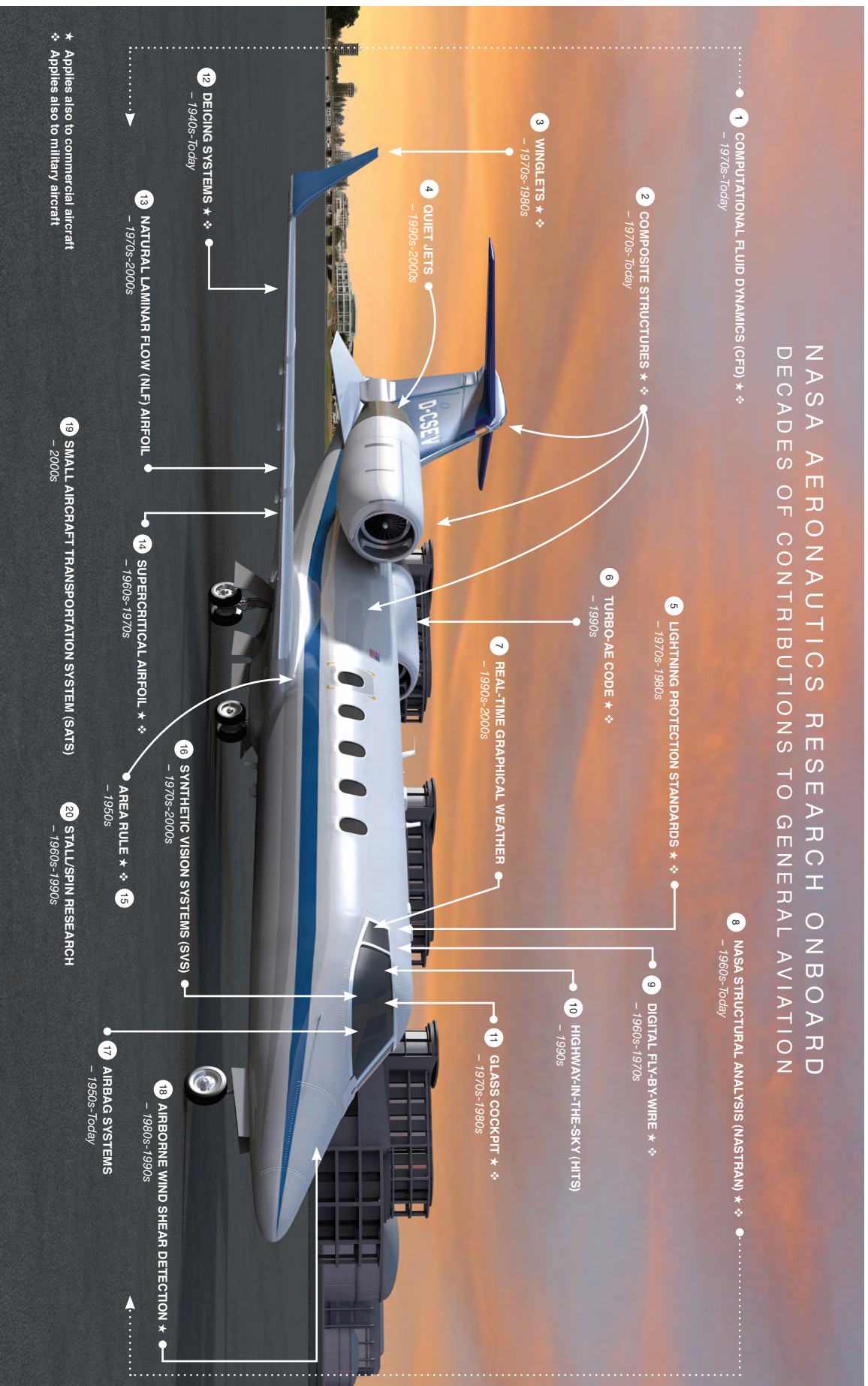
Volunteer Coordinator:

This individual is responsible for the training and recruitment of volunteers to assist the museum staff in various roles such as staffing the information desk or giving tours to students.

Winglets:

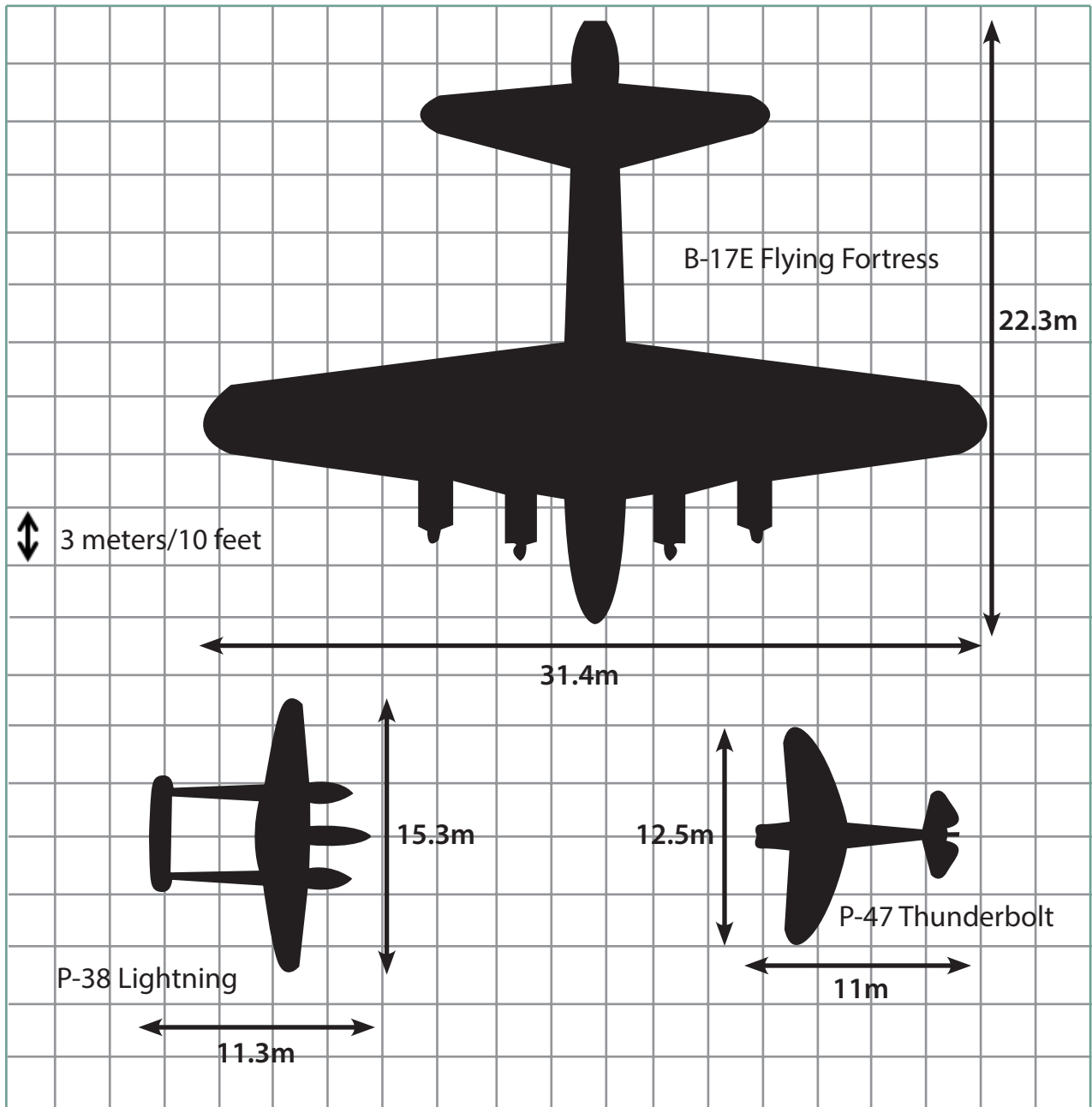
During the 1970s and 1980s, NASA studies led to the development of vertical extensions that can be attached to wing tips in order to reduce aerodynamic drag without having to increase wing span. Winglets help increase an aircraft's range and decrease fuel consumption.

Fig. 1 Decades of Contributions by NASA to General Aviation



(Diagram courtesy of NASA)

Fig. 2 Scale drawing of Aero Gallery



(Each square is 3 meters x 3 meters)

1957



The National Advisory Committee for Aeronautics (NACA), founded in 1915, was soon to become the core of a new federal agency that took NACA's mandate to "direct and conduct research and experimentation in aeronautics, with a view to their practical solution" and expanded it to the realm of space.

October 4, 1957
The Soviet Union launched Sputnik I, the first artificial satellite to orbit Earth.



1958



January 31, 1958
Explorer 1 became the first satellite launched by the United States.

March 17, 1958
The Vanguard I satellite was successfully launched into Earth orbit.

October 1, 1958
The National Aeronautics and Space Administration (NASA) was formed. The 1958 Space Act established NASA as the organization responsible for both aeronautics and astronautics.

1959

X-15 Program 1959–1969: A revolutionary aircraft, the X-15's 199 test flights uncovered space program such as high-temperature materials, reaction control systems, and full-pres

June 8, 1959
First flight of the hypersonic X-15, a planned glide flight to 522 mph piloted by A. Scott Crossfield.

March 25, 1960
First NASA X-15 research flight by pilot Joseph A. Walker.



1961

March 7, 1961
First Mach 4 flight by pilot Robert M. White.

June 23, 1961
First Mach 5 flight by pilot Robert M. White.

November 9, 1961
First Mach 6 flight by pilot Robert M. White.

April 1, 1960
The United States launched TIROS 1, the first successful meteorological satellite, for monitoring Earth's weather.



May 5, 1961
Alan Shepard became the first American to fly in space on the *Freedom 7* suborbital flight from Cape Canaveral, FL.

May 25, 1961
President John F. Kennedy committed the United States and NASA to landing on the moon by the end of the decade.

February 17, 1959
The United States launched Vanguard 2, an International Geophysical Year scientific satellite, from Cape Canaveral, FL. Vanguard produced the first photos of Earth from space.



November 6, 1958
Last flight of the Bell X-1E, the last of the X-1 series of aircraft. The X-1 was the first aircraft to exceed the speed of sound.

March 3, 1959
The United States sent Pioneer 4 to the moon, successfully making the first U.S. lunar flyby.



August 12, 1960
NASA successfully orbited Echo 1, a 100-foot inflatable, passive communications satellite.

U.S. President

Dwight D. Eisenhower
January 20, 1953 – January 19, 1961

John F. Kennedy
January 20, 1961 – November 22, 1963

NASA Administrator

Dr. T. Keith Glennan
August 19, 1958 – January 20, 1961

James E. Webb
February 14, 1961 – October 7, 1968

Price of Gas

\$0.30

\$0.31

\$0.31

\$0.31

Collier Trophy

USAF and the industry team of Lockheed and General Electric for development of the F-104

USAF and the Convair Div. of General Dynamics for creation and operation of the Atlas ICBM

Vice Adm. William F Raborn for directing creation of the Polaris fleet ballistic missile system

X-15 test pilots for invaluable technological contributions to the advancement of flight

Sports Illustrated Sportsman of the Year

Rafer Johnson

Ingemar Johansson

Arnold Palmer

Jerry Lucas

Time Magazine Person of the Year

Charles de Gaulle

Dwight Eisenhower

U.S. Scientists

John F. Kennedy

Academy Award for Best Picture

Gigi

Ben-Hur

The Apartment

West Side Story

1962

1963

1964

1965

1966

Many "first's" in high-speed, high-altitude research that were also later used in the sure pilot suits.

June 27, 1962

Pilot Joseph A. Walker flew the X-15 to an unofficial world speed record of 4,104 mph.

July 17, 1962

Pilot Robert M. White set a Fédération Aéronautique Internationale world altitude record of 314,750 ft.

August 22, 1963

Highest X-15 flight (unofficial), 354,200 ft (67+ miles) by Joseph A. Walker.

June 25, 1964

First flight of the X-15A-2.



Runway Grooves

1962-1987 (approx.)

NASA developed a process for cutting transverse grooves into runways to help aircraft land safely on wet pavement. The process was adapted to U.S. highways and other types of wet surfaces.



Lifting Body Vehicles Research Program

1963-1976: The program demonstrated the low speed entry and landing characteristics of vehicles that use body shape, rather than wings, to generate lift.

March 1, 1963

M2-F1, first flight (ground tow)

August 16, 1963

M2-F1, first air tow



October 21, 1965

M2-F1, last captive flight

July 12, 1966

NASA's Milt Thompson made the first flight of the M2-F2, a heavyweight lifting body vehicle designed to demonstrate the handling characteristics of a spacecraft capable of landing on a runway.

August 16, 1966

M2-F1, last flight (air tow)

December 22, 1966

NASA's Bruce A. Peterson piloted the HL-10 lifting body on its first glide flight.



February 20, 1962

John Glenn became the first American to orbit Earth, making three orbits in his Friendship 7 Mercury spacecraft.



October 30, 1964

The first flight of the Lunar Landing Research Vehicle, the forerunner of the Lunar Lander that was used to train the astronauts for flying the Lunar Excursion Module, was flown at NASA Dryden by Joe Walker.

June 3, 1965

The second piloted Gemini mission, Gemini IV, stayed aloft for four days, and astronaut Ed White performed the first spacewalk by an American.

December 15, 1965

First rendezvous in space between Gemini 6-A and Gemini 7 for five hours of station-keeping.



Lyndon B. Johnson
November 22, 1963 - January 19, 1969

\$0.31	\$0.30	\$0.30	\$0.31	\$0.32
The seven Mercury astronauts for pioneering manned American spaceflight	Clarence "Kelly" Johnson for designing and directing development of the Mach 3 Lockheed A-11	Gen. Curtis LeMay for great achievements with respect to air vehicles and national defense	The Gemini Program teams for significantly advancing the human spaceflight experience	James McDonnell for leadership and perseverance in advancing aeronautics and astronautics

Terry Baker	Pete Rozelle	Ken Venturi	Sandy Koufax	Jim Ryun
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Pope John XXIII	Martin Luther King, Jr.	Lyndon B. Johnson	William Westmoreland	The Generation Twenty-Five & Under
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Lawrence of Arabia	Tom Jones	My Fair Lady	The Sound of Music	A Man for All Seasons
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ONAUTICS: SOLVING DECADES

1967	1968	1969	1970	1971
<p>October 3, 1967 An unofficial world speed record of Mach 6.7 (4,520 mph) was reached in a modified version of the X-15 by research pilot William "Pete" Knight.</p>	<p>October 24, 1968 NASA pilot William H. Dana ended an era by flying the final flight in the X-15 flight research program.</p>		<p>March 3, 1970 NASA researchers began flight tests of the triplesonic YF-12 aircraft to investigate the effects of sustained high-speed flight.</p> 	<p>March 9, 1971 NASA research pilot Thomas McMurtry completed the first flight of an F-8A modified with a new wing called the supercritical airfoil. Work on the airfoil design concept began in the 1960s under NASA chief scientist Richard Whitcomb.</p> 
	<p>Runway Grooves 1968-1972 NASA teamed with the U.S. Air Force and FAA to conduct the first tests of pavement grooving using an F-4 fighter, a Convair 990 jet transport, and a Beech Queen Air twin-propeller aircraft.</p>	<p>Wake Vortex Research 1969-1980 NASA conducted research and test flights on the dangerous wakes of turbulent air that trail behind every aircraft (wing-tip vortices). Resulting data helped the Federal Aviation Administration (FAA) establish safe separation distances between aircraft during takeoffs, landings and cruise flight.</p>		
<p>May 10, 1967 M2-F2, last flight</p> 	<p>October 23, 1968 First rocket-powered flight of the HL-10, flown by Air Force Major Jerauld R. Gentry.</p>	<p>April 17, 1969 First X-24A glide flight, by pilot Jerauld R. Gentry.</p> <p>May 9, 1969 NASA pilot John A. Manke made the first supersonic flight of a wingless lifting body when he reached a top speed of 744 mph.</p> 	<p>February 18, 1970 First max speed of 1,228 mph on the HL-10</p> <p>February 27, 1970 First max altitude of 90,303 ft. on the HL-10</p> <p>June 2, 1970 First M2-F3 glide flight</p> <p>July 17, 1970 HL-10, last flight</p> <p>November 25, 1970 First M2-F3 powered flight</p> 	<p>June 4, 1971 X-24A, last flight</p> <p>August 25, 1971 First M2-F3 supersonic flight</p>
<p>January 27, 1967 During a simulation aboard an Apollo command module on the launch pad at Kennedy Space Center, a flash fire broke out, engulfing the capsule in flames. The three astronauts aboard—Gus Grissom, Ed White, and Roger Chaffee—died of asphyxiation.</p>	<p>December 21, 1968 Apollo 8 launched atop the Saturn V booster from Kennedy Space Center with three astronauts aboard—Frank Borman, James A. Lovell, Jr., and William A. Anders. On Christmas Eve, the crew read from the book of Genesis.</p>	<p>July 20, 1969 Apollo 11 became the first mission to land people on the moon. Astronauts Neil Armstrong and Buzz Aldrin walked on its surface while Michael Collins orbited overhead in the Apollo command module.</p>	<p>April 11-17, 1970 Fifty-six hours into the flight of Apollo 13, the oxygen tank in the service module ruptured and damaged several of the power, electrical, and life support systems. All crew members returned safely to Earth.</p>	<p>July 26, 1971 Apollo 15 made the first use of a Lunar Roving Vehicle on the moon.</p>
		<p>Richard M. Nixon January 20, 1969 – August 9, 1974</p>		
		<p>Dr. Thomas O. Paine March 21, 1969 – September 15, 1970</p>		<p>Dr. James C. Fletcher April 27, 1971 – May 1, 1977</p>
\$0.33	\$0.34	\$0.35	\$0.36	\$0.36
Hughes Aircraft Surveyor Program team and the Jet Propulsion Lab for aiding lunar exploration	The Apollo 8 crew for flawless execution of the first manned lunar orbit	Neil Armstrong, Edwin "Buzz" Aldrin and Michael Collins for the epic flight of Apollo 11	Boeing, Pratt & Whitney and Pan American Airways for pioneering the Boeing 747	The Apollo 15 crew and NASA's Robert Gilruth for most ambitious science lunar mission
Carl Yastrzemski	Bill Russell	Tom Seaver	Bobby Orr	Lee Trevino
Lyndon B. Johnson	The Apollo 8 Astronauts	The Middle Americans	Willy Brandt	Richard Nixon
In the Heat of the Night	Oliver!	Midnight Cowboy	Patton	The French Connection

S OF AVIATION CHALLENGES

1972	1973	1974	1975	1976
<p>April 1972 NASA published fundamental papers introducing the concept of 4-dimensional trajectories (three spatial dimensions plus time), which today are a basis for air traffic guidance in the NextGen.</p>				<p>Advanced Turboprop Propeller The Aircraft Energy Efficiency</p> 
<p>Advanced Supersonic Technology (AST)/Supersonic Cruise Research (SCR) Project 1972–1982: This research effort tackled the technical and environmental challenges of making a viable, advanced commercial supersonic transport. The program resulted in technology of value to the subsonic transport industry such as new aerodynamic design modeling tools.</p>				
	<p>November 1, 1973 First flight of supercritical wing on F-111 variable sweep wing aircraft.</p>	<p>Quiet Short-Haul Research Aircraft (QSRA) Project 1974-1981: Developed and demonstrated technologies necessary to support short-takeoff and landing and high-lift cargo aircraft. These technologies were employed on the C-17 Globemaster III.</p>		
<p>May 25, 1972 NASA research pilot Gary Krier flew an F-8C modified with an all-electric, digital fly-by-wire (DFBW) control system, a prototype of the flight control system used today on some aircraft and on the space shuttle.</p> 		<p>June 7, 1974 First flight of the NASA Boeing 737 Transport Systems Research Vehicle, which conducted thousands of flight hours of research for more than 20 different projects from wind shear detection to noise studies to runway friction.</p> 	<p>Energy Efficient Engines aircraft engines in service at</p>	
		<p>October 22, 1976 After decades of research and wind tunnel testing into technologies to make vertical takeoff and landing (VTOL) possible, NASA and Bell Aircraft rolled out the experimental XV-15 tilt rotor aircraft. Successful flights of the XV-15 led to Department of Defense approval in 1986 to produce the V-22 Osprey.</p>		
<p>December 20, 1972 M2-F3, last flight</p> 	<p>August 1, 1973 First X-24B glide flight</p>	<p>March 5, 1974 First X-24B supersonic flight</p>	<p>November 26, 1975 X-24B, last flight for the Lifting Body Vehicles Research Program</p>	
	<p>November 15, 1973 First X-24B powered flight</p>	<p>October 25, 1974 Fastest lifting body flight (Mach 1.76, 1164 mph) in an X-24B</p> 		
<p>December 7-19, 1972 Apollo 17 was the last of the six Apollo missions to the moon. The astronaut crew included Eugene A. Cernan, Ronald A. Evans and Dr. Harrison H. Jack Schmitt, a geologist.</p> 	<p>May 14, 1973 Skylab, an orbital space platform, was launched. Skylab became home to three crews during 1973–74 for periods of 28, 59 and 84 days.</p> 	<p>July 15–24, 1975 At the height of the Cold War, the Apollo-Soyuz Test Project became the first joint international human space flight effort.</p> 	<p>August 20, 1975 Viking 1 was launched from Kennedy Space Center toward Mars. It landed on the red planet on July 20, 1976.</p> 	

Gerald R. Ford
August 9, 1974 – January 19, 1977

\$0.36	\$0.39	\$0.53	\$0.57	\$0.61
The personnel of the 7th and 8th Air Forces and Task Force 77 during Operation Linebacker II	NASA's Skylab Program, with recognition to director William Schneider and its three astronaut crews	John Clark (NASA) and Daniel Fink for the Earth Resources Technology Satellite Program (LANDSAT)	General Dynamics and the USAF F-16 team for advancements leading to effective fighter aircraft	USAF, the B-1 Industry Team and Rockwell Intl. Corp. for B-1 bomber design and development
Billie Jean King / John Wooden	Jackie Stewart	Muhammad Ali	Pete Rose	Chris Evert
Henry Kissinger / Richard Nixon	John Sirica	King Faisal	American Women	Jimmy Carter
The Godfather	The Sting	The Godfather Part II	One Flew Over the Cuckoo's Nest	Rocky

1977

1978

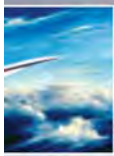
1979

1980

1981

Project 1976-1987: After the energy crisis of the early '70s, NASA initiated research into a unique "swirled" design for propellers used on propeller-powered aircraft.

Agency (ACEE) Program 1975-1986: This program stimulated wide application of lighter and more durable composite materials to secondary and primary aircraft structures.



Storm Hazards Program 1978-1986: This program conducted extensive research and flight tests to identify conditions that could lead to lightning strikes on aircraft. Results informed new design guidelines used in aircraft and flight operations to protect critical digital systems.

(STOL),

July 6, 1978
First flight of QSRA at Boeing Field, Seattle, WA.



July 10, 1980
QSRA began sea carrier trials on the USS Kitty Hawk without catapult launch or landing arresting gear.

Forward Swept Wing Research
forward swept wing technology, controls, and canard effects.

Project 1976-1984: Managed at NASA's Glenn Research Center, this project proved that a 15 percent reduction in fuel consumption could be made relative to the time. Research enabled industry's development of the more fuel-efficient high-bypass GE90 turbofan jet engine, which powers the intercontinental Boeing 747.



May 3, 1977
First hover and low-speed flight of the XV-15.

Highly Maneuverable Aircraft Technology (HiMAT) 1979-1983: HiMAT was installed on a modified Sikorsky HO4S helicopter to validate use on future fighter aircraft. HiMAT's extensive use of composites, wing planform, and control surfaces.

July 27, 1979
The HiMAT remotely piloted vehicle completed its first flight.



July 24, 1979
First full in-flight conversion from helicopter-to-airplane mode with the XV-15.



Oblique Wing Program 1979-1982: The wing of this unique research aircraft could be rotated 45 degrees to decrease drag and increase speed and range. The AD-1 was flown 79 times to collect data on handling qualities.

December 21, 1979
First flight of the AD-1



June 12, 1981
First operational flight of the Lockheed ER-2 high-altitude aircraft used for atmospheric research, observation and mapping missions.



August 12, 1977
First free flight of Enterprise

September 28, 1978
Last NASA YF-12 research flight before returning aircraft to U.S. Air Force.



July 24, 1979
Research pilot Thomas McMurtry flew a KC-135A Stratotanker jet outfitted with winglets, proving that the vertical tips on the ends of the wings reduced drag and improved the aircraft's range.



April 12, 1981
Astronauts John W. Young and Robert L. Crippen flew Space Shuttle Columbia on the first flight of the Space Transportation System (STS-1).

Jimmy Carter
January 20, 1977 - January 19, 1981

Ronald Reagan
January 20, 1981 - January 19, 1989

Dr. Robert A. Frosch
June 21, 1977 - January 20, 1981

James M. Beggs
July 10, 1981 -

\$0.67	\$0.63	\$0.90	\$1.25	\$1.38
Gen. Robert Dixon and the USAF TAC for developing and implementing flight-training programs	Williams Research Corp. for concept and development of a turbofan to power cruise missiles	Paul MacCready and pilot Bryan Allen for design, construction and flight of the Gossamer Condor	NASA's Voyager Mission team for a spectacular fly-by of and return from Saturn	NASA, Rockwell, Martin Marietta, Thiokol and the Space Shuttle Columbia crew
Steve Cauthen	Jack Nicklaus	Terry Bradshaw / Willie Stargell	U.S. Olympic Hockey Team	Sugar Ray Leonard
Anwar Sadat	Deng Xiaoping	Ayatollah Khomeini	Ronald Reagan	Lech Walesa
Annie Hall	The Deer Hunter	Kramer vs. Kramer	Ordinary People	Chariots of Fire

NASA AERONAUTICS: 9

1992 1993 1994 1995 1996

Interest in a supersonic transport had been renewed, and Phase I of HSR focused on (HSCT): the sonic boom, airport and community noise, and ozone depletion.



Low Visibility Landing and Surface Operations
Research created early concepts for GPS-based airport map displays now on the Airbus A380 and for head-up guidance cockpit displays to improve safety.

The Advanced Control Technology for Integrated Vehicles (ACTIVE) Program 1993-2006: A joint NASA, U.S. Air Force, McDonnell Douglas Aerospace, and Pratt & Whitney effort to evaluate thrust vectoring engine nozzles for improved high-angle of attack control and maneuverability, and to explore integrated intelligent flight control systems.

1995: Phase II of the HSR program began to assess technologies to Civil Transport, including weight reduction, advanced control systems

April 24, 1996
The F-15 ACTIVE achieved its supersonic yaw vectoring flight at Dryden Flight Research Center, Edwards, CA.

Low Visibility Landing and Surface Operations Project 1993-2000
Research created early concepts for GPS-based airport map displays now on the Airbus A380 and for head-up guidance cockpit displays to improve safety.

Environmental Research Aircraft and Sensor Technology (ERAST) Project 1994-2003: Pioneering research on high-altitude, long-endurance unmanned aircraft.



September 11, 1995
Pathfinder Unmanned Aerial Vehicle (UAV) set a new altitude record of 50,567 feet for a solar-powered aircraft.



July 1996
The Traffic Management Advisor, a NASA CTAS software tool for controlling arriving air traffic, was deployed at Dallas/Ft. Worth International Airport and later at more FAA en-route facilities.

composite materials, from design through fabrication, on wing and fuselage primary structures as cost-effective, low-weight, high-durability options.

dangerous weather to test the



November 30, 1994
A Continental Airlines Boeing 737-300 was the first commercial flight to use the forward-looking Doppler radar to detect wind shear.

Automatic Dependent Surveillance-Broadcast (ADS-B) private partnership to test and deploy new airborne surveillance radar; provides air-to-air, air-to-ground, and ground-to-air ft

July 1996
The Traffic Management Advisor, a NASA CTAS software tool for controlling arriving air traffic, was deployed at Dallas/Ft. Worth International Airport and later at more FAA en-route facilities.



Automatic Dependent Surveillance-Broadcast (ADS-B) private partnership to test and deploy new airborne surveillance radar; provides air-to-air, air-to-ground, and ground-to-air ft

Sonic Boom Reduction 1994-2000: Improvements in the configuration of aircraft to re

Advanced Subsonic Technology (AST) Program 1992-1999: Led research into areas most likely to improve U.S. civil transport aircraft, including air productivity of the airport terminal area, propulsion, wing design, use of composite materials and improved flight controls. This work continues to inform a

t, generating less drag and promoting better fuel efficiency.

period, but produced advanced technologies in materials, propulsion and other fields.












June 27-July 7, 1995
Space Shuttle Atlantis docked to the Mir space station. It was the first of nine shuttle-Mir link-ups between 1995 and 1998.



William J. Clinton January 20, 1993 - January 19, 2001				
Daniel S. Goldin April 1, 1992 - November 17, 2001				
\$1.13	\$1.11	\$1.11	\$1.15	\$1.23
USAF, USNRL, the Aerospace Corp., Rockwell and IBM for Global Positioning System development	Hubble Space Telescope (HST) Repair Team for successful HST orbital recovery and repair	McDonnell Douglas, USAF and the Industry Team, for C-17 Globemaster creation and production	Boeing Commercial Aircraft Co. for design, development and production of the Boeing 777	Cessna Aircraft Co. for design, development and production of the Citation X
Arthur Ashe	Don Shula	Bonnie Blair / John Olav Koss	Cal Ripken, Jr.	Tiger Woods
Bill Clinton	The Peacemakers	Pope John Paul II	Newt Gingrich	David Ho
Unforgiven	Schindler's List	Forrest Gump	Braveheart	The English Patient

SOLVING DECADES OF AVIATION

1997	1998	1999	2000	2001
improve the economic competitiveness of a High-Speed rail system through improved flight deck instrumentation, and displays.		FutureFlight Central 1999–Ongoing: A full-scale airport operations simulator that can create a virtual airport where airport staff can plan new runways, test new ground traffic and tower communications procedures.		
<p>July 7, 1997 Pathfinder UAV set an unofficial altitude record of 71,500 feet for a solar-powered aircraft.</p> 	<p>August 6, 1998 The modified, extended-wing Pathfinder Plus flew to a record altitude for propeller-driven aircraft of 80,201 feet.</p> 		<p>October 2000 NASA and the FAA tested an early version of the Runway Incursion Prevention System, which alerts pilots and air traffic controllers to planes or other vehicles about to encroach on runways.</p> 	<p>August 13, 2001 The Helios uncrewed solar-powered UAV flew to world record altitude of 96,863 feet.</p>
<p>May 17, 1997 The X-36 subscale prototype tailless fighter made the first of 31 test flights, showing a high-speed vehicle without a tail could fly normally.</p> 	<p>Ultra-Efficient Engine Technology (UEET) Program October 1, 1999–2004: In lieu of reducing nitrogen oxide and carbon dioxide emissions from commercial and military jet engines while maintaining performance, new computer simulation tools were among the beneficial results from UEET.</p>		<p>Intelligent Flight Control Systems (IFCS) 1999–Ongoing: Neural network technology that allows aircraft to fly themselves.</p>	
<p>ADS-B Technology 1995–2008: NASA supported a public/private partnership to develop ADS-B technology that complements existing ATIS functionality; improves safety and increases airport capacity.</p>		<p>Capstone Program 1999–2006 This FAA-led program was the proving ground for ADS-B technology and its ability to reduce accidents and improve efficiency. NASA supported installation of Global Positioning System (GPS)-based avionics and data link communications.</p>		
<p>Research on ways to reduce sonic boom intensity were formulated in a sonic boom study.</p>		<p>Research on aircraft aging, noise reduction, environmental impact, and aeronautics research at NASA.</p>		
<p>July 4, 1997 The Mars Pathfinder landed on Mars and deployed the Sojourner rover. This mission marked the first return of the U.S. to Mars after nearly twenty years.</p> 	<p>October 29, 1998 John Glenn returned to space on the Space Shuttle <i>Discovery</i> (STS-95). He was a test subject for specific investigations on the similarities between space flight and aging.</p> 	<p>July 22–27, 1999 The Space Shuttle <i>Columbia</i>'s 26th flight was led by Air Force Col. Eileen Collins, the first woman to command a shuttle mission (STS-93).</p> 	<p>October 31, 2000 Expedition One of the International Space Station launched from Baikonur Cosmodrome in Kazakhstan. Astronaut William M. Shepherd and cosmonauts Yuri Pavolich Gidzenko and Sergi K. Kirkalev became the first residents of the ISS.</p> 	<p>Advanced General Aviation Transport Experiments (AGATE) Program 1994–2001: Under the AST, AGATE revitalized the general aviation industry through an alliance of government agencies, industry and universities that dramatically updated flight deck and propulsion technologies, certification methods and airspace infrastructure for small aircraft.</p>
<p>George W. Bush January 20, 2001 –</p>				
\$1.23	\$1.06	\$1.17	\$1.51	\$1.46
Gulfstream Aerospace Corp. for design, development and production of the Gulfstream V	Lockheed Martin, General Electric, NASA, USAF and DIA for U-2S/ER-2 development and operation	Boeing Co. for development of the F/A-18E/F Super Hornet	Northrop Grumman, Rolls-Royce, Raytheon, L-3, USAF and DARPA for Global Hawk creation and operation	The Joint Strike Fighter Program Office and industry partners for the Integrated LiftFan Propulsion System
Dean Smith	Mark McGwire / Sammy Sosa	U.S. Women's Soccer Team	Tiger Woods	Randy Johnson / Curt Schilling
Andy Grove	Bill Clinton / Kenneth Starr	Jeffrey P. Bezos	George W. Bush	Rudolph Giuliani
Titanic	Shakespeare in Love	American Beauty	Gladiator	A Beautiful Mind

ON CHALLENGES

2002 2003 2004 2005 2006

reate a functionally accurate physical and software replication of a control tower or operations center (current or future). With NASA experts, cedures, validate air traffic planning simulations, and perform cost-benefit studies for new airport requirements and designs.

February 2006
Test flights of an F-15 proved that a flight control system built on an artificial neural network can help pilots retain control of their aircraft during destabilizing conditions.



June 26, 2003
Helios crashes after malfunction

April 2005
The effects of sonic booms on structures and humans on the ground were measured using microphone arrays to capture sound from aircraft flying at low altitudes.



X-43A Program 2002-2004: The X-43A airplane used innovative scramjet technology to fly at ten times the speed of sound, setting a world's record for air-breathing aircraft.



March 27, 2004
X-43A set a new aeronautical speed record of Mach 6.83—nearly 5,000 mph.

November 16, 2004
A second unpowered flight of the X-43A resulted in a second speed record of Mach 9.68—nearly 7,000 mph.

June 5-7, 2005
The Small Aircraft Transportation System project held a public demonstration to showcase future technologies like "Highway in the Sky" that could help small planes better utilize small airports in all kinds of weather.

August 2006
The Future Air Traffic Management Concepts Evaluation Tool (FACET) won NASA Software of the Year. FACET simulates thousands of aircraft trajectories and assists air traffic control managers plan for efficient travel flow across the country.



ght of future aviation growth, NASA created UEET to research ways to reduce maintaining performance and fuel efficiency. Multiple engine demonstrations and

ty for aircraft control was invented to help aircraft recover from loss of control.

ong the thousands of general aviation pilots in the Alaska region who fly remote routes. tions suites in commercial aircraft, along with ground systems, equipment and services.

2005
ADS-B began deployment at air facilities from Florida to New York.



June 2003
NASA's Performance Data Analysis and Reporting System was recognized for helping air traffic control centers improve safety and efficiency through customized reports.

January 2004
Twenty-one more test flights of the modified F-5E were conducted under the project now renamed "Shaped Sonic Boom Experiment."



August 10, 2006
NASA and Gulfstream Aerospace tested a telescopic "Quiet Spike" sonic boom mitigator on a NASA F-15B aircraft and proved it reduced the intensity of sonic booms caused by supersonic aircraft.

August 27, 2003
The F-5 Shaped Sonic Boom Demonstration research aircraft proved its modified forward section reduced the intensity of sonic booms.



November 2005
A three-week series of flight tests with the Boeing Company and other partners proved that scalloped or asymmetrical chevrons on jet engine nozzles or casings reduce noise inside and outside the aircraft.

December 2006- April 2007
NASA's 8-Foot High-Temperature tunnel hosted testing of Pratt & Whitney Rocketdyne's X-1 scramjet engine, a major technology step toward making hypersonic flight (> Mach 5.0) a reality.



September 2003
NASA's Surface Management System software, which helps manage air traffic from gate to gate, was demonstrated at Memphis International Airport.

Sept - Nov 2004
NASA flight-tested a version of Synthetic Vision Systems that uses GPS signals and computer-based terrain models to create a 3-D image of objects outside the cockpit, improving flight safety in low visibility.

July 26, 2005
The Space Shuttle *Discovery* lifted off into orbit, marking NASA's return to human spaceflight after the Columbia disaster.

January 19, 2006
The New Horizons spacecraft lifted off from Cape Canaveral, beginning its nine-year trip toward Pluto and the Kuiper Belt.

February 1, 2003
All crew members died after the Space Shuttle *Columbia* broke up 15 minutes before landing.

January 3 and 24, 2004
NASA landed two Mars Exploration Rovers, Spirit and Opportunity, on the surface of Mars.

Sean O'Keefe December 21, 2001 – February 11, 2005			Dr. Michael Griffin April 14, 2005 –	
\$1.36	\$ 1.59	\$1.88	\$2.30	\$2.59
Sikorsky and industry team for development and introduction into service of the S-92 helicopter	Gulfstream for setting new safety standards with development of the innovative G550 aircraft	The Rutan SpaceShipOne Team for the first privately financed, built and flown space vehicle	Eclipse Aviation Corp. for development and operation of the very light jet the Eclipse 500	USAF and its industry partners for design, test and operation of the revolutionary F-22 Raptor
Lance Armstrong	Tim Duncan / David Robinson	Boston Red Sox	Tom Brady	Dwyane Wade
The Whistleblowers	The American Soldier	George W. Bush	The Good Samaritans	You
Chicago	The Lord of the Rings: The Return of the King	Million Dollar Baby	Crash	The Departed

2007

2008



April 26, 2007

First test flight of the Stratospheric Observatory for Infrared Astronomy (SOFIA), a Boeing 747 carrying an infrared telescope to capture images and spectra not possible by the largest ground-based telescopes.

2007

Over 300 aircraft in Alaska received ADS-B to help air traffic separation efforts.

**X-48B Flight Tests
2007–Ongoing:**

July 20, 2007

The first test flight of the 21-foot wingspan X-48B Blended Wing Body research aircraft took place at NASA's Dryden Flight Research Center.

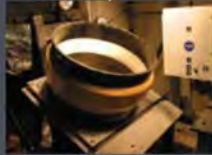


June 6–7, 2007

NASA's MESSENGER (Mercury, Surface, Space Environment, Geochemistry and Ranging) probe flew by Venus on its way to encountering Mercury in 2008.

February 2008

A broken fan blade was used to test the strength and durability of a jet engine containment case made of lighter, composite material versus metal.



March 2008

A NASA wind tunnel hosted tests of the Smart Material Actuated Rotor Technology (SMART)—new trailing edge control flaps and "smart" material actuators that can reduce helicopter vibrations and noise.



May 25, 2008

After deploying a parachute system developed in collaboration with NASA aeronautics, the Phoenix Mars Lander touched down in the northern polar region of Mars to analyze soil and water ice samples.



National Aeronautics and Space Administration



www.nasa.gov

	U.S. President
	NASA Administrator
\$3.03	Price of Gas
The Automatic Dependent Surveillance-Broadcast (ADS-B) team of public and private sector groups	Collier Trophy
Brett Favre	Sports Illustrated Sportsperson of the Year
Vladimir Putin	Time Magazine Person of the Year
No Country for Old Men	Academy Award for Best Picture



Additional Readings



“NASA’s Contributions to Aeronautics, Volume 1”

Edited by Richard P. Hallion

(posted August 2010)

Since its creation, NASA has steadily advanced flight within the atmosphere, repeatedly influencing aviation’s evolution by extending the rich legacy of its predecessor, the National Advisory Committee for Aeronautics, or NACA. This first volume in a two-volume set includes case studies and essays on NACA-NASA research for contributions such as high-speed wing design, the area rule, rotary-wing aerodynamics research, sonic boom mitigation, hypersonic design, computational fluid dynamics, electronic flight control and environmentally friendly aircraft technology.



“NASA’s Contributions to Aeronautics, Volume 2”

Edited by Richard P. Hallion

(posted September 2010)

The second volume includes studies and essays on NACA-NASA research for contributions including wind shear and lightning research, flight operations, human factors, wind tunnels, composite structures, general aviation aircraft safety, supersonic cruise aircraft research and atmospheric icing.

The NASA Aeronautics: Solving Decades of Aviation Challenges PDF’s can be downloaded at the following websites:

http://www.aeronautics.nasa.gov/pdf/timeline_poster_back.pdf

http://www.aeronautics.nasa.gov/pdf/timeline_poster_front.pdf

NASA Aeronautics Research Onboard Lithographs can be downloaded at the following website:

http://www.aeronautics.nasa.gov/onboard_lithos.htm

Lithographs are also available in Spanish.

To learn more about the numerous contributions that NASA has made to aeronautics visit NASA’s interactive website:

http://www.nasa.gov/externalflash/ae_o_onboard/

Do internet searches:

Smithsonian Institution—National Air and Space Museum

National Museum of the United States Air Force

Aviation Museums in the United States



Worksheets

The following topics were given as several of NASA’s major contributions to aeronautics.

Airbag Systems	NASA Structural Analysis (NASTRAN)
Airborne Wind Shear Detection	Natural Laminar Flow (NLF) Airfoil
Area Rule	Real-Time Graphical Weather
Composite Structures	Small Aircraft Transportation System (SATS)
Computational Fluid Dynamics (CFD)	Stall/Spin Research
Deicing Systems	Supercritical Airfoil
Digital Fly-By-Wire	Synthetic Vision Systems (SVS)
Glass Cockpit	TURBO-AE Code
Highway-In-The-Sky (HITS)	Quiet Jets
Lightning Protection Standards	Winglets

Your team is to decide which of these categories you want to include in your gallery. You may decide to build a gallery around only 1 category, 3 or 4 of the categories, or all of the categories.

Follow the steps below to create your gallery.

Step 1. As a team, brainstorm ideas for the theme of your gallery. Have each team member offer an idea. Once everyone has had an opportunity to offer an idea, repeat the process until no additional ideas are offered.

Idea 1	
Idea 2	
Idea 3	
Idea 4	
Idea 5	
Idea 6	
Idea 7	
Idea 8	
Idea 9	
Idea 10	
Idea 11	
Idea 12	

Step 2. Have every team member vote for the three of the ideas they like the best. Then, as a team, discuss the 3 ideas that received the most votes. After the discussion, decide on the final idea or your gallery. Record your theme on the summary page at the end of this worksheet.

Step 3. Decide how large you want your gallery to be. Consider details such as whether there will be any large artifacts in the gallery. Since many museums have an interactive and/or hands-on section, consider this in your team’s design as well. Record the gallery dimensions on the summary page at the end of the lesson. Remember that the larger a gallery is, the more costly it is for the museum to operate.

Step 4. Now that you know the theme for the gallery and its size, it is time to decide on the categories to include in the gallery.

As a team, discuss each of the categories and decide which ones to include in the gallery. List the selected categories on the summary page at the end of this worksheet.

Step 5. Have each team member take 1 or 2 of the categories and research them for ideas of things to include in the gallery. For example, if a team member researched the category winglets, he or she might recommend including an aircraft with winglets in the gallery. The team member might also indicate that 1 or 2 displays would also be needed to use with the aircraft to explain certain concepts.

Use the responsibility form below to assign tasks to be completed.

Responsibility Form	
Assignment	Responsible Person

As each team member conducts their research, he or she must use the Category Exhibit Sheet to record research results. Ideas for displays, artifacts, photos, etc., should be listed. A Category Exhibit Sheet needs to be completed for each category by each person.

Category Exhibit Sheet - Ideas of Things to Include in Gallery		
Aeronautics Category:		
Recommended Artifact or Display	Description	Size of Area (L x W) Required in Gallery

Step 6. As a team, come back together and select the final artifacts and displays for your gallery. List the artifact, display, etc., that your team has selected for inclusion on the summary page.

Step 7. For each artifact, display, etc., cut them to scale using an index card and label it with what it is. Then place the index card on the graph paper.

Step 8. Now that the team has selected the items to be included in the gallery, it is time to finalize the layout of your gallery. Think about the visitor flow through the gallery: Is it to be directional? This means that everyone enters the gallery at same place and follows a certain route through the gallery to its exit. Make sure to show the entrances and exits for the gallery. Once everything has been decided upon, create a final scale drawing of your gallery on the graph paper. Decide the scale for each square on the graph paper. Note the dimensions on the graph paper. After completing your scale drawing attach it to the worksheet.

Summary Page

Gallery Theme: _____

Gallery Dimensions: Length _____Meters Width _____Meters
 _____Feet _____Feet

Worksheet 2

Gallery Programs Worksheet

Assume that you will have to build an addition to the aviation museum for your team's gallery. What will be the cost to construct and operate the gallery?

Note as building costs are given in square feet, the metric system will not be used in this section of the activity.

A factor not considered in your team's gallery design was the costs associated with the construction and operation of your gallery. If a new gallery space was constructed to house your collection, the following description represents some of the costs:

Assume your gallery space is 100 feet by 100 feet. The total area of the gallery would be 10,000 square feet. It costs approximately \$200 a square foot for construction costs. For this gallery, the construction costs would be approximately 2 million dollars. To outfit the gallery, the cost would be an additional \$150 a square foot or in this case, it would be an additional 1.5 million dollars. Also, the yearly operation costs for lights, heat, and air conditioning approximates \$40 a square foot each year. This would add another \$400,000 to the total costs. In addition to all of these costs, are the staff salaries, maintenance and security fees.

Museums are dependent on admissions to help fund the expenses of the museum. Calculate the greatest number of visitors that your team's gallery can safely hold at one time. To calculate this, the first thing that needs to be determined is what is called the "load factor." This is the number of square feet required by each visitor in the gallery. Let us assume that it is 5 square feet. Now suppose that the artifacts and displays take up 60 percent of the space. This leaves 40 percent of the space for visitors. In our example, this would be 4,000 square feet, and if each gallery visitor requires 5 square feet, then the maximum number of visitors in the gallery at one time is 800. In our example, assume that a visitor stays in the gallery for one hour.

Now assume that your gallery is open from 9 to 5 each day. Over the course of a few months, it is determined that the occupancy rate for the gallery is 6 percent. The gallery is open 8 hours a day. If there was a 100 percent occupancy rate, this would translate into 6400 visitors a day (8 hours x 800 visitors/hour). Since the occupancy rate is only 6 percent, approximately 384 visitors would visit the gallery each day (6400 X .06).

If the admission to the gallery was \$10, the museum would generate \$3,840 a day in admissions. If the museum was open 360 days a year, the total income based on admissions of 384 visitors per day is \$1,382,400. If the operations expenses are deducted, \$982,000 is left to pay for salaries and the operation of the rest of the building. A rule of thumb is that the exhibit space is approximately one-half the space in a museum. Therefore, another \$400,000 would have to be deducted for the operations costs for the remaining museum space leaving only \$532,000 to fund all the other museum expenses.

For your team's gallery:

1. What is the number of square feet of exhibit space? _____
2. What is the number of square feet required for the artifacts and displays? _____
3. What is the amount of space available for visitors? _____
4. Assuming the load factor is 5 square feet, what is the greatest number of visitors that can be in the gallery at any one time? _____
5. Based on the information given above in the explanation and a 5 percent visitor occupancy rate what is the expected number of gallery visitors each year? _____
6. Decide on an admission rate and then calculate how much money can be generated based on a 5 percent visitor occupancy each year. Does the admissions cover the expenses for the team's gallery?

Worksheet 3

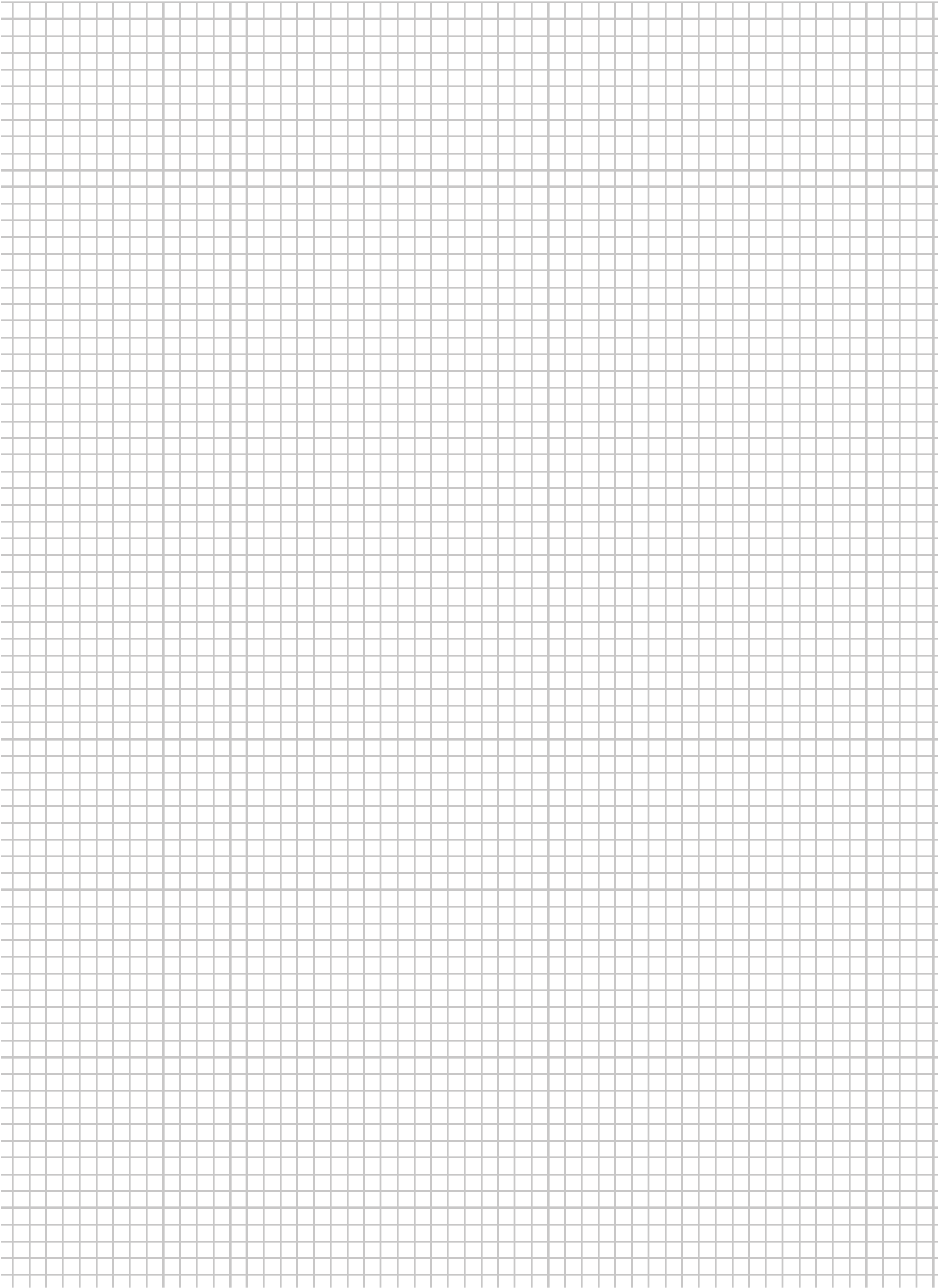
Aeronautics Gallery Guide Worksheet

When a visitor goes to a museum, they want to make the most of their time. A map of the museum or a gallery guide can assist them in planning their visit. A gallery guide provides detailed information about the artifacts in the gallery. In some cases, the guide shows the path the visitor needs to follow to gain a better understanding of the gallery's theme.

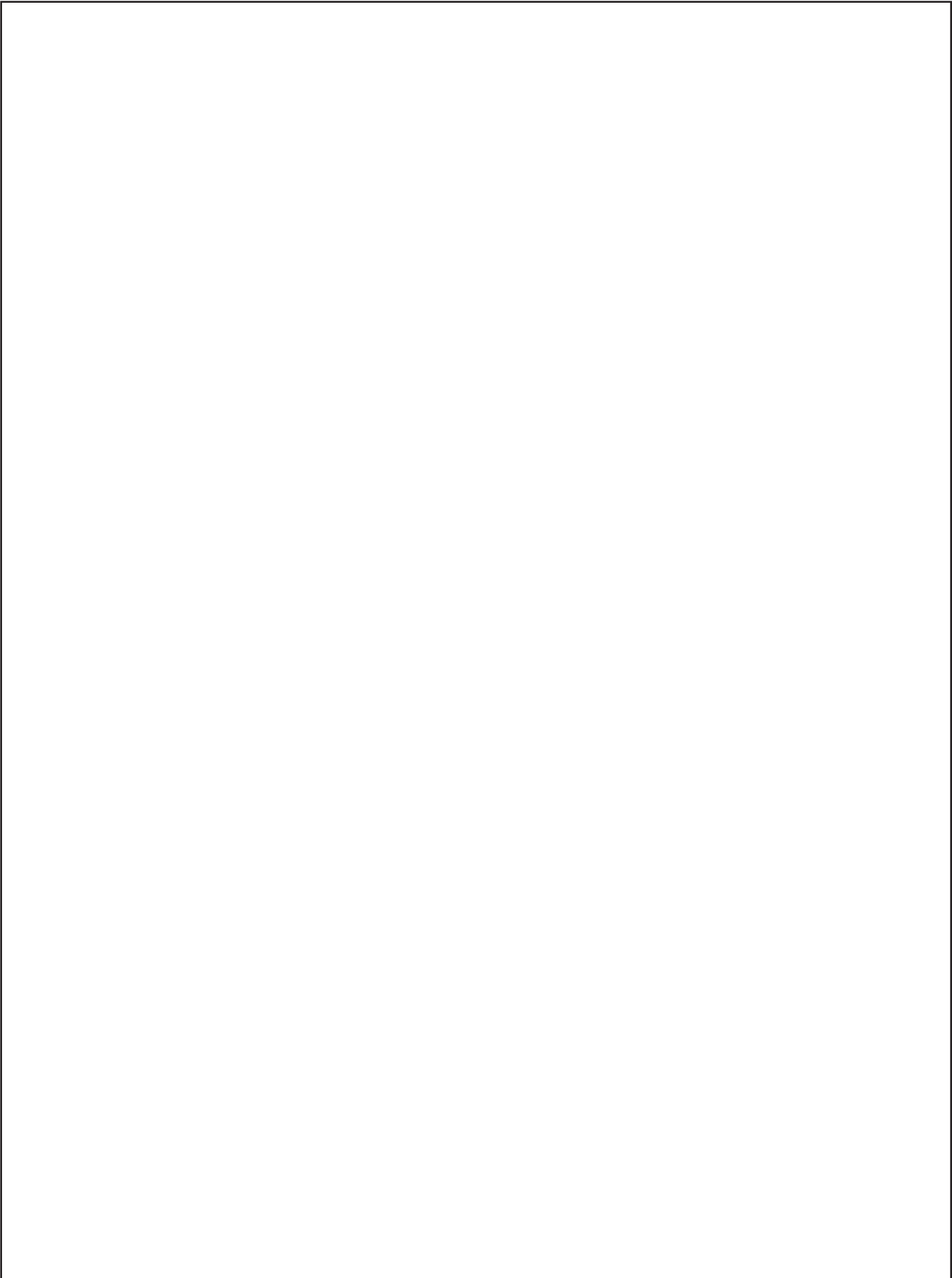
Your team is to design a guide for your team's gallery. On the front side, you need to include a detailed map of the gallery, drawn to scale, identifying the various artifacts and displays. On the reverse side of the guide, your team must highlight the story of the gallery including important artifacts or displays, and any special programs or activities associated with the gallery.

Specific tions for the guide:

The guide must be 8 inches by 10 inches. The guide should be black and white. The font is to be no smaller than 10 points. A scale drawing of the map is to be on the front side of the guide. The reverse side of the guide is to have the text in 3 columns. Use the Gallery Guide Design sheets to assist in the planning of the layout of your gallery guide.



Gallery Guide Design



Story	Displays	Programs



Images

Img. 1 National Air and Space Museum



(Photo courtesy of Eric Long - National Air and Space Museum)

Img. 2 National Museum of the United States Air Force

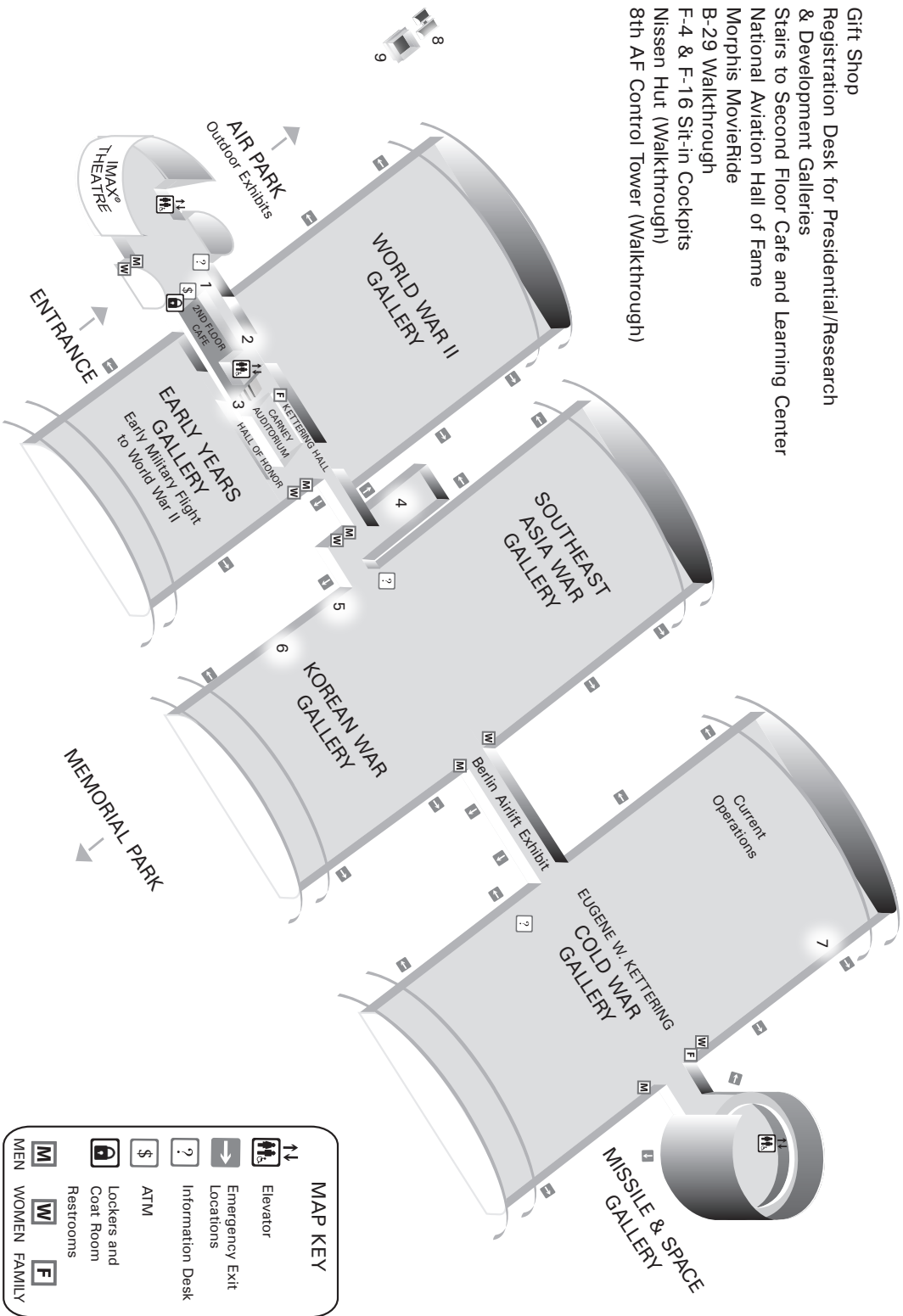


(Photo courtesy of the National Museum of the United States Air Force)

NATIONAL MUSEUM OF THE UNITED STATES AIR FORCE

Img. 3 Gallery Map of the National Museum of the United States Air Force

- 1 - Gift Shop
- 2 - Registration Desk for Presidential/Research & Development Galleries
- 3 - Stairs to Second Floor Cafe and Learning Center
- 4 - National Aviation Hall of Fame
- 5 - Morphis MovieRide
- 6 - B-29 Walkthrough
- 7 - F-4 & F-16 Sit-in Cockpits
- 8 - Nissen Hut (Walkthrough)
- 9 - 8th AF Control Tower (Walkthrough)



Visit us online at www.nationalmuseum.af.mil, experience a virtual tour at www.nmusafvirtualtour.com, become a fan on Facebook or follow us on Twitter @airmuseum

(courtesy of U S Air Force, National Museum of USAF <http://www.nationalmuseum.af.mil/shared/media/document/AFD-110620-020.pdf>)

Img. 4 Photo of How Things Fly Exhibit at the National Air and Space Museum

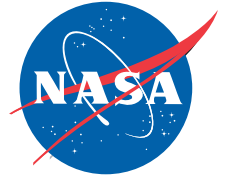


(Photo courtesy of Eric Long - National Air and Space Museum)

Aeronautics
Research
Mission
Directorate



history of flight



GRADES

K-2

Getting on an Airplane



parts of an airplane

Aeronautics
Research
Mission
Directorate





(Photo courtesy of NASA - www.nasaimages.org)

Getting on an Airplane

Lesson Overview

In this lesson comprised of three activities, students will learn about properties of objects and materials, and position of motion and objects through song, simple choreography, and classroom activities about the main parts of an airplane. Students will also learn the function of these parts as they relate to flight.

Objectives

Students will:

1. Identify the following parts of an airplane given a simple diagram: fuselage, cockpit, propeller (or jet engines), tail, horizontal stabilizer, elevator, vertical stabilizer, rudder, wings ailerons, and wing flap .
2. Explain in simple terms the function of each part they name.
3. Pitch, roll and yaw using their bodies.
4. Lift and drag using their bodies.

Materials:

In the Box

Song file "I'm Getting on an Airplane" can be downloaded from the MIB website:
<http://www.aeronautics.nasa.gov/mib.htm>

Provided by User

Chart paper, white board or chalkboard

GRADES

K-2

Time Requirements: 1 hour 30 minutes

parts of an airplane

Background

Airplanes are heavy and massive, which may make them seem impossible to be able to fly. Even though these metal machines, which are often also filled with many pounds of cargo, are extremely heavy, they have specialized parts and a design that allows them to lift off the ground and move through the air safely for many hours.

While there are many parts to an airplane, the basic parts include the fuselage or body, wings, tail, and jet or propeller-driven engines, depending on the size and model of the airplane. Each of these larger parts have even more specialized parts. The fuselage is made up of the cockpit, which includes the seating and instruments for the pilot and sometimes the co-pilot, and the body of the plane, which may carry passengers, cargo or both. The wings of the airplane include ailerons and wing flap, and depending on the size and model of the plane, may have the engines attached as well. Finally the tail of the airplane is made up of two main parts, the vertical stabilizer and the horizontal stabilizer. Each of these parts has a role to play in the flight of the airplane.

The wings of an airplane generate most of its lift, the force that keeps the airplane up in the air. To generate lift, air needs to flow over the aircraft or other lifting body (such as a kite or a glider). In the case of an airplane engine, the thrust generated by the engine can help produce or increase the airflow over the airplane, helping the airplane fly. Increased airflow adds more lift. The resistance to thrust is referred to as drag. Drag is a kind of aerodynamic friction. When studying lift, the weight of an airplane is lift's resistive force. Smaller, low-speed airplanes use propellers instead of jet engines. Lift, weight, drag, and thrust are together called the four forces of flight.

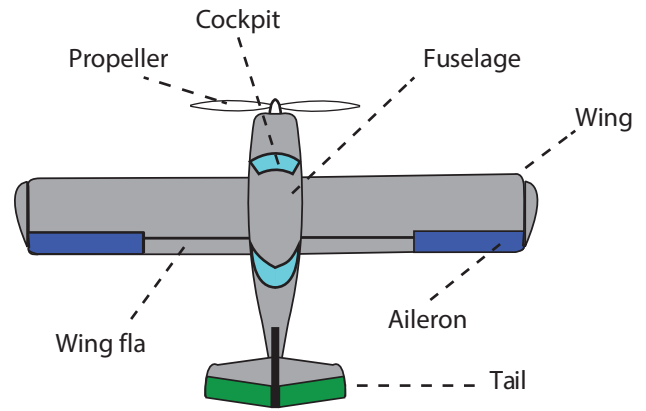


Fig. 1 Propeller powered airplane

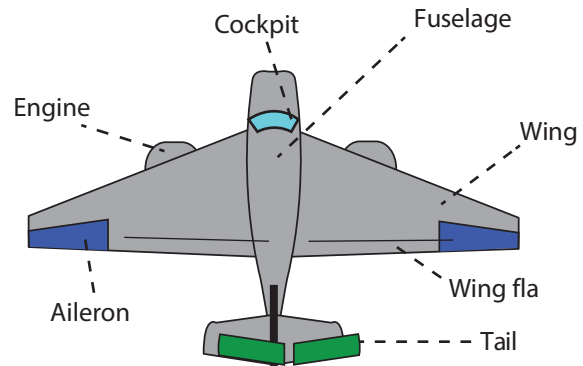


Fig. 2 Jet-engine powered airplane

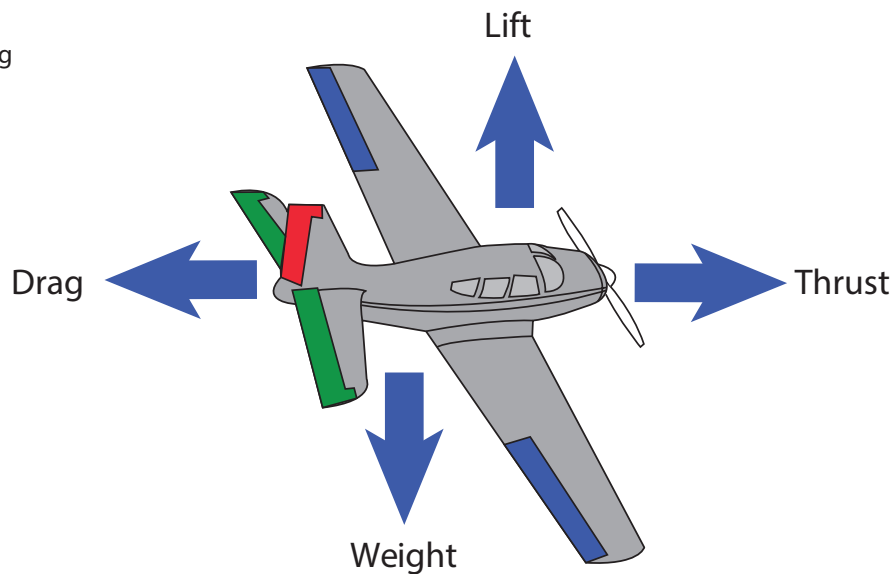


Fig. 3 The four forces of flight

Wings are used to control and maneuver the airplane. Smaller wings located on the tail of the airplane are called stabilizers. The fixed horizontal tailpiece is called the horizontal stabilizer, and the fixed vertical tailpiece is called the vertical stabilizer. The job of the stabilizers is to keep the airplane flying straight. The vertical stabilizer keeps the nose of the airplane from swinging from side to side, a motion called yaw. The horizontal stabilizer controls pitch, or the up-and-down motion of the nose of the airplane.

On the edges of each stabilizer are small moveable flaps attached by hinges. The hinged part on the vertical stabilizer is called the rudder. The rudder directs the nose of the airplane to the left or to the right (yaw). The hinged part of the horizontal stabilizer is called the elevator, which is used to direct the nose of the airplane up or down (pitch).

The wings of an airplane have similarly hinged parts: ailerons, which are used to roll the wings from side to side and the wing flap, which are located closest to the fuselage. During takeoff as well as landing, the wing flaps are directed downward in order to increase the amount of lift produced by the wings.

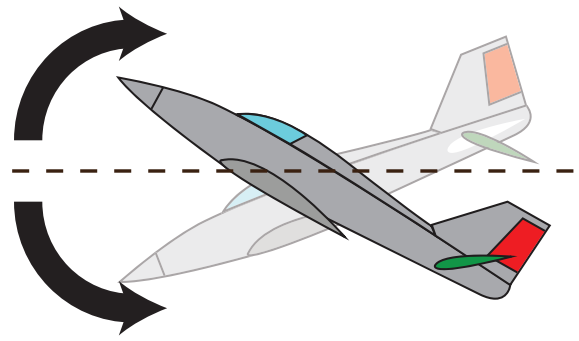


Fig. 4 Pitch

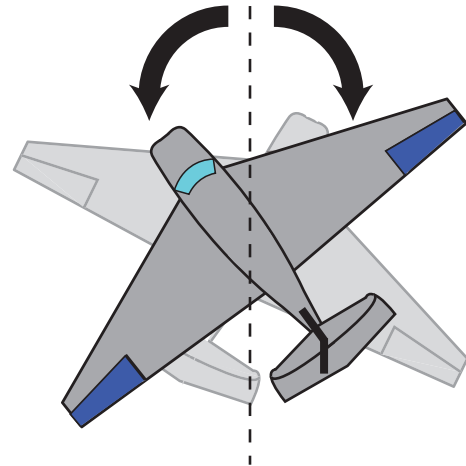


Fig. 5 Yaw

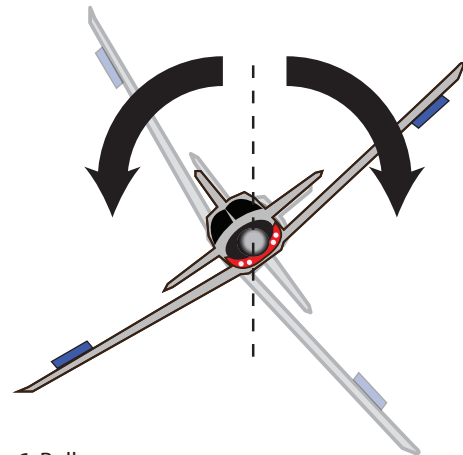


Fig. 6 Roll

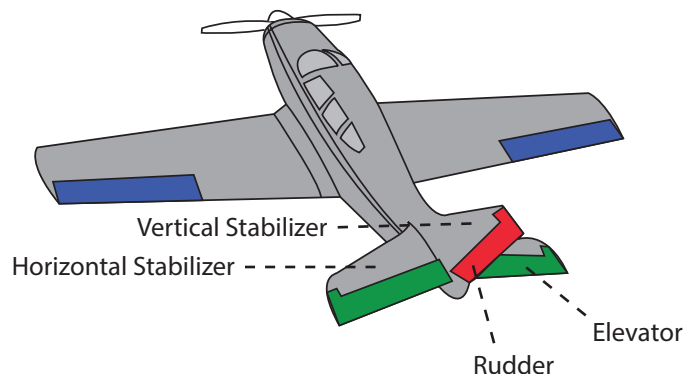


Fig. 7 Airplane tail parts

Activity 1

Learning the Parts of an Airplane

GRADES **K-2**

Time Requirement: 30 minutes

Materials:

In the Box

Song file "I'm Getting on an Airplane"
(downloaded from:
<http://www.aeronautics.nasa.gov/mib.htm>)

Provided by User

Chart paper, white board or chalkboard

Worksheets

Airplane diagram (Worksheet 1)
[2 copies per student]

"I'm Getting On An Airplane" Lyrics (Worksheet 2)

Reference Materials

None

Key Terms:

- Ailerons
- Cockpit
- Elevator
- Engine
- Fuselage
- Horizontal Stabilizer
- Propellers
- Rudder
- Tail
- Vertical Stabilizer
- Wing flap

Objective:

In this activity, students will learn about the properties of objects and materials, and the abilities of technical design as they utilize prior knowledge regarding airplanes. Also, they will record questions they have about airplanes and how airplanes fly and identify the main parts of an airplane using labeled and unlabeled drawings. Those parts include fuselage, wings, tail, vertical stabilizer, horizontal stabilizer, rudder, elevator, ailerons, wing flaps, engine, propellers, and cockpit.

Activity Overview:

Using a KWL (Know, Want to know, Learned) chart, students will first utilize prior knowledge they have about airplanes. Next, students will generate questions they have about airplanes. Before listening to the song at the center of the activity, students will label a blank diagram of an airplane as best they can. Students then will be introduced to the song, "I'm Getting on an Airplane", which they will eventually sing. Finally, after listening to and singing along with the song, students will label a blank diagram of an airplane again, this time with greater accuracy.

Activity:

1. Have a KWL chart drawn on chart paper or a board that looks like this:

K What do we already know about airplanes?	W What do we want to know about airplanes?	L What have we learned about airplanes?

2. **Begin by asking students:** *Who has ever been on an airplane?
What was it like?*
3. **Next, ask the students:** *What do we already know about airplanes?*
4. **Tell the students that you are going to put their answers about what they already know in the K (or KNOW) column of the KWL chart you have drawn.** Begin writing student responses about what they already know. Redirect answers that are inaccurate, combing out what you know to be true and rephrasing the students' responses in order to make them more accurate or realistic.
5. **Now, ask students:** *What don't you know about airplanes that you wish you knew?
What questions do you have about airplanes?*
6. **Tell the students that you are going to put their question ideas in the W column of the chart because those are things we WANT to know.**
7. **Tell the students that by the end of the lesson all of the things they learned will be recorded in the final column, the L or what we have LEARNED column**
8. **Now, show the students the blank diagram of an airplane (worksheet one) and ask them to name as many of the parts they can.** Teachers may write on the diagram directly or use labels that may be attached to the diagram.
9. **Next, tell the students that they are going to listen to a really fun song called "I'm Getting on an Airplane".** The song will teach them about two things, the major parts of an airplane and what these parts do. Tell them that today's focus will be on learning the parts of an airplane.
10. **Either pass out copies of the song lyrics or use a projector to display the lyrics.** Teachers may choose to read through the lyrics with the students before the song is played.
11. **Play the song 2 to 3 times, each time, encouraging the students to sing along any time they feel ready.** The song is 2:53 (2 minutes and 53 seconds long).
It might be fun to have the students pretend to play a trumpet during the parts of the song where it sounds like a horn is being played.
12. **After playing the song 2 to 3 times, show the students a blank airplane diagram again.** Have students identify parts and part locations again, either moving around the labels or labeling the diagram.

13. **As an alternative, older students may be asked to label a blank diagram of an airplane similar to the diagram the teacher is using as a post-lesson quiz.**
14. **End the lesson by asking the students what they learned today.** Record their answers in the L column of the KWL chart.

NATIONAL SCIENCE STANDARDS K-2

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

Activity 2

Learning the Function of the Parts of an Airplane

GRADES**K-2****Time Requirement:** 30 minutes**Materials:**In the Box

Song file "I'm Getting on an Airplane"
(downloaded from:
<http://www.aeronautics.nasa.gov/mib.htm>)

Provided by User

KWL chart
(from [Activity One](#))

Worksheets

Airplane diagram
(Worksheet 1)

"I'm Getting On An Airplane" Lyrics
(Worksheet 2)

Reference Materials

None

Key Terms:

Pilot

Pitch

Roll

Yaw

Objective:

In this activity, students will learn about the properties of physical objects and materials, and about the abilities of technological design when they review the names and locations of the airplane parts they have learned. They will also learn, in simple terms, the function of each part they learned previously as it relates to pitch, yaw and roll and demonstrate pitch, yaw, and roll using their bodies.

Activity Overview:

After reviewing the airplane parts they have learned, students will learn the function of each part using the lyrics of the song "I'm Getting on an Airplane". Additionally, students will learn the airplane movements of pitch, yaw and roll and demonstrate those movements using their bodies.

Activity:

1. Refer to the [Activity One](#) diagram to review the airplane parts and part locations students learned previously.
2. Tell students that they will expand their knowledge about airplanes today by learning what each of the parts of an airplane do, and how each part helps the airplane take flight
3. Distribute or display lyrics for "I'm Getting on an Airplane". Listen to the song, again encouraging students to sing along.
4. Before listening to the song again, have the children pretend to be airplanes. Ask them to move around the room as if they were airplanes. Carefully observe their movements for examples of pitch, yaw and roll.
5. When a good example of pitch, yaw or roll is observed, ask the students to freeze. Choose the student whose movements demonstrate pitch, yaw, or roll. Ask that student to demonstrate his or her movement again for the rest of the class while the teacher explains what that movement is called.

6. **Before proceeding, make sure students understand who flies the airplane.** Ask them what name that person is given (*pilot*).
7. **Go back to the movements just introduced.** Explain how the pilot controls each movement and what part of the airplane is involved. The movement chart below will help you identify and explain pitch, yaw and roll and may be posted for the students to see as well.

Technical Term	Airplane Movement	Use of Airplane Part
Pitch	The nose of the airplane slants up or down.	Pilots use the elevators on the vertical stabilizers to control pitch.
Yaw	The nose of the airplane moves side to side on the horizontal axis.	Pilots use the rudder on the horizontal stabilizer to control yaw.
Roll	The entire airplane tilts to the left or the right.	Pilots use the ailerons to control roll.

8. **Display the diagrams showing pitch, yaw and roll.**
9. **Guide the students to use their bodies to create pitch, yaw and roll.** Begin by dividing the students into pairs. Then begin using the movements described below to model the flight of an airplane (Fig. 8, 9, 10).



Fig. 8 Yaw



Fig. 9 Pitch



Fig. 10 Roll

Airplane Movement	Body Movement (from airplane pose)
Pitch	<p>Have each student stand with their arms outstretched, pretending they are wings.</p> <p>Next, have them bend forwards and backwards at the waist while keeping their head upright. This demonstrates the effect the elevator has on the airplane.</p>
Yaw	<p>Have one student in each pair (Student A) stand with his or her arms outstretched, representing wings. Have the other student in the pair (Student B) place his or her hands on Student A's waist. Now, have Student B twist student A around the waist.</p> <p>This demonstrates the effect the rudder has on the airplane.</p>
Roll	<p>Place both students' chairs together so that Student A can lay face down on them, again with his or her arms outstretched. Have Student B hold the arms of Student A, rolling them from side to side on the chair.</p> <p>This demonstrates the effect ailerons have on an airplane.</p>

10. **Listen to the song again.** This time students will demonstrate pitch, yaw and roll as the singer brings up each movement in the song. Until then they may use their bodies to make other motions. See the suggestions below.
 - a. Song lyrics "I'm getting on an airplane" – students march
 - b. Song lyrics "How does the plane fly?" – students tap finger to chin with questioning look
 - c. Song lyrics "There are many parts to an airplane" – students use right index finger to point in front of them, bouncing finger in the air from right to left
 - d. Song lyrics "To keep it moving through the sky" – arms in wing positions, tilting up and down
 - e. Song lyrics "It carries people and cargo" – put one hand out in front of body, slightly cupped, then with the other hand do the same
 - f. Song lyrics "The pilot sits in the cockpit..." – pretend to grip steering wheel at the 10 and 2 positions and steer

11. **Ask students:** *When do you think a pilot has to rely on or use pitch, yaw and roll?*
Answers might include the following:
 - a. *Pitch is used to ascend or descend.*
 - b. *Yaw is used to change course of the nose of the airplane.*
 - c. *Roll is used to change course (heading) of the airplane.*

12. **Finally, return to the KWL chart from Activity One.** Ask the students what they learned today. Record their responses in the L column of the chart.

NATIONAL SCIENCE STANDARDS K-2

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

Activity 3

Learning About Thrust, Drag and Lift

GRADES**K-2****Time Requirement:** 30 minutes**Materials:**In the Box

Song file "I'm Getting on an Airplane"
(downloaded from:
<http://www.aeronautics.nasa.gov/mib.htm>)

Provided by User

KWL chart
(from [Activity One](#))

Worksheets

Labeled airplane diagram
(Worksheet 1)

I'm Getting On An Airplane Lyrics
(Worksheet 2)

Reference Materials

None

Key Terms:

Cargo

Drag

Lift

Thrust

Objective:

In this activity, students will learn about the position and motion of objects, and about the abilities of technical design by reviewing what they have learned so far from [Activities One and Two](#). They will learn the basics of the four forces of flight: thrust, drag, weight, and lift. They will also learn which parts of the airplane are involved in thrust, drag and lift and demonstrate thrust, drag and lift using their bodies.

Activity Overview:

After reviewing the concepts they have learned about airplanes so far, students will learn the four forces of flight: thrust, drag, weight and lift. Students will learn that the jet engines or propellers on airplanes provide thrust, wings provide lift, and drag and weight are forces that lift and thrust must overcome.

Activity:

1. **Begin by reviewing all of the concepts learned by the students thus far including parts of an airplane and how those parts work.**
2. **Play the song again while students sing along, moving their bodies along with the song mimicking the movements they have learned so far.**
3. **Ask:** *What materials are used to make an airplane?*
(Responses will vary but may include metal)
4. **Ask:** *What do you think makes airplanes heavy?*
Why?
(Responses will vary but may include: They're made of metal and carry people and other heavy things.)
5. **Ask:** *So if airplanes are so heavy how do they get off of the ground?*
(Responses will vary but may include: They fly.)
6. **Ask:** *How do airplanes fly?*
(Responses will vary.)

7. **Say:** *Let's look at our diagram of an airplane. Which parts do you think are used to get the airplane to fly in the air?*
(Responses will vary but may include wings and engine.)
8. **Tell students that the engine or propellers provide the power to move the airplane forward, but the wings are needed to lift the airplane into the air.**
9. **Say:** *The force the jet engines or propellers provide is called thrust. Thrust from the engines cause air to flow over the wings and over the other parts of the airplane. Air flowing over the wings causes the plane to get off the ground. This is called lift.*
10. **Ask:** *What forces do you think want to keep the airplane from moving forward and lifting into the air?*
(Answers will vary but may include the size or weight of the airplane and the wind.)
11. **Remind the students that an airplane is heavy because it carries people and cargo (the items people want or need).** Tell students that it is the weight itself that acts as a force to keep the airplane on the ground. And, when the airplane finally does overcome the weight and lifts off of the ground and thrust pushes the plane through the air, the air starts pushing back on the airplane. This is a force called drag or air resistance.
12. **In order to give the students a better understanding of drag, explain how a parachute uses drag to keep the jumper from falling too fast.**
13. **Explain the relationship between thrust and drag.**
Greater thrust increases the capacity to overcome drag.
14. **Show students a diagram of the four forces of flight (Fig. 3).**
15. **Explain how the wing flaps (the final airplane part to discuss) are used to control drag.** When the flaps are up (meaning in a neutral position – even with the wing surface), drag is decreased. When the flaps are down, drag is increased.
16. **Ask:** *When might a pilot want to increase drag?*
(Responses will vary but may include slowing the airplane down or braking.)
17. **Ask:** *When might a pilot want to decrease drag?*
(Responses will vary but may include when the pilot wants to speed up.)

18. **Remind the students about their “airplane pose” from Activity 2.** Tell the students that you are going to play the song again. This time when they hear the singer mention thrust they should move forward in their airplane pose. When they hear the singer mention lift, they should maintain their airplane pose while bending at the knees and squatting down when they hear “down” and standing on their toes when they hear “up”. Finally, when they hear “drag,” they should move forward, faster first then slow, depending on the song lyrics.
19. **Practice the movements with the students before playing the song.** Then play the song and have the students move around adding thrust, lift and drag to the set of body movements they have already learned.
20. **Play the song one more time and conclude the activity by adding to the L column of the KWL chart.**
21. **Review everything the students have learned, pointing to the various diagrams and charts to illustrate each concept.**
22. **Conclude the lesson by giving students a picture of an airplane, which they will label.** Under the picture students will write three sentences about what they learned about airplane parts and flight.

NATIONAL SCIENCE STANDARDS K-2

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology



Reference Materials

Glossary

Aileron:

Flap on an airplane wing responsible for roll (tilt)

Cargo:

Goods carried as freight on an airplane

Cockpit:

The part on an airplane that houses the pilot

Drag:

One of the forces of flight; resistance to motion

Elevator:

Flap on an airplane tail that controls climb and descent

Engine:

A source of power or thrust for an airplane

Fuselage:

The airplane body

Horizontal Stabilizer:

Part of the tail; prevents the up-and-down motion of the airplane nose, also called pitch

Lift:

The force that opposed the weight of an airplane, causes the airplane to lift into the air

Pilot:

The person flying the airplane

Pitch:

The up and down movement of the airplane nose; controlled by elevator on the tail

Propeller:

Revolving curved wood or metal object on an airplane that provides source of power or thrust

Roll:

The tilt of the airplane to the right or left

Rudder:

The small moving section at the rear of the stabilizer that is attached to the fixed sections by hinges; controls the yawing motion of the airplane

Tail:

Located at the rear of the airplane; provides stability; it usually has a fixed horizontal piece, called the horizontal stabilizer, and a fixed vertical piece, called the vertical stabilizer

Thrust:

A force generated by the airplane's engine, which moves an airplane forward through the air. Thrust is used to overcome the drag of an airplane

Vertical Stabilizer:

The vertical wing-like part of the tail that keeps the nose of the plane from swinging from side to side, which is called yaw

Wing flaps:

Hinged flaps attached to the back edge of a wing located nearest the fuselage; flaps are deployed downward on takeoff and landing to increase the amount of lift produced by the wing

Yaw:

Side to side movement of an airplane

Fig. 1 Propeller powered airplane

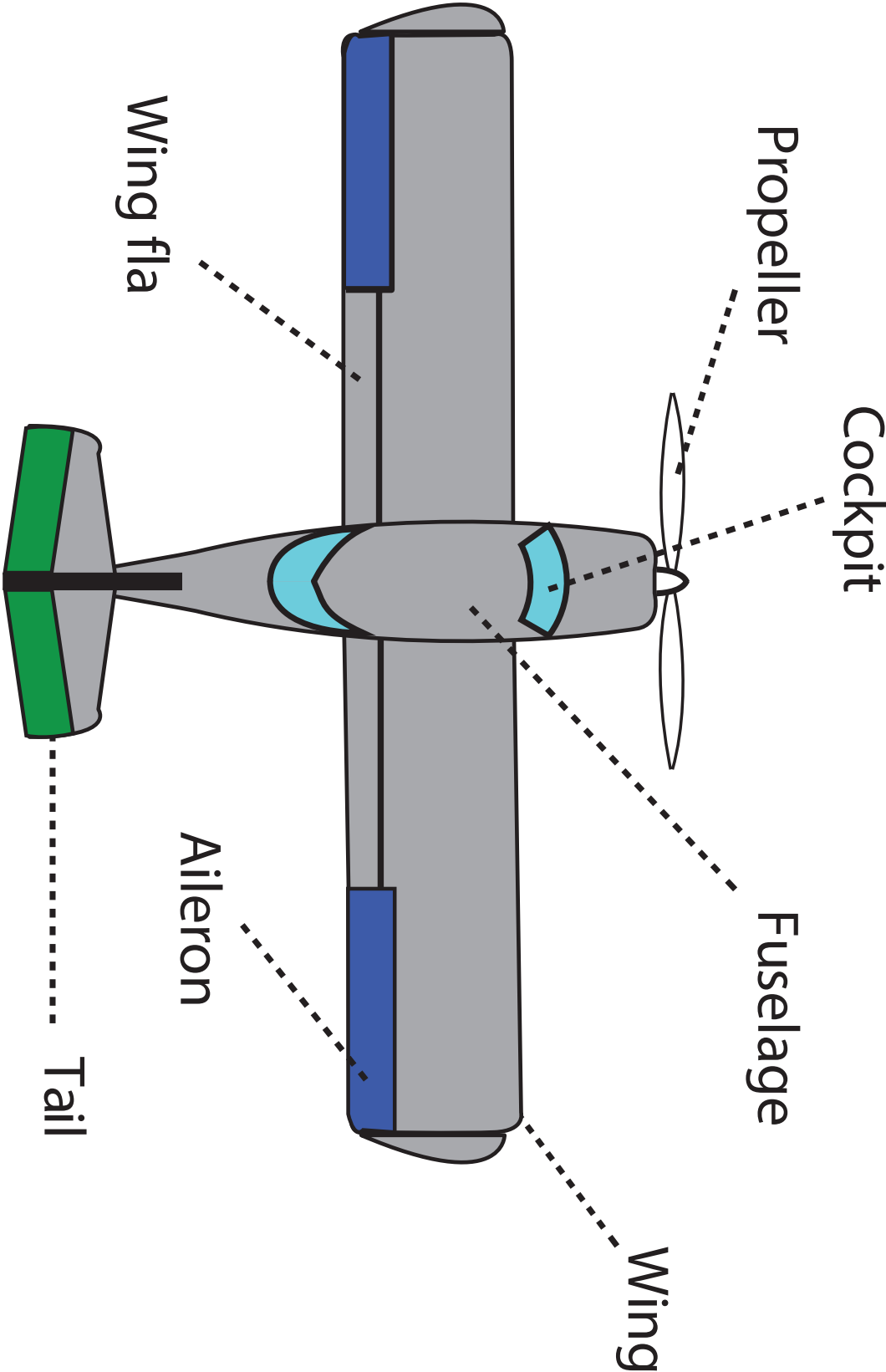


Fig. 2 Jet-engine powered airplane

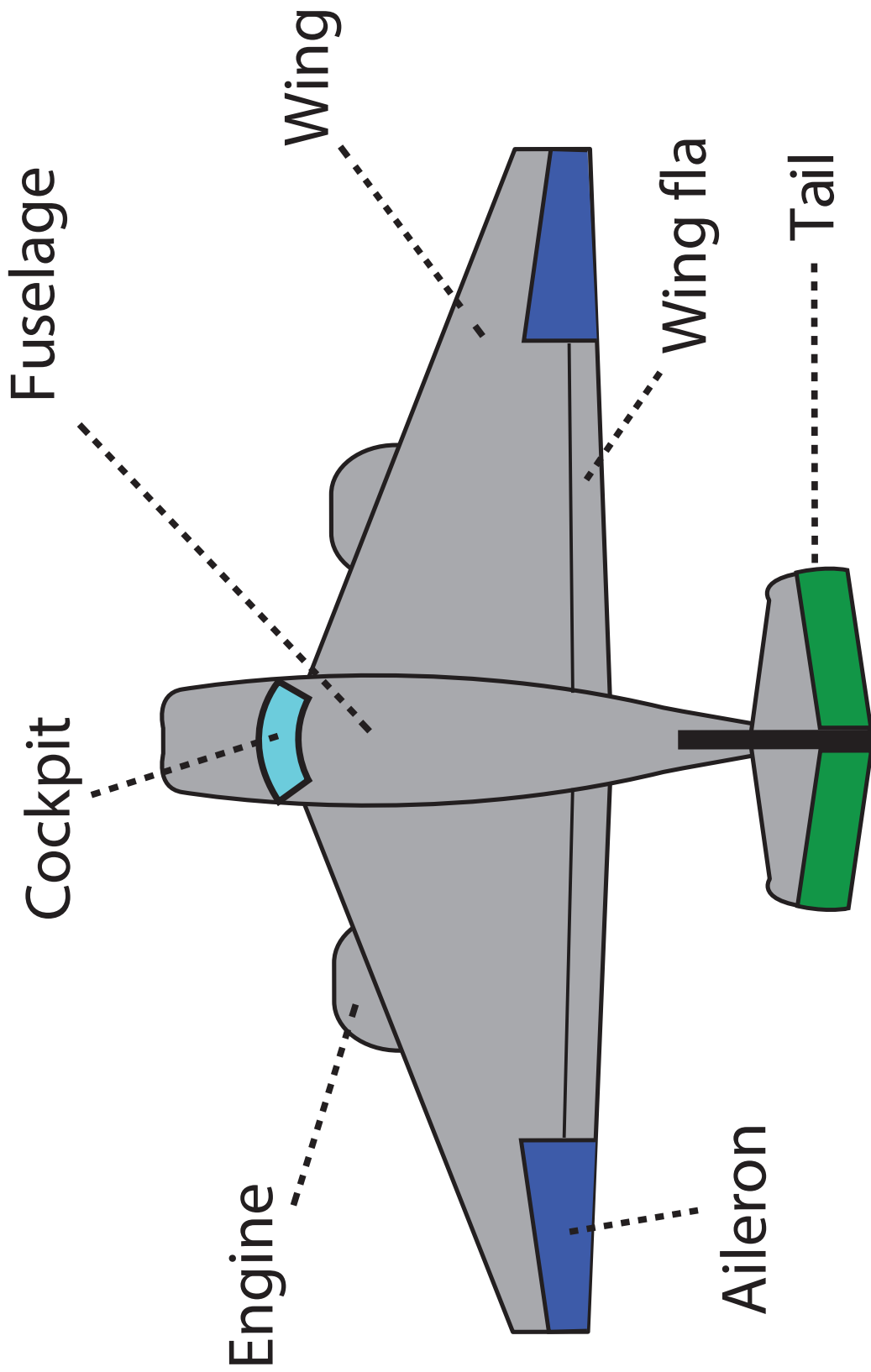


Fig. 3 The four forces of flight

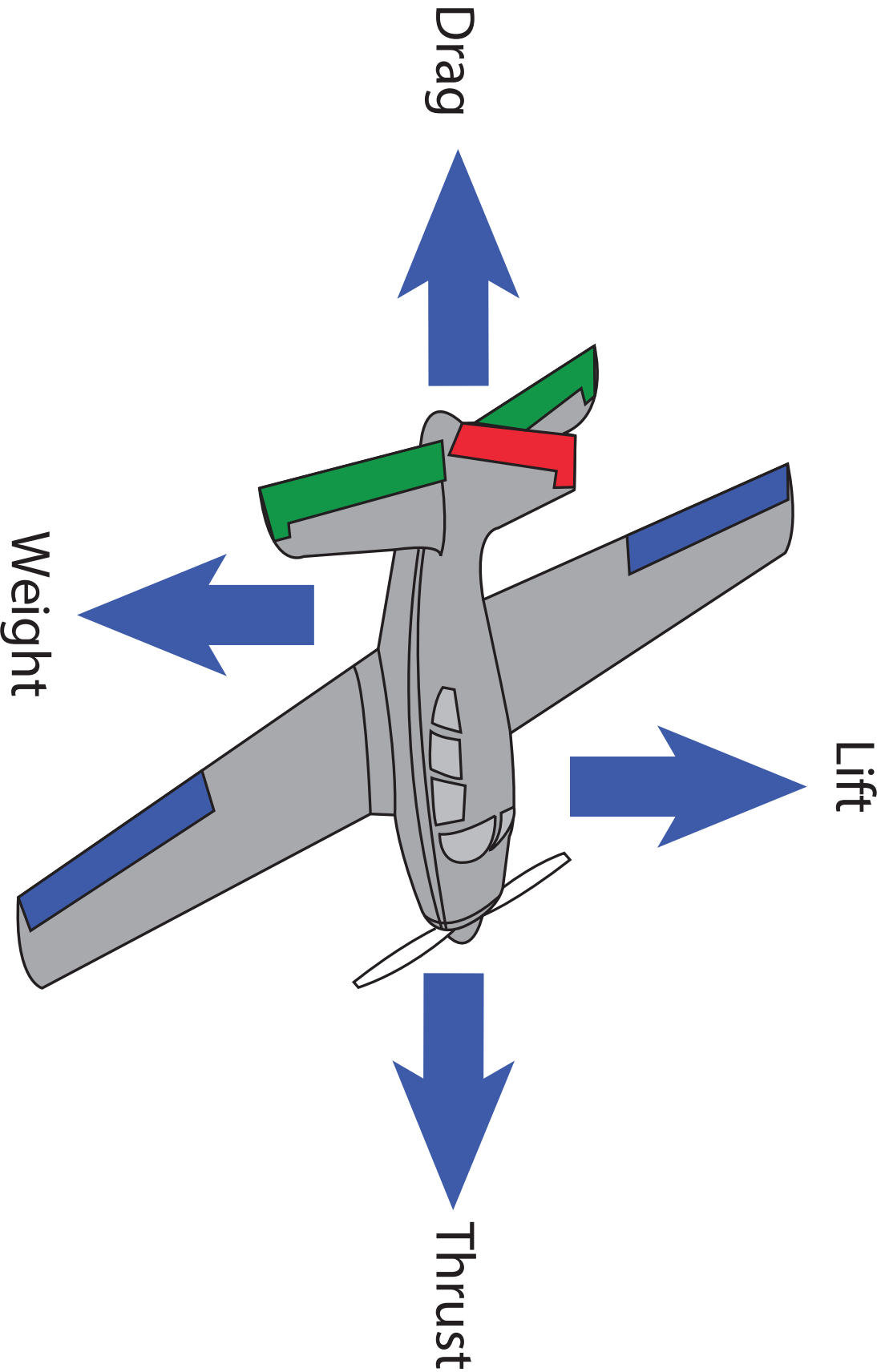


Fig. 4 Pitch

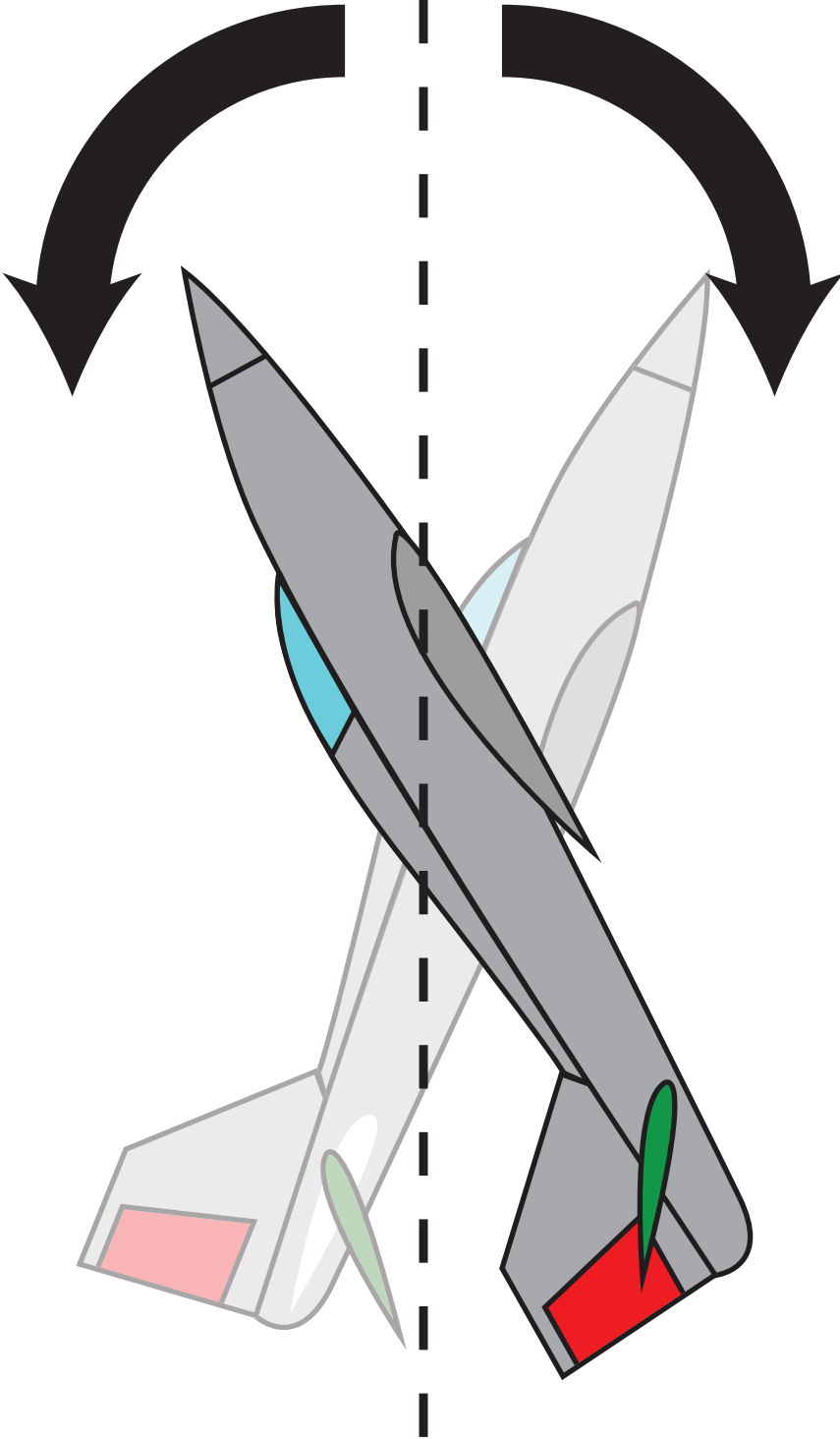


Fig. 5 Yaw

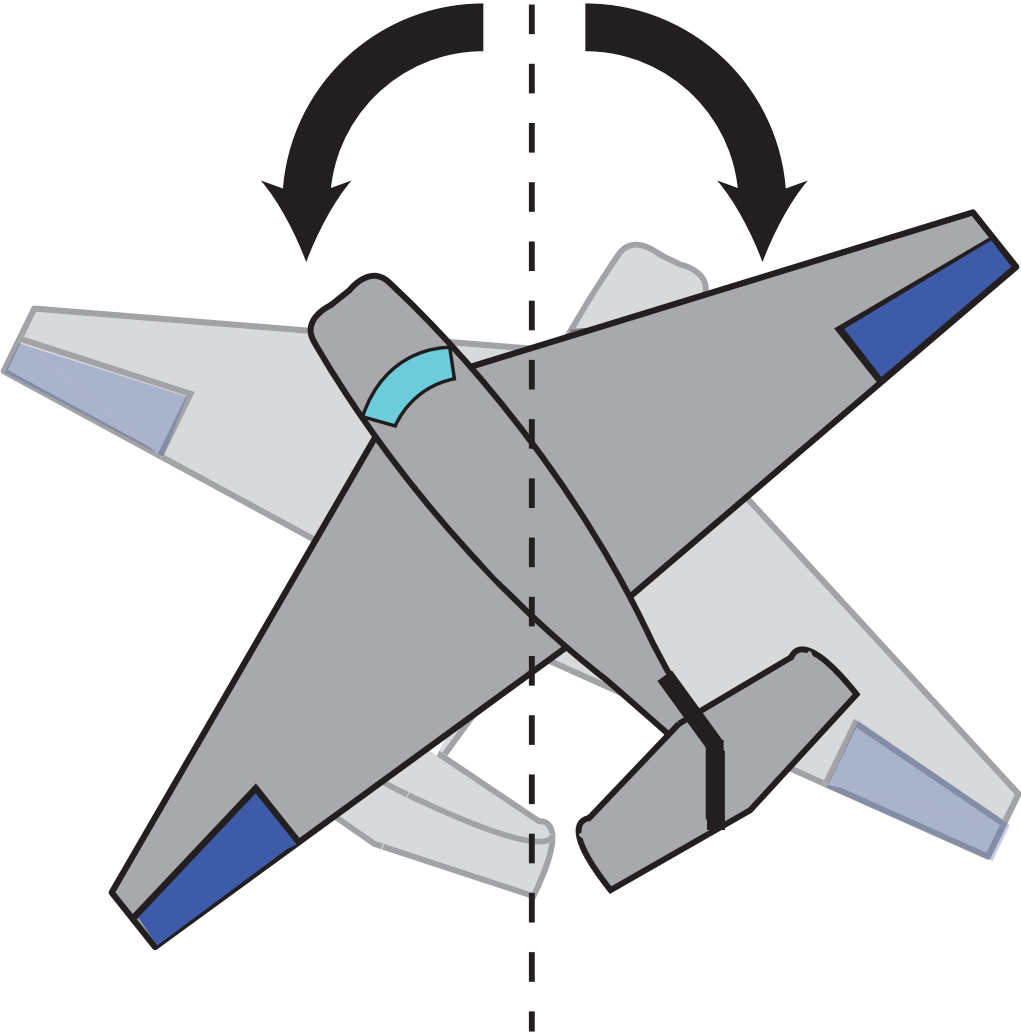


Fig. 6 Roll

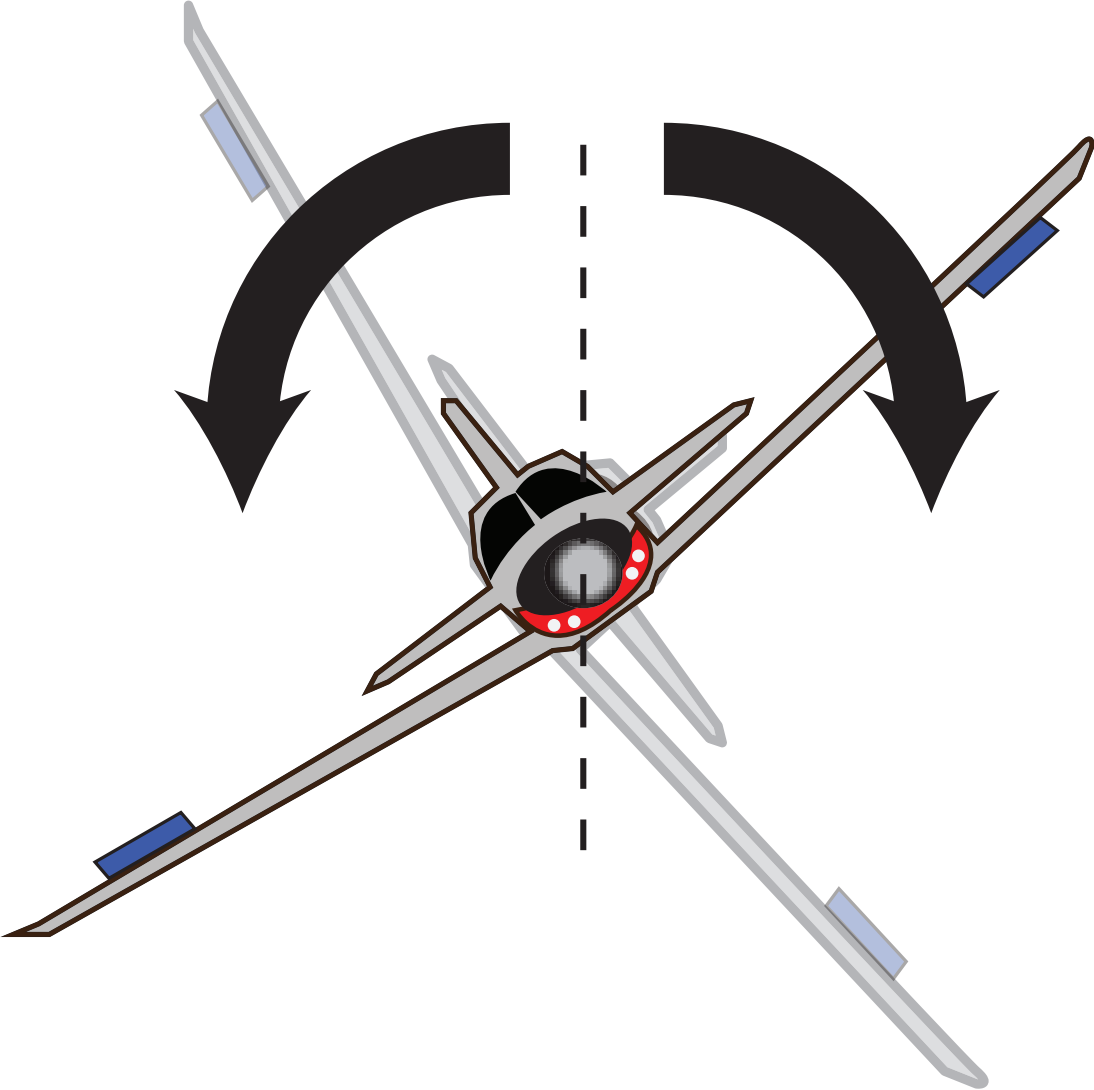


Fig. 7 Airplane tail parts

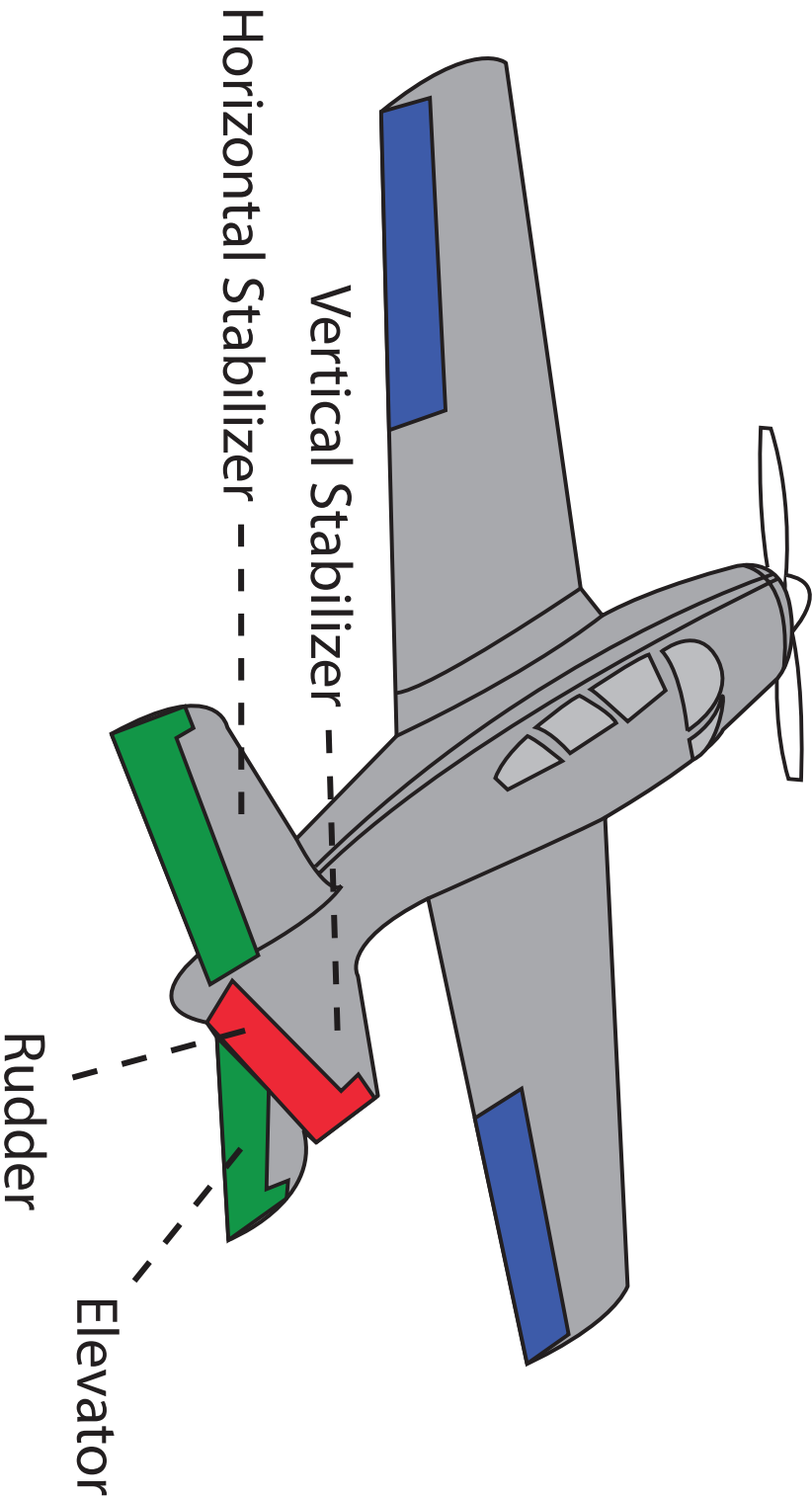


Fig. 8 Yaw



Fig. 9 Pitch

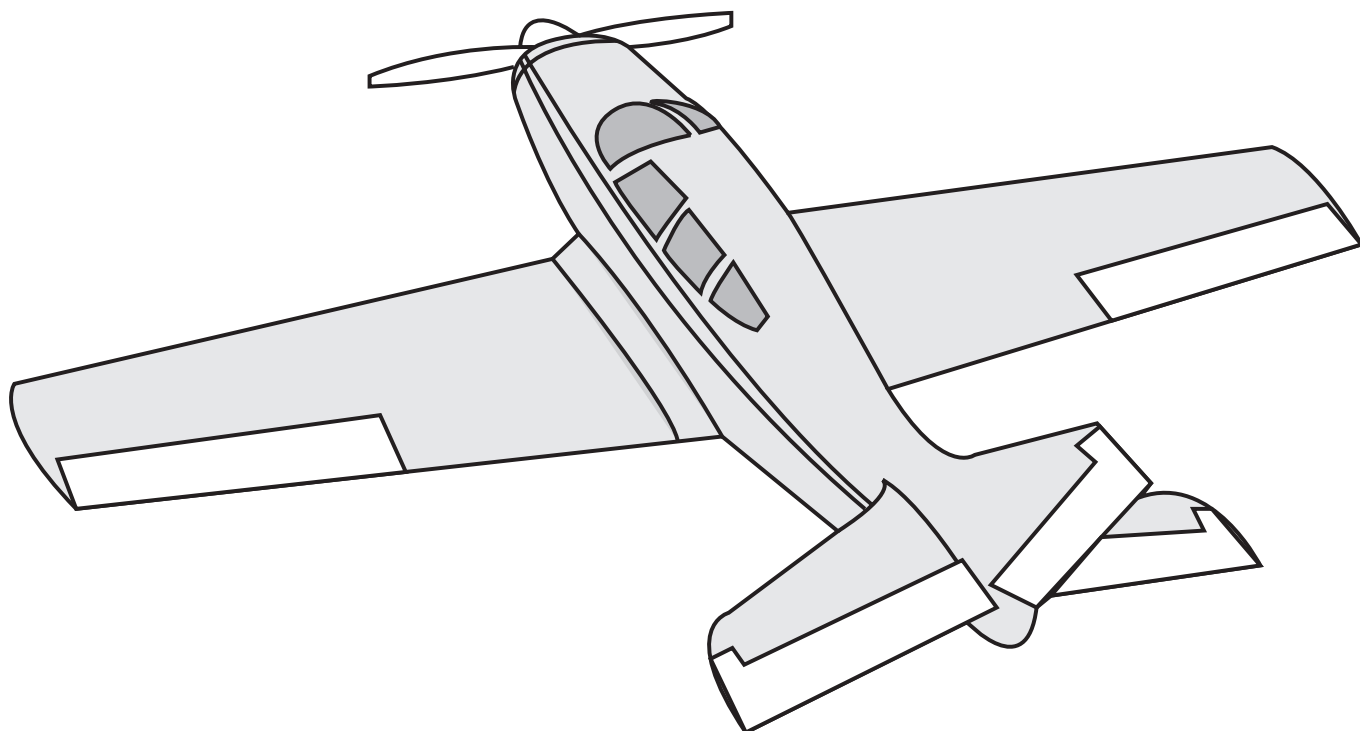


Fig. 10 Roll





Student Worksheets



I'm gettin' on an airplane, but how does a plane fly
There are many parts in an airplane, to keep it movin' through the sky
I'm gettin' on an airplane, but how does a plane fly
There are many parts in an airplane, to keep it movin' through the sky

The body is the fuselage, it carries people and cargo
The pilot sits in the cockpit, for command and control
Jet engines or propellers provide the needed thrust
In order to lift the plane in the air, wings are a must

I'm gettin' on an airplane, but how does a plane fly
There are many parts in an airplane, to keep it movin' through the sky

In the tail of the plane, are some smaller wings
They keep the craft flying straight, a very important thing
The horizontal stabilizer controls the pitch
The vertical stabilizer controls the yaw – but that's not all...

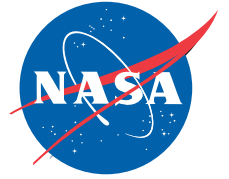
There are many hinged parts that bring about change
Let's describe them, and see how they affect the plane
The flaps change lift – up and down
And they change drag – fast and slow
The ailerons cause tilt – that's called roll
Left up – roll left, right up – roll right
The rudder changes yaw – side to side
The elevators change the pitch

I'm gettin' on an airplane, but how does a plane fly
There are many parts in an airplane, to keep it movin' through the sky
I'm gettin' on an airplane, but how does a plane fly
There are many parts in an airplane, to keep it movin' through the sky
I'm gettin' on an airplane.

Aeronautics
Research
Mission
Directorate



parts of an airplane



GRADES

K-4

Parts of an Airplane



parts of an airplane

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Parts of an Airplane

Lesson Overview

In this lesson, students will learn about characteristics of organisms, properties of objects and materials, abilities to distinguish between natural objects and objects made by humans, and abilities of technological design as they discover how the individual components of aircraft come together to make a fully functioning vehicle. To help in identifying the parts, students will first study the parts of a bird's body, then correlate them to those on an airplane.

Objectives

Students will:

1. Compare pictures of birds and airplanes and learn to identify the individual components of both.
2. Reinforce the concept that it takes many individual parts to build an object.
3. Realize that it takes many unique, individual parts to build an object.

Materials:

In the Box

Crepe rubber puzzles
Peg-A-Plane kit

Provided by User

Tape or thumbtacks

Worksheets

Peg-A-Plane 1 (Worksheet 1)
Peg-A-Plane 2 (Worksheet 2)
Peg-A-Plane 3 (Worksheet 3)

GRADES

K-4

Time Requirements: 1 hour 35 minutes

parts of an airplane

Background

Any vehicle, whether it's a car, truck, boat, airplane, helicopter or rocket, is made up of many individual component parts. Some components are common amongst a variety of vehicles, while others are exclusive to specific types. Occasionally, a component is modified and given a different name, although its basic principle of operation remains intact. This lesson is designed to look at those individual components and allow students to not only identify them, but to understand how they work together to create a functioning aircraft.

Figure 1 shows a typical airplane with its major components listed. Many external airplane components are constructed of metal alloys, although composites made of materials such as carbon fiber and a variety of fiber glass resins are becoming more popular as technology improves.

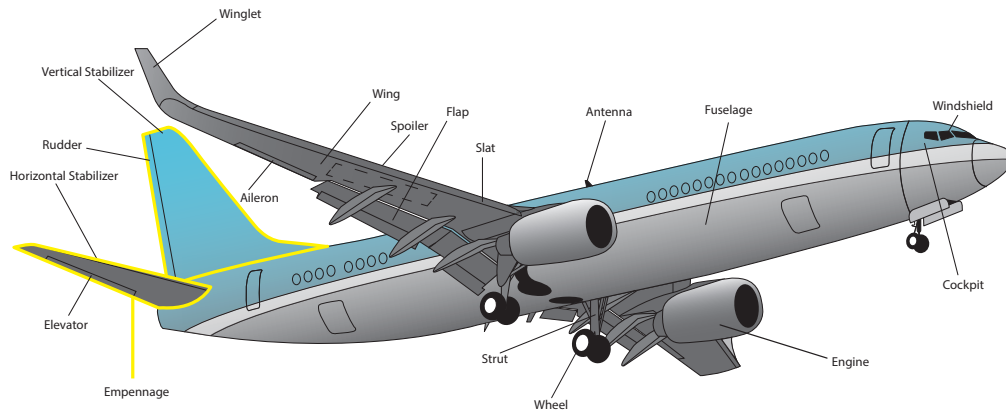


Fig. 1 Airplane Diagram

Aileron

The ailerons are located at the rear of the wing, typically one on each side. They work opposite to each other, meaning that when one is raised, the other is lowered. Their job is to increase the lift on one wing while reducing the lift on the other. By doing this, they roll the aircraft sideways, causing the aircraft to turn. This is the primary method of steering a fixed-wing aircraft.

Antenna

There are numerous radio antennas located around an aircraft, their size and position corresponding to the type of work each antenna must perform and the frequencies being transmitted or received. The GPS antenna, for example, is always mounted to the top of an airplane. This is because the GPS satellites are in space, and therefore always above the aircraft. As a general rule, longer antennas are used for radio communication and navigation (VHF frequencies), while shorter antennas are reserved for higher frequency data such as the GPS signals and the transponder, which provides air traffic control with information about the aircraft's position and altitude.

Cockpit

The cockpit, sometimes referred to as the Flight Deck, is where the pilots sit. It contains the flight controls, which move the airplane, as well as all the buttons and switches used to operate the various systems.

Elevator

As the name implies, the elevator helps "elevate" the aircraft. It is located on the tail of the aircraft and directs the nose of the aircraft either upwards or downwards (pitch) in order to make the airplane climb and descend.

Empennage

This name stems from the French word “empenner,” meaning “to feather an arrow”. The empennage is the name given to the entire tail section of the aircraft, including both the horizontal and vertical stabilizers, the rudder and the elevator. As a combined unit, it works identically to the feather on the arrow, helping guide the aircraft to its destination.

Engine

An airplane has at least one, or as many as eight engines, which provide the thrust needed to fly. There are many different makes and models of aircraft today but all perform the same basic function of taking the air that’s in front of the aircraft, accelerating it and pushing it out behind the aircraft. Jet powered aircraft perform this function by compressing the air using turbines, while propeller-powered aircraft use a propeller mounted to the engine. In general, the propeller works like a big screw, pulling the aircraft forward while pushing the air behind it (Fig. 2).

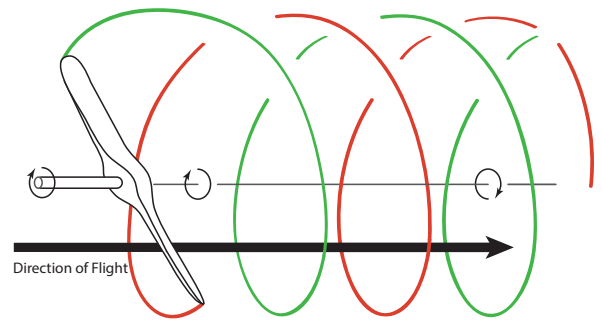


Fig. 2 Propeller path

Flap

Flaps are a “high lift / high drag” device. Not only do they improve the lifting ability of the wing at slower speeds by changing the camber, or curvature of the wing, but when extended fully they also create more drag. This means an aircraft can descend (or lose altitude) faster, without gaining airspeed in the process. Flaps come in 4 main varieties: plain, split, slotted and fowler (Fig. 3).

- The plain flap is the simplest of the four varieties. It works by lowering the aft portion of the wing, increasing its camber, which in turn causes the wing to produce more lift. Plain flaps are typically used only when the aircraft is required to be as simple to construct as possible.
- The split flap works by lowering just the bottom section of the wing. Rather than providing additional lift, the split flap is primarily used to allow an aircraft to descend quickly without gaining forward momentum, or airspeed. As such, it is typically found on aircraft that have to operate in smaller areas, such as those used for crop dusting, or in the Alaskan bush. It was invented by Orville Wright in 1920 and became popular in the 1930’s but due to the large quantity of drag it produces, has been rarely used since then.
- The slotted and fowler flaps are both designed to physically increase the overall surface area of the wing, literally making the wing bigger. In addition, the slotted flap, as the name implies, creates one or more slots within the wing. These slots provide additional energy to the air on the upper surface of the wing, ensuring that as the airspeed decreases, the air still has sufficient momentum to reach the rear of the wing. In technical terms, it is referred to as preventing the separation of the boundary layer.

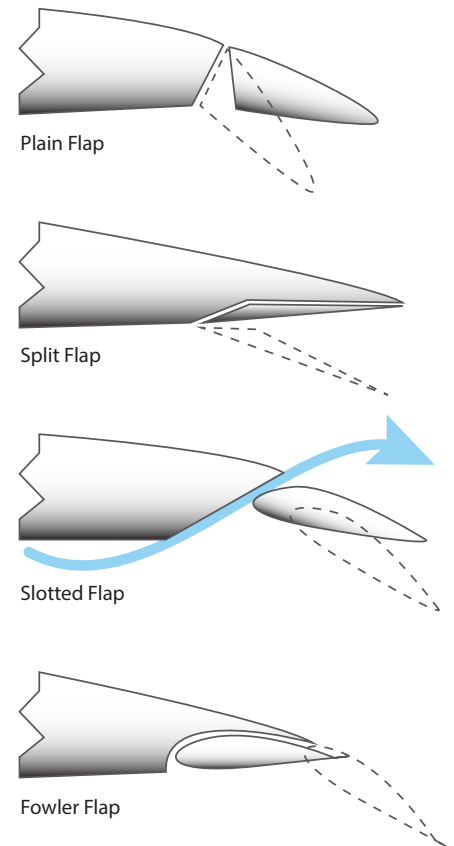


Fig. 3 Flaps

Fuselage

The fuselage, from the French word “fuselé” meaning “spindle shaped”, is the portion of the airplane used to literally join, or fuse, the other parts together. It is commonly thought of as the body of the aircraft and holds the passengers and cargo safely inside.

Horizontal Stabilizer

The horizontal stabilizer is quite simply an upside-down wing, designed to provide a downward force (push) on the tail. Airplanes are traditionally nose-heavy and this downward force is required to compensate for that, keeping the nose level with the rest of the aircraft. Some aircraft can control the angle of the stabilizer and therefore the level of downward force while in flight, while others are fixed in place.

Rudder

The rudder is attached to the vertical stabilizer, located on the tail of the aircraft. It works identically to a rudder on a boat, helping to steer the nose of the aircraft left and right; this motion is referred to as yaw. Unlike the boat however, it is not the primary method of steering. Its main purpose is to counteract certain types of drag, or friction, ensuring that the aircraft’s tail follows the nose, rather than sliding out to the side.

Slat

A slat is a “high lift” device typically found on jet-powered aircraft. Slat is similar to the flaps except they are mounted on the leading edge of the wing. They also assist in changing the camber, or curvature of the wing, to improve lifting ability at slower speeds.

Spoiler

The spoiler’s function is to disrupt, or spoil, the flow of air across the upper surface of the wing. They are usually found on larger aircraft, which can have two types installed. The in-flight spoilers are small and designed to reduce the lifting capability of the wing just enough to allow the aircraft to descend quicker without gaining airspeed. Although the flaps can also perform this function, the spoiler is intended to be used temporarily, while the flaps are typically used for longer durations such as during the approach and landing. The ground spoilers (img. 1) typically deploy automatically on landing and are much larger than their in-flight cousins. They are used to completely destroy the lifting ability of the wing upon landing, ensuring that the entire weight of the airplane rests firmly on the wheels, making the brakes more effective and shortening the length of runway needed to stop the aircraft.



Img. 1 Ground spoilers on an Airbus 320 aircraft

Struts

The struts are part of the undercarriage, more commonly known as the landing gear. There are two main types - straight leg (Img. 2) and trailing link (Img. 3) - but their function is the same: to absorb the impact of the landing as the aircraft touches the ground. Each strut contains a shock absorber (a collection of springs), hydraulic oil and gasses which work together to reduce the impact felt by the passengers.



(Photo courtesy of Lost Tribe Media, Inc.)

Img. 3 Trailing link landing gear

On some aircraft, such as those used by student pilots, the struts are made entirely out of spring steel. This type of steel is treated in such a way that it can absorb the shock of landings repeatedly, bending automatically back into shape (Img. 4).

Vertical Stabilizer

The vertical stabilizer is designed to stabilize the left-right motion of the aircraft. While most aircraft use a single stabilizer, some models, such as the Lockheed C-69 Constellation (Img. 5), use multiple, smaller stabilizers.



(Photo courtesy of www.NASAIMages.org)

Img. 6 A modified Boeing 747 carrying the Space Shuttle Enterprise



(Photo courtesy of NASA)

Img. 2 The straight leg landing gear of the Space Shuttle Atlantis



(Photo courtesy of NASA)

Img. 4 A NASA modified Cessna 190



(Photo courtesy of the United States Air Force)

Img. 5 A Lockheed C-69 Constellation

Wheel

The wheels are another part of the undercarriage, or landing gear. While most aircraft have a minimum of three wheels, larger aircraft require many more to support the immense weight (Img. 6). Typically aircraft wheels are filled with nitrogen instead of air. This is because the pressure of nitrogen gas changes very little with changes in altitude or temperature, which is something aircraft constantly experience.

Windshield

The windshield on smaller aircraft is usually made from polycarbonate, a type of plastic, while pressurized airplanes use a sandwich of plastic and glass layers, called a laminate, up to 20mm thick. This is necessary to absorb the impact of birds, insects and other debris that may collide with the windshield as the airplane flies t close to the speed of sound.

Wing

The wing provides the majority of the lift an airplane requires for flight. Its shape is specifically designed for the aircraft to which it is attached. On most aircraft, the interior of the wing is used to store the fuel required to power the engines.

Winglet

Some aircraft wings have an additional component called a winglet, which is located at the end of each wing. Its purpose is to reduce the drag (or air resistance) the wing produces as it pushes through the air. This not only allows the airplane to fly faster, but also means it burns less fuel, allowing it to fly longer distances without refuelling.



(Photo courtesy of NASA)

Img. 7 The winglet of a KC-135A cargo plane.

Activity 1

Birds & Planes

GRADES**K-4****Time Requirement:** 20 minutes**Materials:**In the Box

None

Provided by User

Tape or thumbtacks

Worksheets

None

Reference Materials

Img. 7 - A robin in flight

Img. 8 - A seagull in flight

Img. 9 - A hummingbird in flight

Img. 10 - Boeing 787 Dreamliner

Key Terms:

None

Objective:

By comparing pictures of birds and airplanes, students will learn to identify the individual parts of both.

Activity Overview:

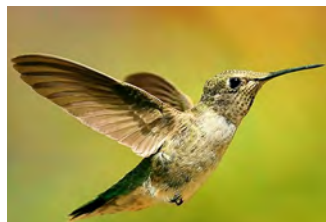
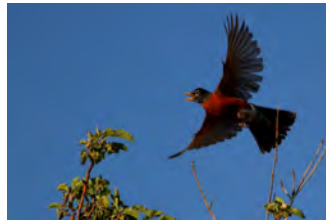
In this activity, the students will learn about properties of objects and materials, as well as characteristics of organisms, and will develop the ability to distinguish between natural objects and objects made by humans as they identify the similar components and understand their purposes.

Activity:

1. **Begin by discussing the **Background** information with the students.**

*The topics covered in the **Background** information are quite detailed in nature. As such, it should be simplified as required to suit the abilities of the students. The priority of this lesson is for students to understand the similarities between birds and airplanes rather than for them to be fluent in naming the individual components.*

2. **Next, distribute copies of each of the bird pictures to the students, keeping a copy for yourself which will be used as a demonstration piece.**
3. **Hold up one of the bird pictures and ask the students to name each of the major parts:** Head, Body, Wings, Tail, Legs, Feet.



parts of an airplane

4. **Repeat the process with another of the bird pictures.** This time, ask the students what each part is for.

Head: This is what the bird uses to think, hear, eat and see

Body: Holds the other parts together; digests food

Wings: Provide the lift needed for the bird to fly

Tail: Helps the bird both steer and fly in a straight line

Legs & Feet: Allow the bird to land and walk on the ground

5. **Repeat the process with the final bird picture.** Ensure that the students now understand that while each of the birds looks different, the names of the body parts are the same.

If desired, use the tape or thumbtacks to secure the bird pictures to the wall for easier reference during the next step.

6. **Hold up the picture of the airplane.** Ask the students to use what they have just learned about birds to identify the main components.

At this point, they will likely name each part using bird terms. There is no need to correct them yet.

7. **Finally, point to each of the parts again, but this time tell them the actual name and how it correlates to the bird.**

Head – Cockpit: *Instead of a bird's brain and eyes, this is where the pilot sits and controls the plane.*

Body – Fuselage: *While the bird holds food in its belly for fuel, the airplane holds jet fuel or gasoline. The fuselage is also where all the people and bags go.*

Wings – Wings: *Unlike the bird, the airplane doesn't flap its wings to provide lift. Instead, the plane uses the shape of its wings to provide lift. Also, instead of using its wings to provide thrust like the bird, the airplane uses engines.*

Tail – Empennage: *The part of an aircraft commonly referred to as the tail is really called the empennage. It works much the same as a bird's tail, guiding the airplane through the air and helping it fly in a straight line.*

Legs & Feet – Landing Gear or Undercarriage: *The plane uses these wheels to move on the ground like a car, just like the bird walks on the ground.*

Discussion Points:

1. **An airplane is made up of lots of parts. Can you name other manmade objects that are made up of lots of parts?**

The answer is self-explanatory, but expect responses such as cars, trains, etc. If desired, correlate this to non-mechanical objects such as a pencil, where the lead, eraser and wood shell are considered its parts.

2. **If a part was taken away, or missing, would the bird or plane work properly?**

In most situations involving living or mechanical objects, the answer would be no. For simpler objects like the pencil, it could still function if the item missing was less critical, such as the eraser. Even though objects or living things might be able to function without some of their parts, they wouldn't be able to do everything. For example, a pencil would still write without an eraser, but what wouldn't it be able to do? If a bird was missing its feathers, what might it have trouble with?

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology
- Abilities to distinguish between natural objects and objects made by humans

LIFE SCIENCE

- Characteristics of organisms

Activity 2

Plane Puzzles

GRADES**K-4****Time Requirement:** 30 minutes**Materials:**In the Box

Crepe rubber puzzles

Provided by User

None

Worksheets

None

Reference Materials

None

Key Terms:

None

Objective:

By completing jigsaw puzzles of airplanes, students will reinforce their abilities of technological design as they review the concept that it takes many individual parts to build an object.

Activity Overview:

In this activity, the students will complete crepe rubber jigsaw puzzles of airplanes.

Activity:

1. **If you have not completed [Activity 1 – Birds & Planes](#), discuss the [Background information](#) with the students.**
It is important for this activity to convey the basic concept that many parts can come together to build the whole, rather than attempting to understand how they interact together in flight.
2. **Depending on the number of students and puzzles available, divide the class into even sized groups.** Provide each group with a completed jigsaw puzzle. Ask them to study the puzzle, then remove and jumble all of the pieces. If you are teaching older students, begin with the puzzles in many pieces already.
When working with younger students, you may wish to pre-stage the puzzle, removing just the larger pieces such as the fuselage and wings, leaving the smaller items, such as the windows, attached to the fuselage. Also, each puzzle contains a paper template to assist the students in reassembly. This can be removed to increase the level of difficulty if desired.
3. **Ask the students to reassemble the puzzle. Repeat this as desired, rotating the different puzzles amongst the groups**

Discussion Points:

1. **What picture did the puzzle make?**

An airplane

2. **Where would we find airplanes?**

At the airport

3. **If a part was missing, could you still tell it was an airplane?**

Answers will vary by student

4. **Could we take a part from each of the different puzzles and make a completely different airplane?**

Most likely, no. It is important for the students to understand that each part is specially designed to work with one aircraft and the parts are not interchangeable. Have the students picture a big bird with wings from a really tiny bird; could it fly? No, because the wings were designed for the small bird, not the big one.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

Activity 3

Peg-a-plane

GRADES**K-4****Time Requirement:** 45 minutes**Materials:**In the Box

Peg-A-Plane kit

Provided by User

None

WorksheetsPeg-A-Plane 1
(Worksheet 1)Peg-A-Plane 2
(Worksheet 2)Peg-A-Plane 3
(Worksheet 3)Reference Materials

None

Key Terms:

None

Objective:

By building model airplanes, students will realize that it takes many unique, individual parts to build an object.

Activity Overview:

In this activity, the students will work in groups to complete wood and rubber models of airplanes.

Activity:

1. **If you have not completed [Activity 1 – Birds & Planes](#), discuss the [Background](#) information with the students.**
2. **Divide the students into three groups.** Provide each group with one of the worksheets and the corresponding aircraft parts as listed on the worksheet.
3. **Ask the students to build the aircraft per the instructions on the worksheet.** As they build the aircraft, students should refer to each part by its correct name, reinforcing what was studied in the [Background](#) information earlier. After completing the build, have the students dismantle the aircraft again.
4. **Rotate the worksheets and parts around the three groups ensuring that each group has an opportunity to build all three aircraft.**
5. **Finally, have the students trade just the fuselage pieces and attempt to rebuild their aircraft, using the new pieces.**

It should be discovered that rebuilding the aircraft with the incorrect fuselage piece is impossible.

Discussion Points:

1. **What happened when we tried to build an aircraft using a fuselage designed for a different model?**

As with real aircraft, each part is designed specifically for a particular aircraft. As such, attempting to build a bi-plane with the fuselage for a monoplane aircraft, for example, is virtually impossible.

2. **Name some other items or machines that require many components to be assembled in order to construct the object.**

Answers will vary but may include: car, blender, clock, cake, computer, pencils, etc.



Reference Materials

Fig. 1 Airplane Diagram

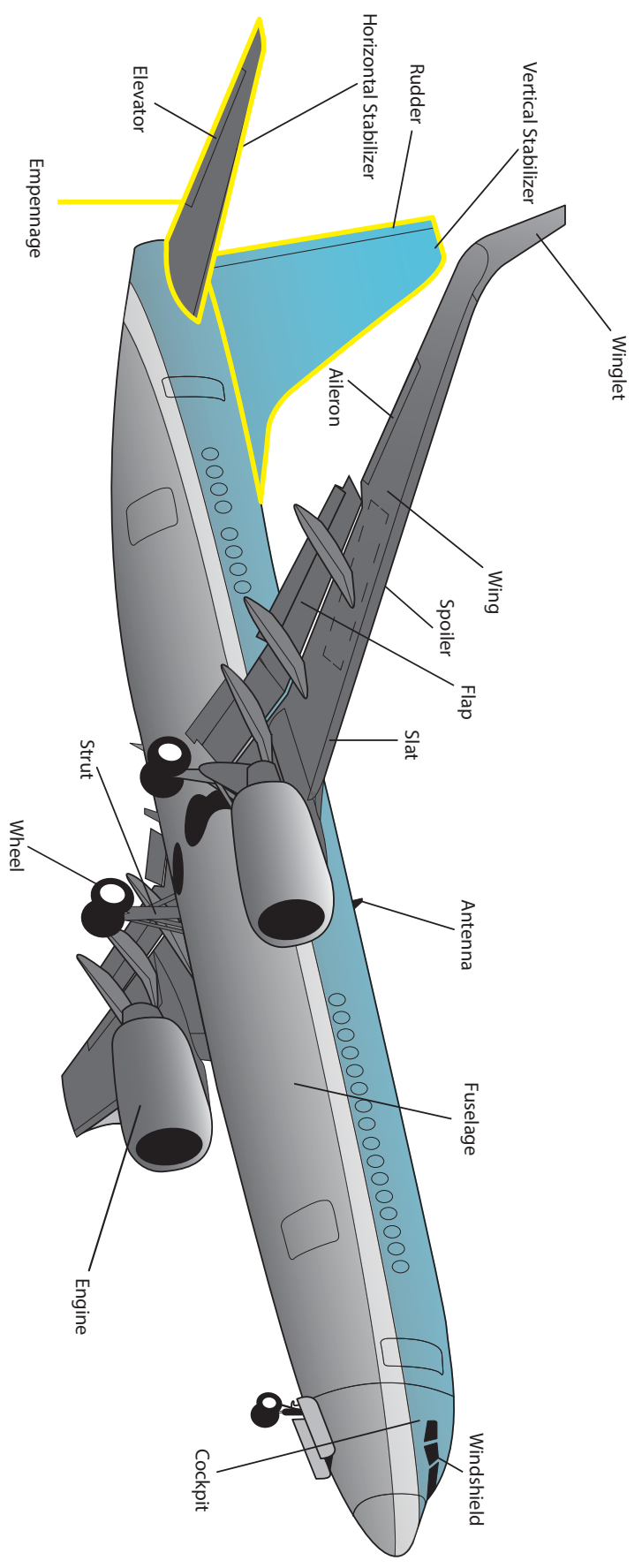


Fig. 2 Propeller Path

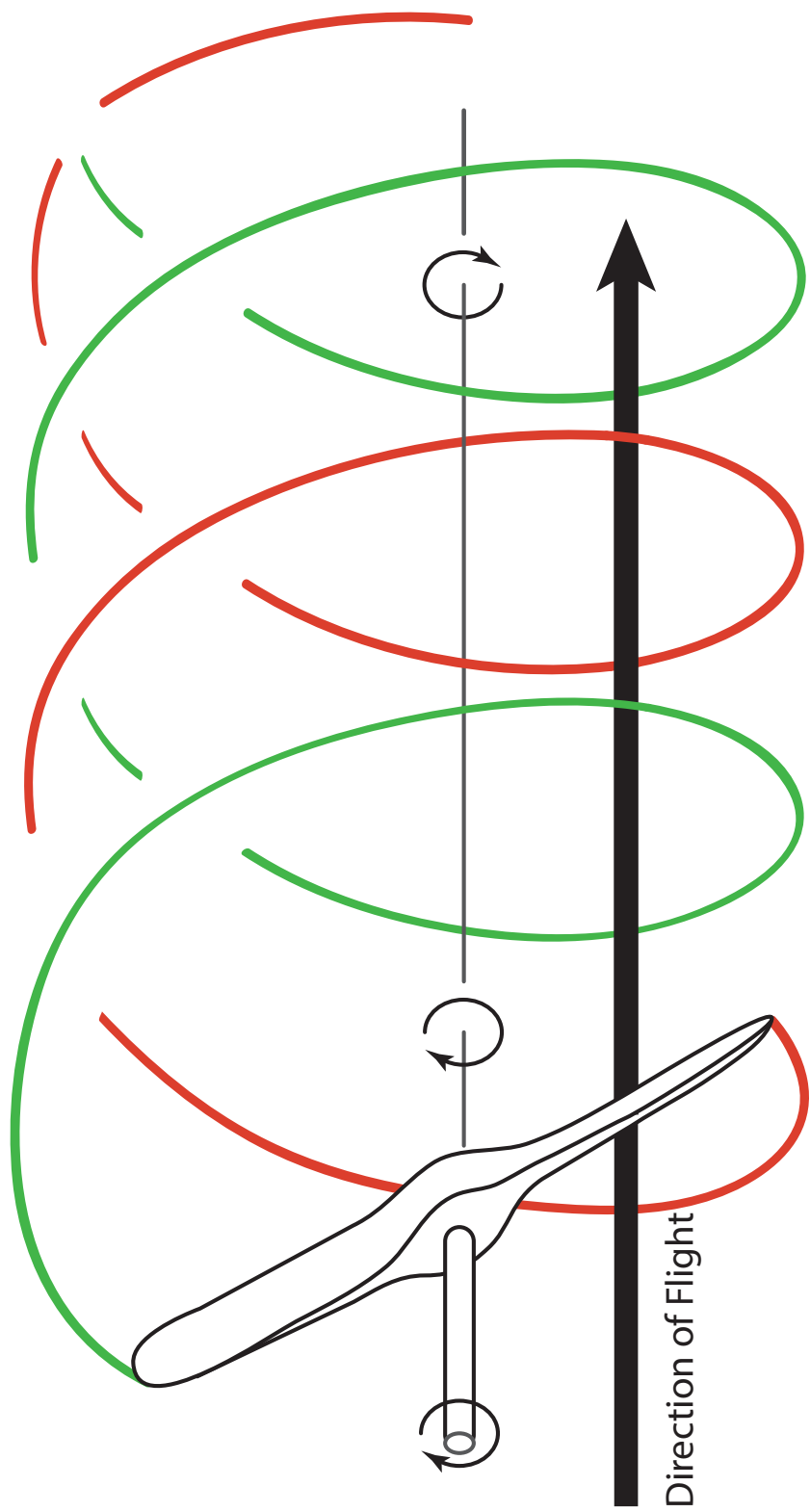
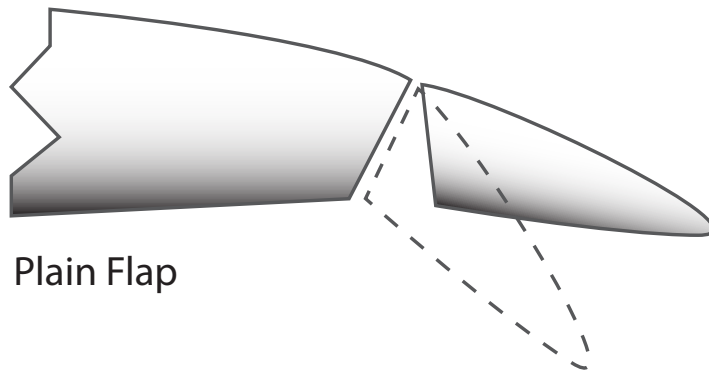
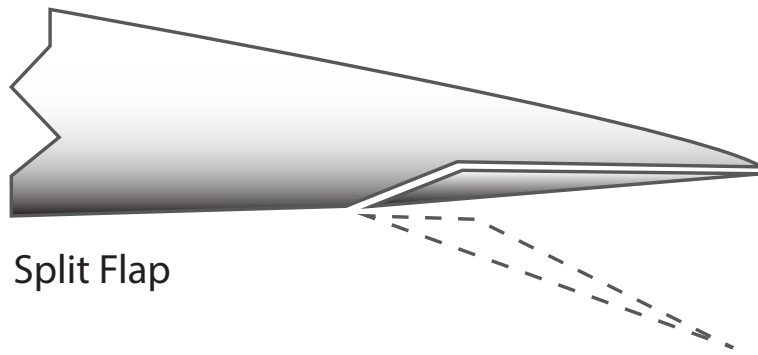


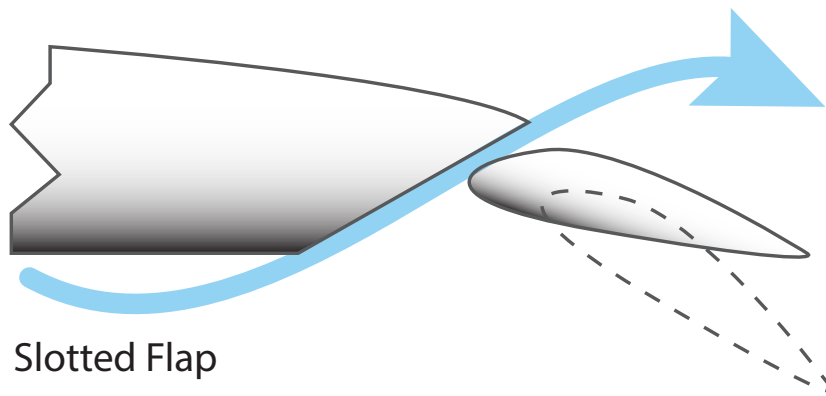
Fig. 3 Flaps



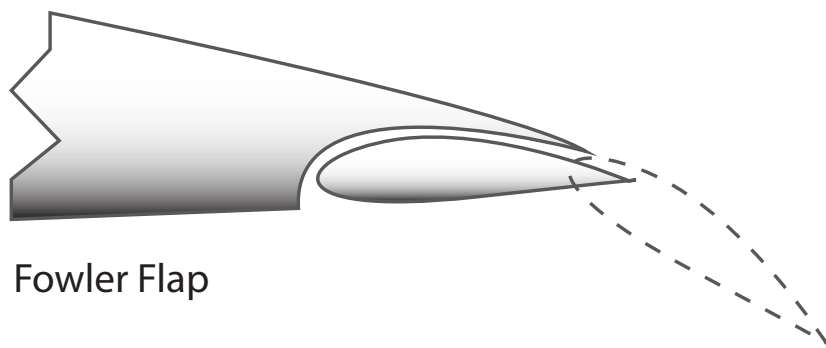
Plain Flap



Split Flap



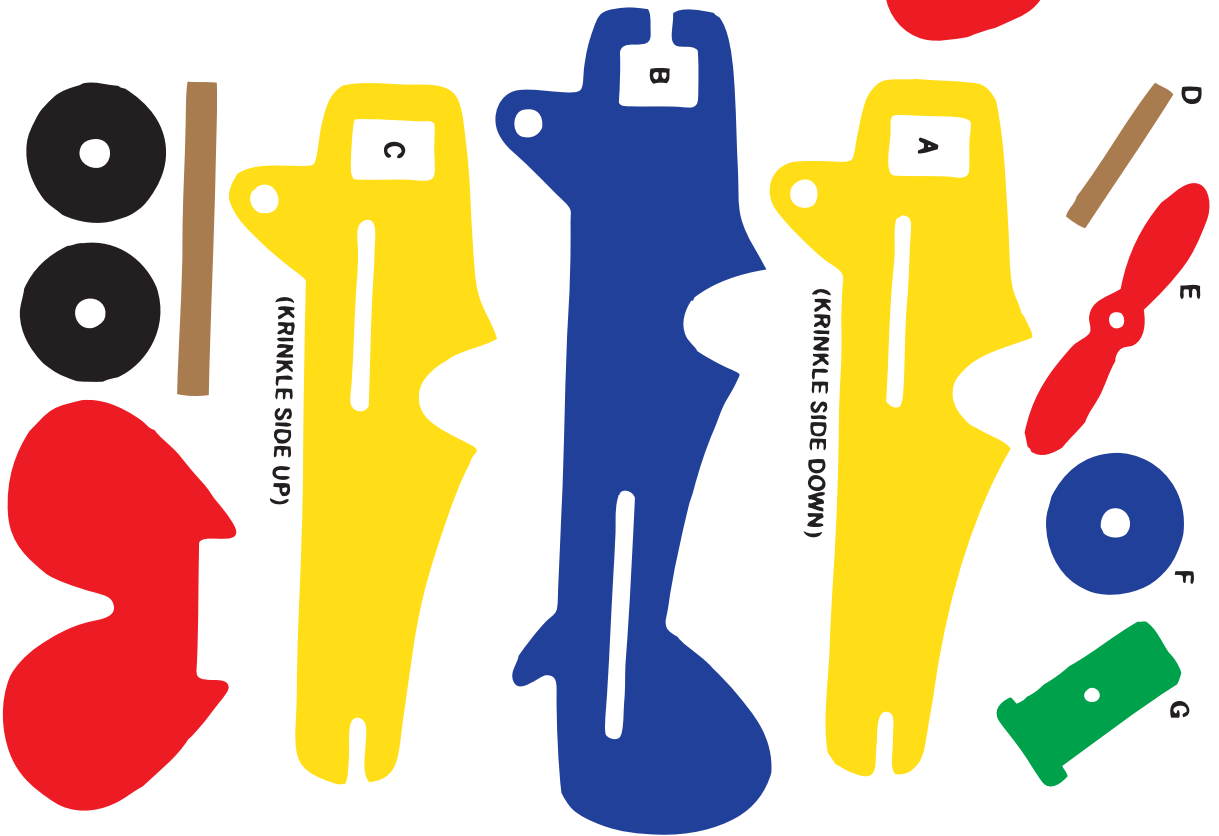
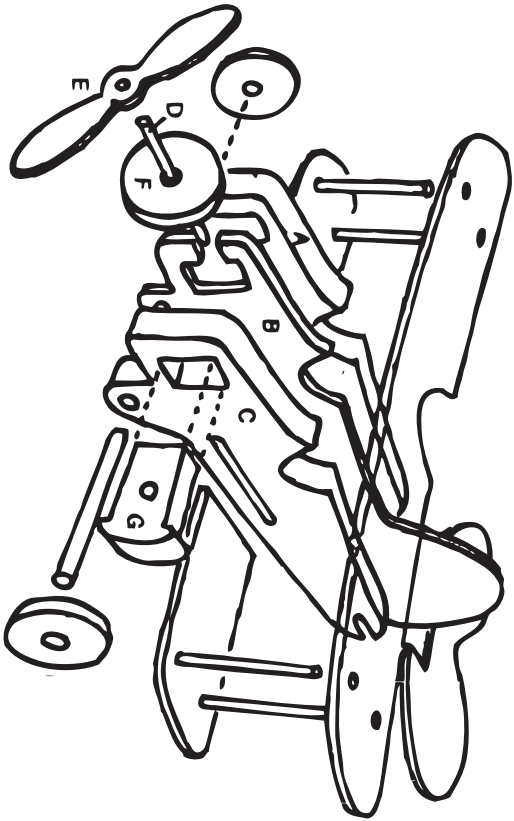
Slotted Flap

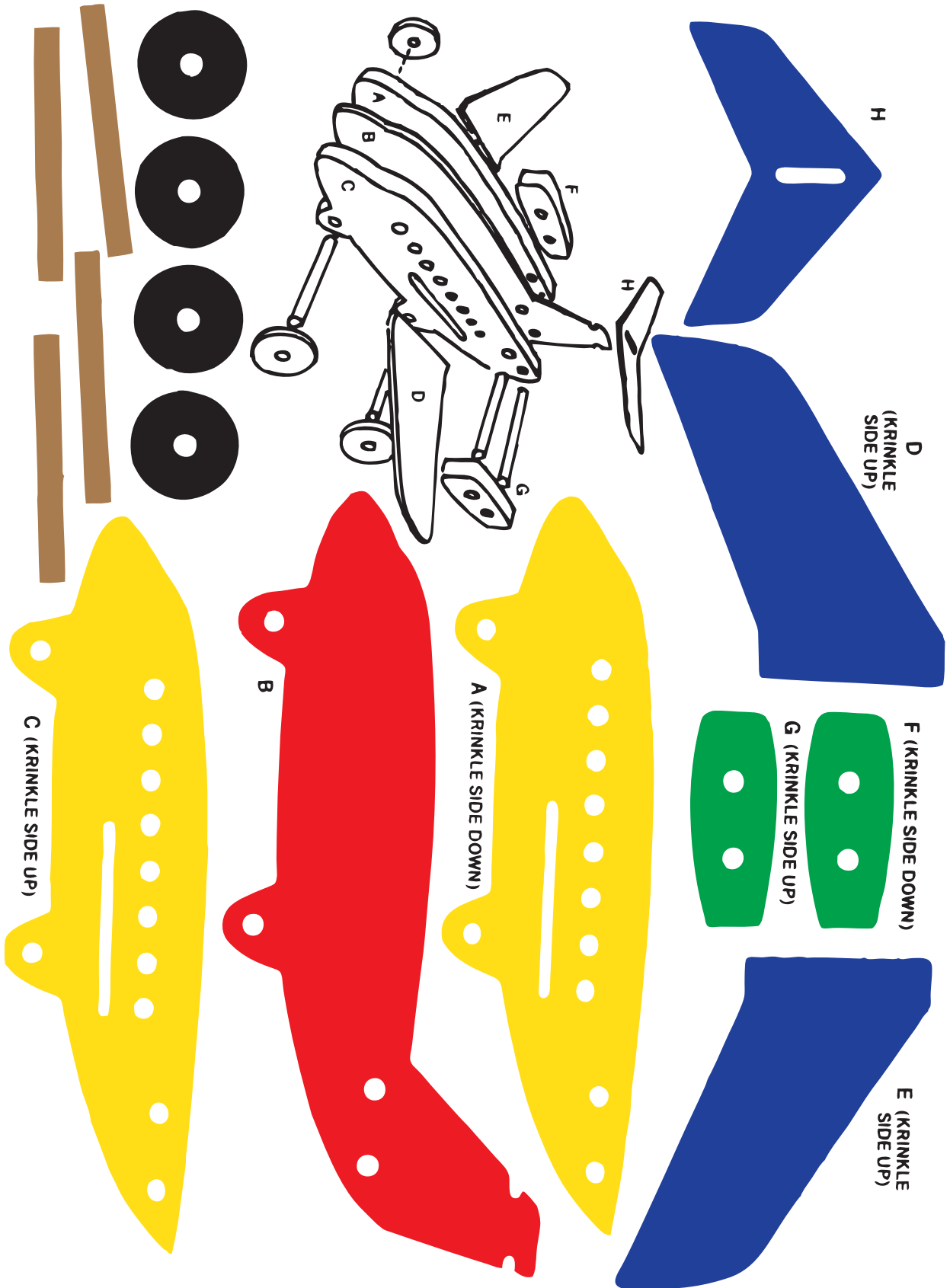


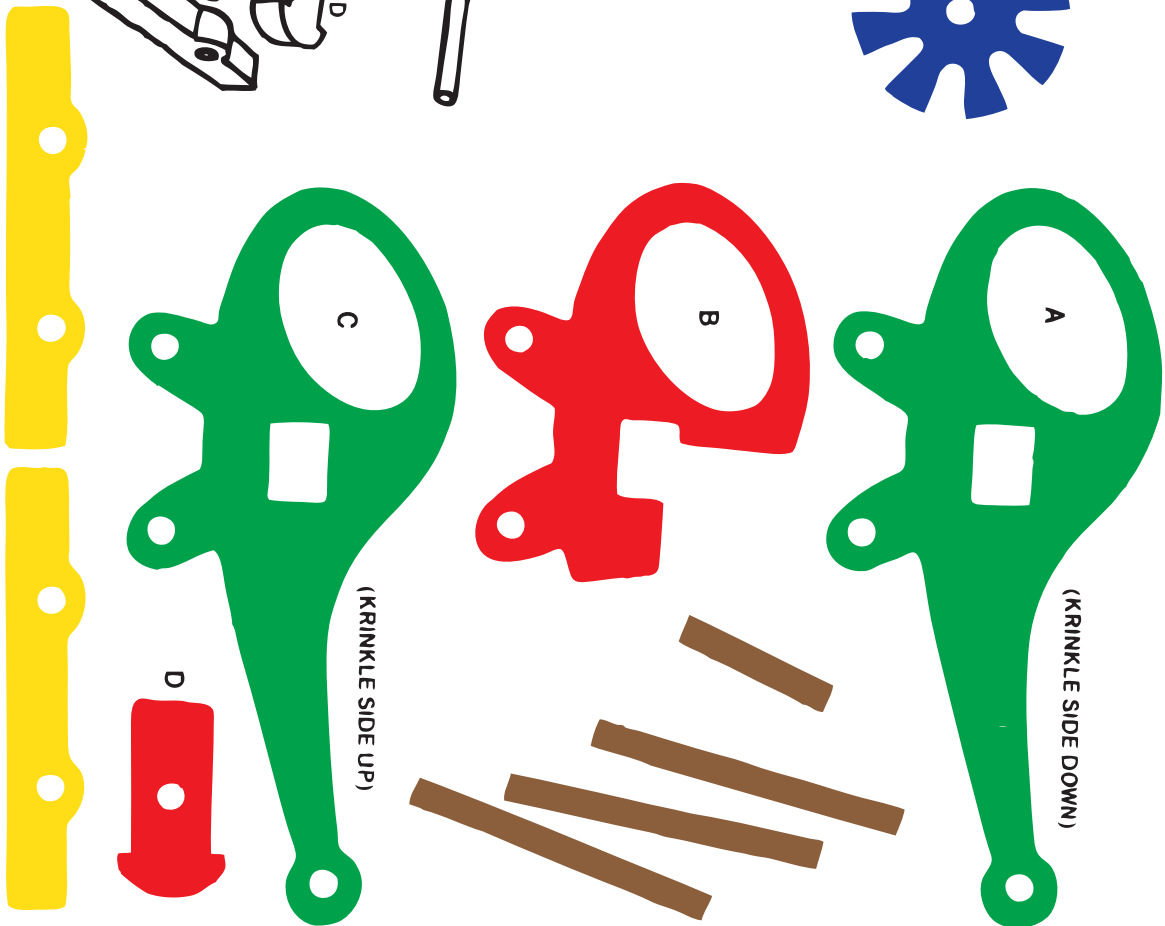
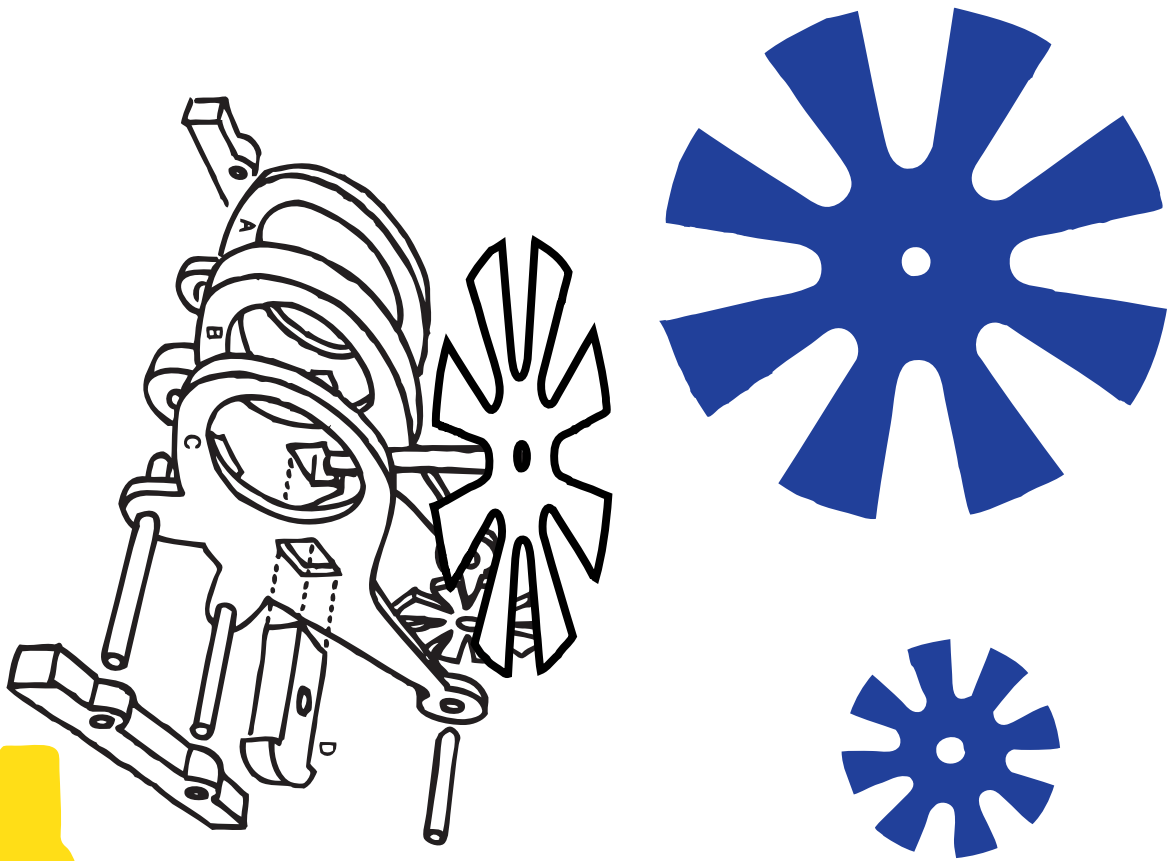
Fowler Flap



Student Worksheets









Images

Img. 1 Ground spoilers on an Airbus 320 aircraft



(Public Domain)

Img. 2 The straight leg landing gear of the Space Shuttle Atlantis



(Photo courtesy of NASA)

Img. 3 Trailing link landing gear



(Photo courtesy of Lost Tribe Media, Inc.)

Img. 4 A NASA modified essna 190



(Photo courtesy of NASA)

Img. 5 A Lockheed C-69 Constellation



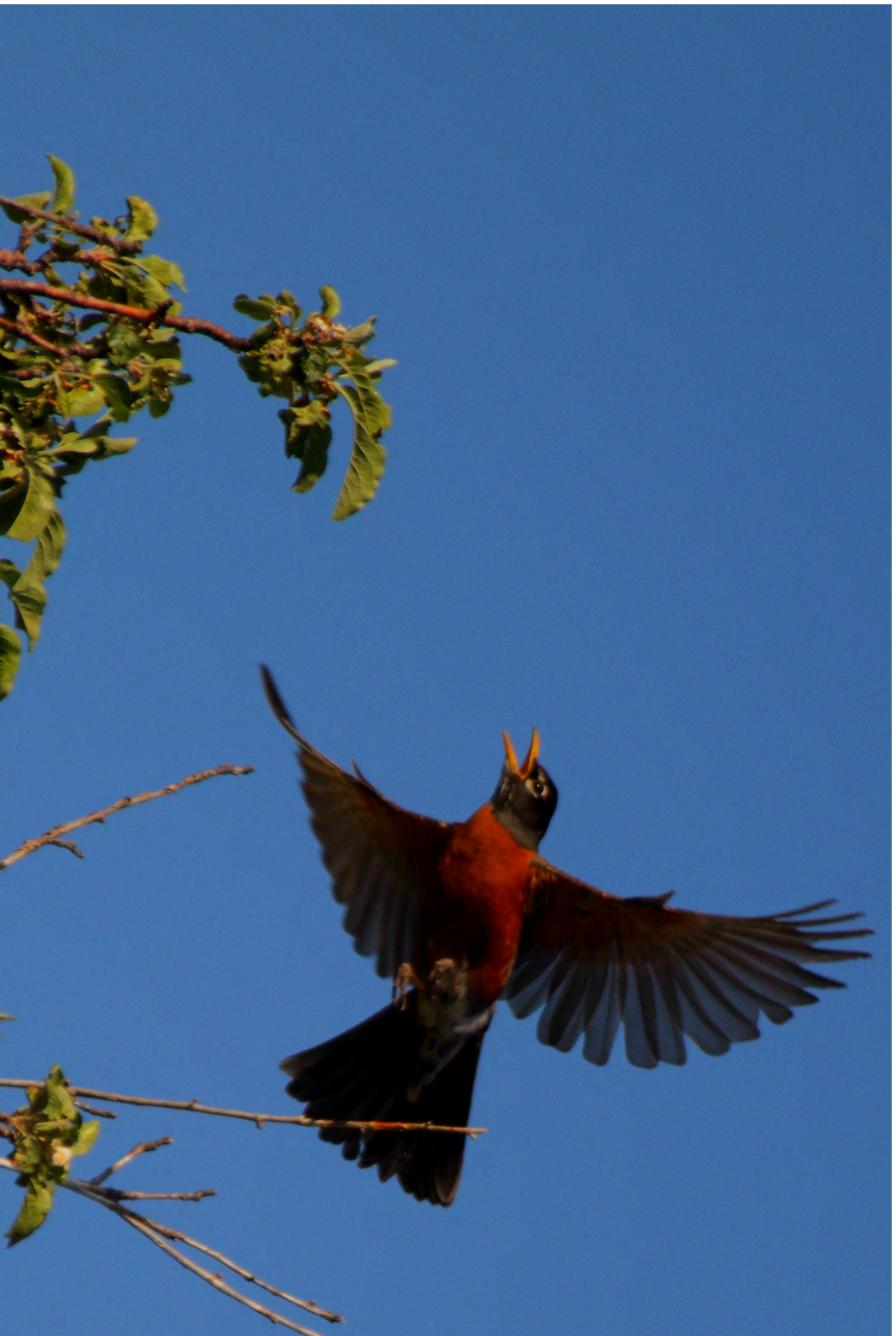
(photo courtesy of The United States Air Force)

Img. 6 A Boeing 747 carrying the Space Shuttle Enterprise



(Photo courtesy of www.NASAimages.org)

Img. 7 A robin in flight



(photo courtesy of Fauxpaysgrapher, CC BY-NC-ND 3.0 License)

Img. 8 A seagull in flight



(Photo courtesy of Arnold Paul, CC BY-SA 2.5 License)

Img. 9 A hummingbird in flight



(Public Domain)

Img. 10 A Boeing 787 Dreamliner

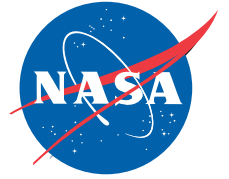


(Photo courtesy of Boeing)

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parts of an airplane



GRADES

5-8

Parts of an Airplane



parts of an airplane

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Parts of an Airplane

Lesson Overview

In this lesson, students will learn about the abilities of technological design and understandings of science and technology as they analyze the individual components of an aircraft, first learning how to identify them, then gaining an understanding of how each component works.

Objectives

Students will:

1. Learn about the abilities of technological design and understandings about science and technology as they identify individual aircraft components, regardless of design or manufacturer.

Materials:

In the Box

None

Provided by User

None

GRADES

5-8

Time Requirements: 1 hour

Background

Any vehicle, whether it's a car, truck, boat, airplane, helicopter or rocket, is made up of many individual component parts. Some components are common amongst a variety of vehicles, while others are exclusive to specific types. Occasionally, a component is modified and given a different name, although its basic principle of operation remains intact. This lesson is designed to look at those individual components and allow students to not only identify them, but to understand how they work together to create a functioning aircraft.

Figure 1 shows a typical airplane with its major components listed. Many external airplane components are constructed of metal alloys, although composites made of materials such as carbon fiber and a variety of fiber glass resins are becoming more popular as technology improves.

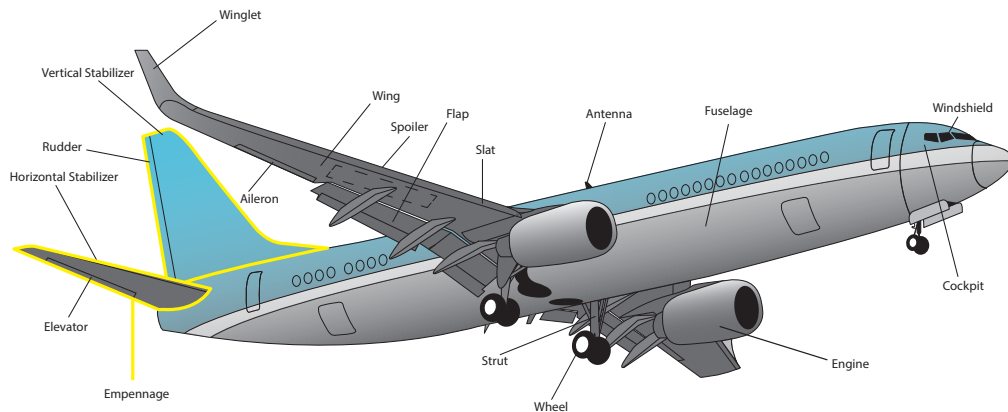


Fig. 1 Airplane Diagram

Aileron

The ailerons are located at the rear of the wing, typically one on each side. They work opposite to each other, meaning that when one is raised, the other is lowered. Their job is to increase the lift on one wing while reducing the lift on the other. By doing this, they roll the aircraft sideways, causing the aircraft to turn. This is the primary method of steering a fixed-wing aircraft.

Antenna

There are numerous radio antennas located around an aircraft, their size and position corresponding to the type of work each antenna must perform and the frequencies being transmitted or received. The GPS antenna, for example, is always mounted to the top of an airplane. This is because the GPS satellites are in Space, and therefore always above the aircraft. As a general rule, longer antennas are used for radio communication and navigation (VHF frequencies), while shorter antennas are reserved for higher frequency data such as the GPS signals and the transponder, which provides air traffic control with information about the aircraft's position and altitude.

Cockpit

The cockpit, sometimes referred to as the Flight Deck, is where the pilots sit. It contains the flight controls, which move the airplane, as well as all the buttons and switches used to operate the various systems.

Elevator

As the name implies, the elevator helps "elevate" the aircraft. It is located on the tail and directs the nose of the aircraft either upwards or downwards (pitch) in order to make the airplane climb and descend.

Empennage

This name stems from the French word “empenner,” meaning “to feather an arrow”. The empennage is the name given to the entire tail section of the aircraft, including both the horizontal and vertical stabilizers, the rudder and the elevator. As a combined unit, it works identically to the feather on the arrow, helping guide the aircraft to its destination.

Engine

An airplane has at least one, or as many as eight engines, which provide the thrust needed to fly. There are many different makes and models on aircraft today but all perform the same basic function of taking the air that’s in front of the aircraft, accelerating it and pushing it out behind the aircraft. Jet powered aircraft perform this function by compressing the air using turbines, while propeller-powered aircraft use a propeller mounted to the engine. In general, the propeller works like a big screw, pulling the aircraft forward while pushing the air behind it (Fig. 2).

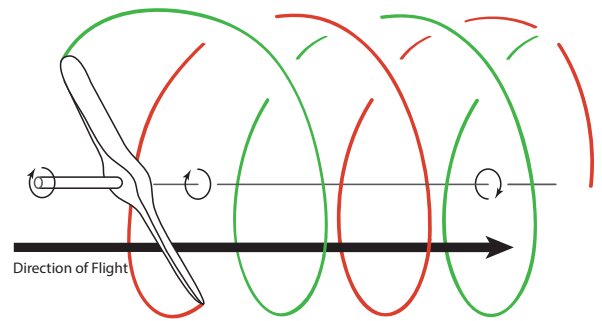


Fig. 2 Propeller path

Flap

Flaps are a “high lift / high drag” device. Not only do they improve the lifting ability of the wing at slower speeds by changing the camber, or curvature of the wing, but when extended fully they also create more drag. This means an aircraft can descend (or lose altitude) faster, without gaining airspeed in the process.

Fuselage

The fuselage, from the French word “fuselé” meaning “spindle shaped”, is the portion of the airplane used to literally join, or fuse, the other parts together. It is commonly thought of as the body of the aircraft and holds the passengers and cargo safely inside.

Horizontal Stabilizer

The horizontal stabilizer is quite simply an upside-down wing, designed to provide a downward force (push) on the tail. Airplanes are traditionally nose-heavy and this downward force is required to compensate for that, keeping the nose level with the rest of the aircraft. Some aircraft can control the angle of the stabilizer and therefore the level of downward force while in flight, while others are fixed in place.

Rudder

The rudder is attached to the vertical stabilizer, located on the tail of the aircraft. It works identically to a rudder on a boat, helping to steer the nose of the aircraft left and right; this motion is referred to as yaw. Unlike the boat however, it is not the primary method of steering. Its main purpose is to counteract certain types of drag, or friction, ensuring that the aircraft’s tail follows the nose, rather than sliding out to the side.

Slat

A slat is a “high lift” device typically found on jet-powered aircraft. Slat is similar to the flaps except they are mounted on the leading edge of the wing. They also assist in changing the camber, or curvature of the wing, to improve lifting ability at slower speeds.

Spoiler

The spoiler’s function is to disrupt, or spoil, the flow of air across the upper surface of the wing. They are usually found on larger aircraft, which can have two types installed.

The in-flight spoilers are small and designed to reduce the lifting capability of the wing just enough to allow the aircraft to descend quicker without gaining airspeed. Although the flaps can also perform this function, the spoiler is intended to be used temporarily, while the flaps are typically used for longer durations such as during the approach and landing. The ground spoilers (Img. 1) typically deploy automatically on landing and are much larger than their in-flight cousins. They are used to completely destroy the lifting ability of the wing upon landing, ensuring that the entire weight of the airplane rests firmly on the wheels, making the brakes more effective and shortening the length of runway needed to stop the aircraft.



Img. 1 Ground spoilers on an Airbus 320 aircraft

Struts

The struts are part of the undercarriage, more commonly known as the landing gear. Their function is to absorb the impact of the landing as the aircraft touches the ground. Each strut contains a shock absorber (a collection of springs), hydraulic oil and gasses which work together to reduce the impact felt by the passengers (Img. 2).

On some aircraft, such as those used by student pilots, the struts are made entirely out of spring steel. This type of steel is treated in such a way that it can absorb the shock of landings repeatedly, bending automatically back into shape (Img. 3).



Img. 2 The straight leg landing gear of the Space Shuttle Atlantis



Img. 3 A NASA modified Cessna 190

Vertical Stabilizer

The vertical stabilizer is designed to stabilize the left-right motion of the aircraft. While most aircraft use a single stabilizer, some models, such as the Lockheed C-69 Constellation (Img. 4), use multiple, smaller stabilizers.



(Photo courtesy of the United States Air Force)

Img. 4 A Lockheed C-69 Constellation

Windshield

The windshield on smaller aircraft is usually made from polycarbonate, a type of plastic, while pressurized airplanes use a sandwich of plastic and glass layers, called a laminate, up to 20mm thick. This is necessary to absorb the impact of birds, insects and other debris that may collide with the windshield as the airplane flies t close to the speed of sound.

Wing

The wing provides the majority of the lift an airplane requires for flight. Its shape is specifically designed for the aircraft to which it is attached. On most aircraft, the interior of the wing is also used to store the fuel required to power the engines.

Winglet

Some aircraft wings have an additional component called a winglet, which is located at the end of each wing. Its purpose is to reduce the drag (or air resistance) the wing produces as it pushes through the air. This not only allows the airplane to fly faster, but also means it burns less fuel, allowing it to fly longer distances without refuelling.

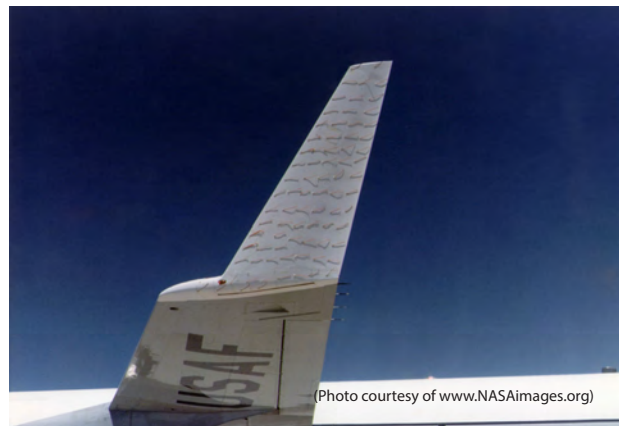
Wheel

The wheels are another part of the undercarriage, or landing gear. While most aircraft have a minimum of three wheels, larger aircraft require many more to support their immense weight (Img. 6). Typically aircraft wheels are filled with nitrogen instead of air. This is because the pressure of nitrogen gas changes very little with changes in altitude or temperature, which is something aircraft constantly experience.



(Photo courtesy of www.NASAIMages.org)

Img. 5 A modified Boeing 747 carrying the Space Shuttle Enterprise



(Photo courtesy of www.NASAIMages.org)

Img. 6 The winglet of a KC-135A cargo plane

Activity 1

Plane Parts

GRADES**5-8****Time Requirement:** 1 hour**Materials:**In the Box

None

Provided by User

None

WorksheetsPlane Parts
(Worksheet 1)Plane Parts Quiz
(Worksheet 2)Reference Materials

Figure 1

Key Terms:

None

Objective:

Students will learn about the abilities of technological design and understandings about science and technology as they identify individual aircraft components, regardless of design or manufacturer.

Activity Overview:

In this activity, students will identify and label the major components of an aircraft as well as discuss the purpose of each part.

Activity:

1. **Provide each student with a copy of both worksheets and Figure 1 from the Reference Materials section.**
2. **Next, discuss the Background information with the students.** During the discussion, be sure to note that although every airplane looks somewhat different, the names and functions of each part are the mostly the same.
3. **Have the students complete Worksheet 1 by identifying and labeling the components of each aircraft.**
4. **Have the students study the various components in greater detail, either using the Internet or by providing them with a copy of the Background information in its entirety.** The students should then use the information from their research to complete Worksheet 2.

- Describe the following aircraft motions:**
Pitch: *Pitch is the name given to the up-down motion of the nose of the aircraft. The pilot changes an aircraft's pitch to make it climb or descend.*
Roll: *Roll is the name given to the side-to-side rotation of the aircraft, during which time one wing is raised while the other is lowered.*
Yaw: *Yaw is the name given to the left-to-right motion of the nose of the aircraft.*
- Which aircraft component has two parts, installed one on each wing, that operate in opposite directions (i.e., one up and one down)?**
Ailerons
- What language do the terms "fuselage" and "empennage" come from?**
French
- What is a spoiler and why would a pilot use it?**
A spoiler is designed to interrupt the airflow over the wings. This causes the wings to produce less lift and as such, descend quicker than could be achieved by simply lowering the nose.

The following questions should only be answered if Internet access is available for additional research. For time purposes, this material is not covered within the **Background** information.

- There are four main types of flaps; what are they and how does each design differ from the others?**
*Plain, Split, Slotted and Fowler. Details of each can be found in the **Background** information.*
- If the pilot pushes forwards on the control column or control stick, what will the airplane do?**
By pushing forwards, the pilot lowers the elevator on the rear of the aircraft, lifting the tail, which conversely points the nose downwards. This results in the aircraft descending.
- What is a Canard-style airplane?**
Unlike a traditional airplane where the wings are forwards of the elevator, in the Canard design the elevator is placed ahead of the wings.
- What is the difference between a spoiler and a spoileron?**
A spoileron is a combination of an aileron and a spoiler. They are often used on faster aircraft where the additional drag generated by the lowered aileron would be unacceptable. Instead, a single wing's spoileron is raised, which reduces the lift on that wing, causing it to drop and the aircraft to roll in that direction. The spoileron on the other wing remains in place, eliminating any additional drag that would've been caused by an aileron.
- What is the difference between a stabilator and an elevator?**
With a stabilator, the entire horizontal surface of the tail moves, as opposed to an elevator, where the horizontal stabilizer remains stationary while just the elevator moves.

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Structure and properties of matter
- Interactions of energy and matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology



Reference Materials

Fig. 1 Airplane Diagram

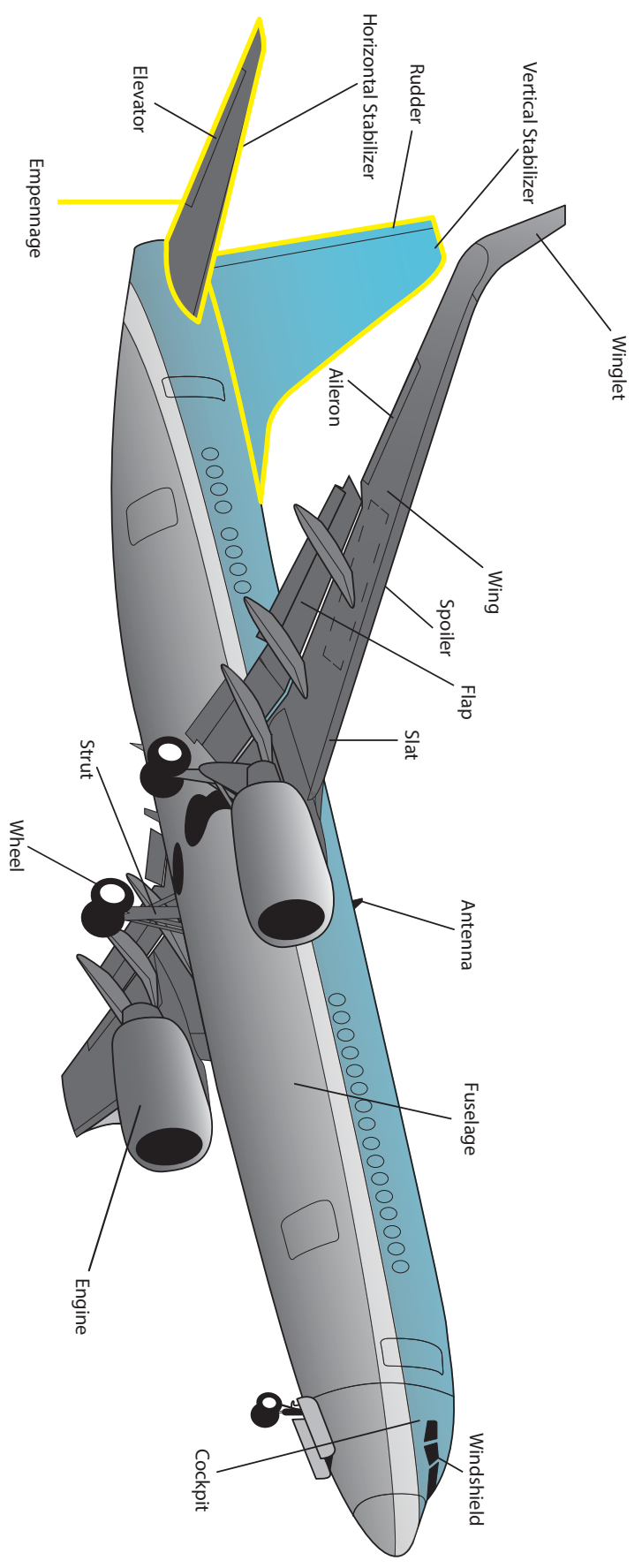
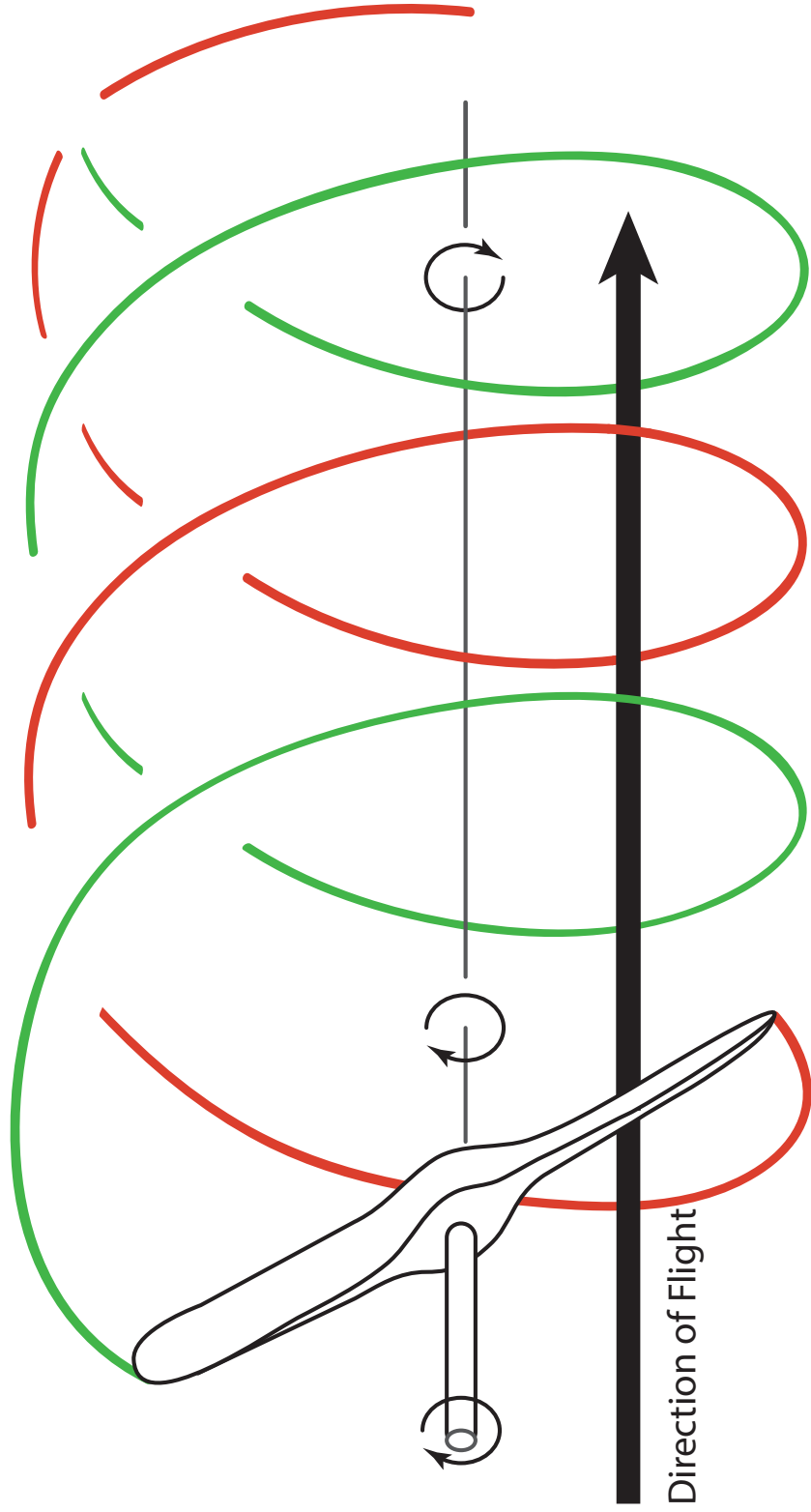
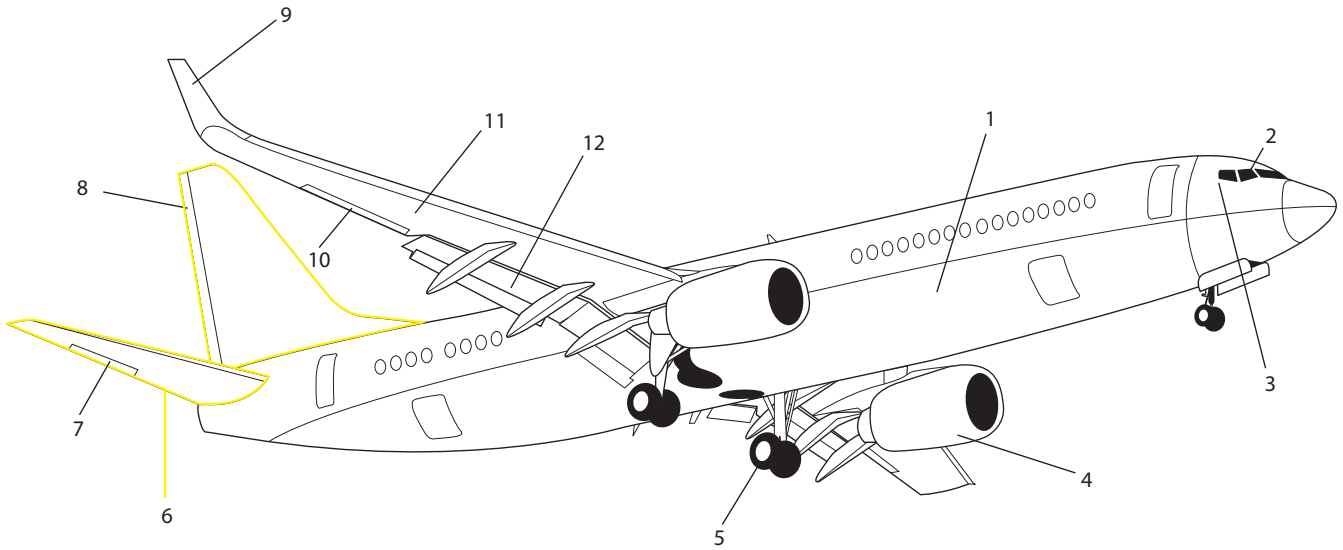


Fig. 2 Propeller Path





Student Worksheets



- 1. _____
- 2. _____
- 3. _____
- 4. _____
- 5. _____
- 6. _____
- 7. _____
- 8. _____
- 9. _____
- 10. _____
- 11. _____
- 12. _____

Word Bank	
Aileron	Fuselage
Cockpit	Rudder
Elevator	Wheel
Empennage	Windshield
Engine	Wing
Flap	Winglet

1. Describe the following aircraft motions.

Pitch:

Roll:

Yaw:

2. Which aircraft component has two parts, installed one on each wing, that operate in opposite directions (i.e., one up and one down)?
3. What language do the terms "fuselage" and "empennage" come from?
4. What is a spoiler and why would a pilot use it?

5. There are four main types of flaps; what are they and how does each design differ from each other?

6. If the pilot pushes forwards on the control column or control stick, what will the airplane do?

7. What is a Canard-style airplane?

8. What is the difference between a spoiler and a spoileron?

9. What is the difference between a stabilator and an elevator?



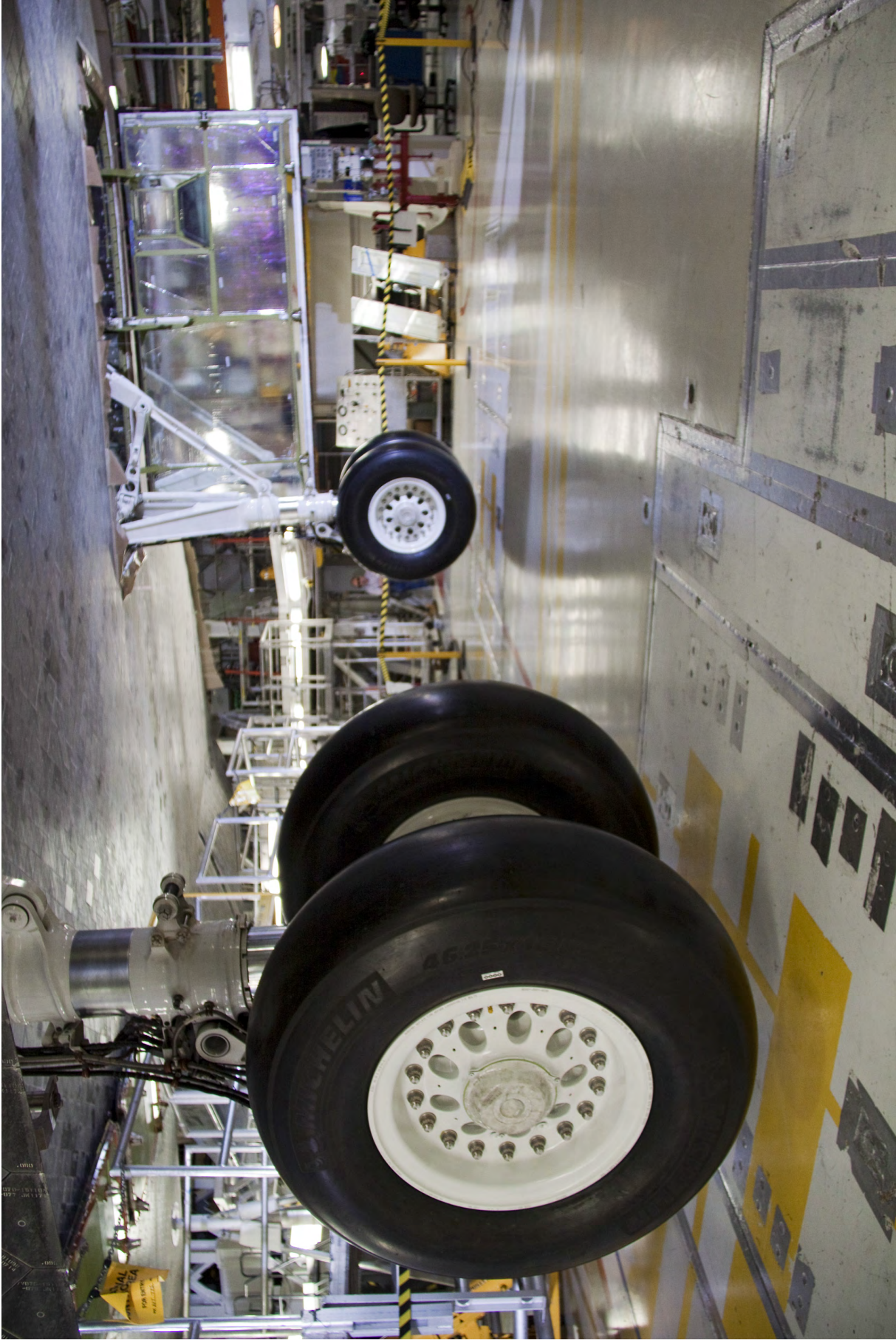
Images

Img. 1 Ground spoilers on an Airbus 320 aircraft



(Public Domain)

Img. 2 The straight leg landing gear of the Space Shuttle Atlantis



(Photo courtesy of NASA)

Img. 3 A NASA modified essna 190



(Photo courtesy of NASA)

Img.4 A Lockheed C-69 Constellation



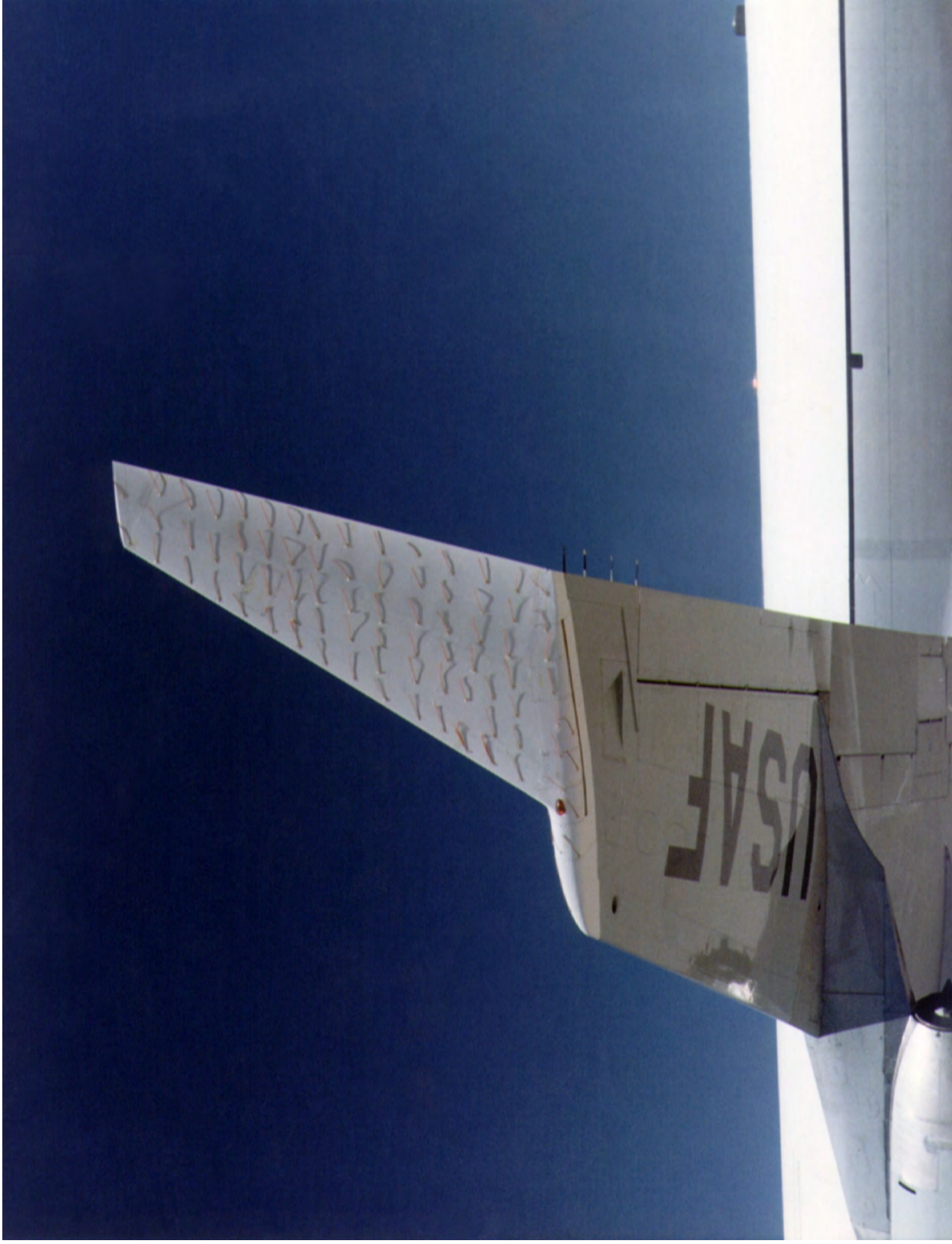
(Photo courtesy of The United States Air Force)

Img. 5 A modified Boeing 747 carrying the Space Shuttle Enterprise



(Photo courtesy of www.NASAMimages.org)

Img.6 The winglet of a KC-135A cargo plane

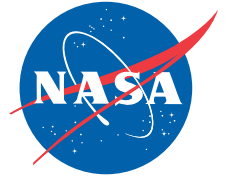


(Photo courtesy of www.NASAIimages.org)

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parts of an airplane



GRADES 9-12

Parts of an Airplane



parts of an airplane

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Parts of an Airplane

Lesson Overview

In this lesson, students will learn about the abilities of technological design and understandings of science and technology as they analyze the individual components of an aircraft, first learning how to identify them, then gaining an understanding of how each component works.

Objectives

Students will:

1. Learn about the abilities of technological design and understandings about science and technology as they identify individual aircraft components, regardless of design or manufacturer.

Materials:

In the Box

None

Provided by User

None

GRADES 9-12 **Time Requirements:** 1 hour

parts of an airplane

Background

Any vehicle, whether it's a car, truck, boat, airplane, helicopter or rocket, is made up of many individual component parts. Some components are common amongst a variety of vehicles, while others are exclusive to specific types. Occasionally, a component is modified and given a different name, although its basic principle of operation remains intact. This lesson is designed to look at those individual components and allow students to not only identify them, but to understand how they work together to create a functioning aircraft.

Figure 1 shows a typical airplane with its major components listed. Many external airplane components are constructed of metal alloys, although composites made of materials such as carbon fiber and a variety of fiber glass resins are becoming more popular as technology improves.

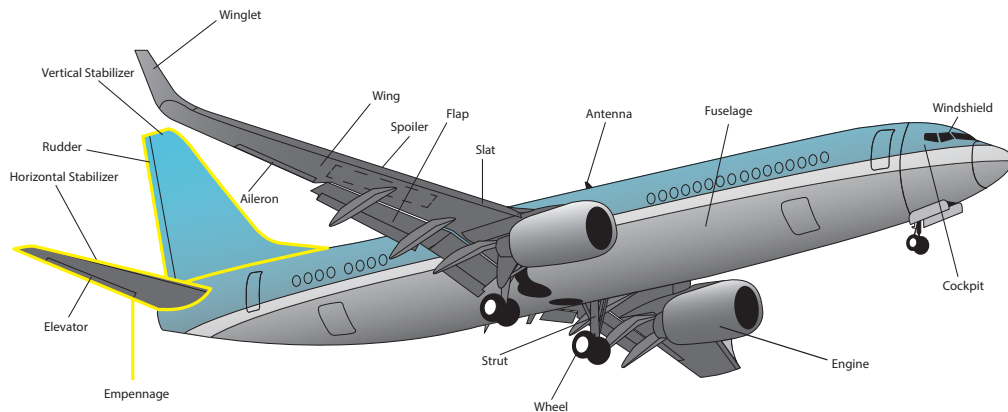


Fig. 1 Airplane Diagram

Aileron

The ailerons are located at the rear of the wing, typically one on each side. They work opposite to each other, meaning that when one is raised, the other is lowered. Their job is to increase the lift on one wing while reducing the lift on the other. By doing this, they roll the aircraft sideways, causing the aircraft to turn. This is the primary method of steering a fixed-wing aircraft.

Antenna

There are numerous radio antennas located around an aircraft, their size and position corresponding to the type of work each antenna must perform and the frequencies being transmitted or received. The GPS antenna, for example, is always mounted to the top of an airplane. This is because the GPS satellites are in Space, and therefore always above the aircraft. As a general rule, longer antennas are used for radio communication and navigation (VHF frequencies), while shorter antennas are reserved for higher frequency data such as the GPS signals and the transponder, which provides air traffic control with information about the aircraft's position and altitude.

Cockpit

The cockpit, sometimes referred to as the Flight Deck, is where the pilots sit. It contains the flight controls, which move the airplane, as well as all the buttons and switches used to operate the various systems.

Elevator

As the name implies, the elevator helps "elevate" the aircraft. It is located on the tail of the aircraft and directs the nose of the aircraft either upwards or downwards (pitch) in order to make the airplane climb and descend.

Empennage

This name stems from the French word “empenner,” meaning “to feather an arrow”. The empennage is the name given to the entire tail section of the aircraft, including both the horizontal and vertical stabilizers, the rudder and the elevator. As a combined unit, it works identically to the feather on the arrow, helping guide the aircraft to its destination.

Engine

An airplane has at least one, or as many as eight engines, which provide the thrust needed to fly. There are many different makes and models of aircraft today but all perform the same basic function of taking the air that’s in front of the aircraft, accelerating it and pushing it out behind the aircraft. Jet powered aircraft perform this function by compressing the air using turbines, while propeller-powered aircraft use a propeller mounted to the engine. In general, the propeller works like a big screw, pulling the aircraft forward while pushing the air behind it (Fig. 2).

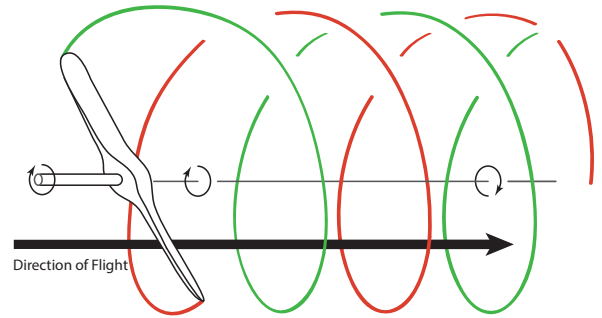


Fig. 2 Propeller path

Flap

Flaps are a “high lift / high drag” device. Not only do they improve the lifting ability of the wing at slower speeds by changing the camber, or curvature of the wing, but when extended fully they also create more drag. This means an aircraft can descend (or lose altitude) faster, without gaining airspeed in the process. Flaps come in 4 main varieties: plain, split, slotted and fowler (Fig. 3).

- The plain flap is the simplest of the four varieties. It works by lowering the aft portion of the wing, increasing its camber, which in turn causes the wing to produce more lift. Plain flaps are typically used only when the aircraft is required to be as simple to construct as possible.
- The split flap works by lowering just the bottom section of the wing. Rather than providing additional lift, the split flap is primarily used to allow an aircraft to descend quickly without gaining forward momentum, or airspeed. As such, it is typically found on aircraft that have to operate in smaller areas, such as those used for crop dusting, or in the Alaskan bush. It was invented by Orville Wright in 1920 and became popular in the 1930’s but, due to the large quantity of drag it produces, has been rarely used since then.
- The slotted and fowler flaps are both designed to physically increase the overall surface area of the wing, literally making the wing bigger. In addition, the slotted flap, as the name implies, creates one or more slots within the wing. These slots provide additional energy to the air on the upper surface of the wing, ensuring that as the airspeed decreases, the air still has sufficient momentum to reach the rear of the wing. In technical terms, it is referred to as preventing the separation of the boundary layer.

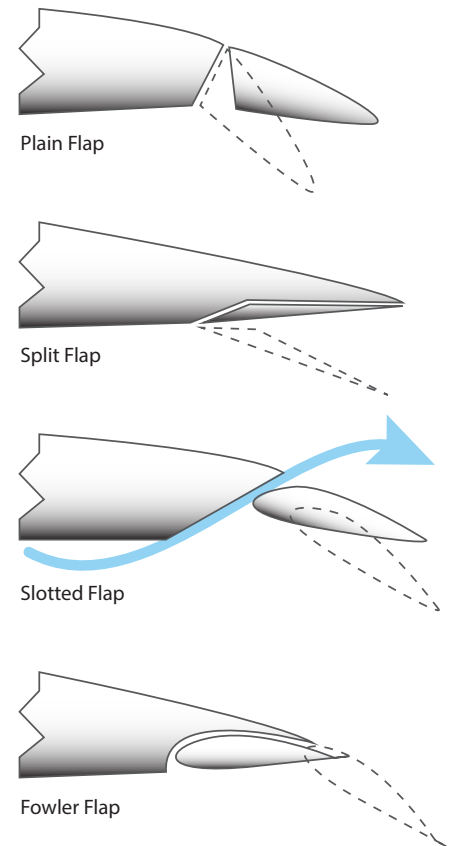


Fig. 3 Flaps

Fuselage

The fuselage, from the French word “fuselé” meaning “spindle shaped”, is the portion of the airplane used to literally join, or fuse, the other parts together. It is commonly thought of as the body of the aircraft and holds the passengers and cargo safely inside.

Horizontal Stabilizer

The horizontal stabilizer is quite simply an upside-down wing, designed to provide a downward force (push) on the tail. Airplanes are traditionally nose-heavy and this downward force is required to compensate for that, keeping the nose level with the rest of the aircraft. Some aircraft can control the angle of the stabilizer and therefore the level of downward force while in flight, while others are fixed in place.

Rudder

The rudder is attached to the vertical stabilizer, located on the tail of the aircraft. It works identically to a rudder on a boat, helping to steer the nose of the aircraft left and right; this motion is referred to as yaw. Unlike the boat however, it is not the primary method of steering. Its main purpose is to counteract certain types of drag, or friction, ensuring that the aircraft’s tail follows the nose, rather than sliding out to the side.

Slat

A slat is a “high lift” device typically found on jet-powered aircraft. Slat is similar to the flaps except they are mounted on the leading edge of the wing. They also assist in changing the camber, or curvature of the wing, to improve lifting ability at slower speeds.

Spoiler

The spoiler’s function is to disrupt, or spoil, the flow of air across the upper surface of the wing. They are usually found on larger aircraft, which can have two types installed. The in-flight spoilers are small and designed to reduce the lifting capability of the wing just enough to allow the aircraft to descend quicker without gaining airspeed. Although the flaps can also perform this function, the spoiler is intended to be used temporarily, while the flaps are typically used for longer durations such as during the approach and landing. The ground spoilers (img. 1) typically deploy automatically on landing and are much larger than their in-flight cousins. They are used to completely destroy the lifting ability of the wing upon landing, ensuring that the entire weight of the airplane rests firmly on the wheels, making the brakes more effective and shortening the length of runway needed to stop the aircraft.



Img. 1 Ground spoilers on an Airbus 320 aircraft

Struts

The struts are part of the undercarriage, more commonly known as the landing gear. There are two main types - straight leg (Img. 2) and trailing link (Img. 3) - but their function is the same: to absorb the impact of the landing as the aircraft touches the ground. Each strut contains a shock absorber (a collection of springs), hydraulic oil and gasses which work together to reduce the impact felt by the passengers.



(Photo courtesy of Lost Tribe Media, Inc.)

Img. 3 Trailing link landing gear

On some aircraft, such as those used by student pilots, the struts are made entirely out of spring steel. This type of steel is treated in such a way that it can absorb the shock of landings repeatedly, bending automatically back into shape (Img. 4).

Vertical Stabilizer

The vertical stabilizer is designed to stabilize the left-right motion of the aircraft. While most aircraft use a single stabilizer, some models, such as the Lockheed C-69 Constellation (Img. 5), use multiple, smaller stabilizers.



(Photo courtesy of www.NASAIMages.org)

Img. 6 A modified Boeing 747 carrying the Space Shuttle Enterprise



(Photo courtesy of NASA)

Img. 2 The straight leg landing gear of the Space Shuttle Atlantis



(Photo courtesy of NASA)

Img. 4 A NASA modified Cessna 190



(Photo courtesy of the United States Air Force)

Img. 5 A Lockheed C-69 Constellation

Wheel

The wheels are another part of the undercarriage, or landing gear. While most aircraft have a minimum of three wheels, larger aircraft require many more to support the immense weight (Img. 6). Typically aircraft wheels are filled with nitrogen instead of air. This is because the pressure of nitrogen gas changes very little with changes in altitude or temperature, which is something aircraft constantly experience.

Windshield

The windshield on smaller aircraft is usually made from polycarbonate, a type of plastic, while pressurized airplanes use a sandwich of plastic and glass layers, called a laminate, up to 20mm thick. This is necessary to absorb the impact of birds, insects and other debris that may collide with the windshield as the airplane flies t close to the speed of sound.

Wing

The wing provides the majority of the lift an airplane requires for flight. Its shape is specifically designed for the aircraft to which it is attached. On most aircraft, the interior of the wing is also used to store the fuel required to power the engines.

Winglet

Some aircraft wings have an additional component called a winglet, which is located at the end of each wing. Its purpose is to reduce the drag (or air resistance) the wing produces as it pushes through the air. This not only allows the airplane to fly faster, but also means it burns less fuel, allowing it to fly longer distances without refuelling.



Img. 7 The winglet of a KC-135A cargo plane.

Activity 1

Plane Parts

GRADES 9-12**Time Requirement:** 1 hour**Materials:**In the Box

None

Provided by User

None

WorksheetsPlane Parts
(Worksheet 1)Plane Parts Quiz
(Worksheet 2)Reference Materials

Figure 1

Key Terms:

None

Objective:

Students will learn about the abilities of technological design and understandings about science and technology as they identify individual aircraft components, regardless of design or manufacturer.

Activity Overview:

In this activity, students will identify and label the major components of an aircraft as well as discuss the purpose of each part.

Activity:

1. **Provide each student with a copy of both worksheets and Figure 1 from the Reference Materials section.**
2. **Next, discuss the Background information with the students.** During the discussion, be sure to note that although every airplane looks somewhat different, the names and functions of each part are the mostly the same.
3. **Have the students complete Worksheet 1 by identifying and labeling the components of each aircraft.**
4. **Have the students study the various components in greater detail, either using the Internet or by providing them with a copy of the Background information in its entirety.** The students should then use the information from their research to complete Worksheet 2.

Worksheet 2 Questions

Plane Parts Quiz - Answer Sheet

1. **Describe the following aircraft motions:**
Pitch: *Pitch is the name given to the up-down motion of the nose of the aircraft. The pilot changes an aircraft's pitch to make it climb or descend.*
Roll: *Roll is the name given to the side-to-side rotation of the aircraft, during which time one wing is raised while the other is lowered.*
Yaw: *Yaw is the name given to the left-to-right motion of the nose of the aircraft.*
2. **Which parts of an airplane are used to control lift at low speed for takeoff and landing?**
Flaps and/or Slats
3. **Which aircraft component has two parts, installed one on each wing, that operate in opposite directions (i.e., one up and one down)?**
Ailerons
4. **If the component in question 3 is up on the right wing and down on the left, what will the aircraft do?**
The aircraft will roll to the right. The lowered aileron increases the lift on the left wing, causing it to rise, while the raised aileron on the right wing reduces lift, causing it to lower. This results in a roll towards the upward-facing aileron.
5. **What language do the terms "fuselage" and "empennage" come from?**
French
6. **What is a spoiler and why would a pilot use it?**
A spoiler is designed to interrupt the airflow over the wings. This causes the wings to produce less lift and as such, descend quicker than could be achieved by simply lowering the nose.
7. **There are four main types of flaps; what are they and how does each design differ from the others?**
Plain, Split, Slotted and Fowler. Details of each can be found in the [Background](#) information.

The following questions should only be answered if Internet access is available for additional research. For time purposes, this material is not covered within the [Background](#) information.

8. **If the pilot pushes forwards on the control column or control stick, what will the airplane do?**
By pushing forwards, the pilot lowers the elevator on the rear of the aircraft, lifting the tail, which conversely points the nose downwards. This results in the aircraft descending.
9. **What is a Canard-style airplane?**
Unlike a traditional airplane where the wings are forwards of the elevator, in the Canard design, the elevator is placed ahead of the wings.
10. **What is the difference between a spoiler and a spoileron?**
A spoileron is a combination of an aileron and a spoiler. They are often used on faster aircraft where the additional drag generated by the lowered aileron would be unacceptable. Instead, a single wing's spoileron is raised, which reduces the lift on that wing, causing it to drop and the aircraft to roll in that direction. The spoileron on the other wing remains in place, eliminating any additional drag that would've been caused by an aileron.
11. **What is the difference between a stabilator and an elevator?**
With a stabilator, the entire horizontal surface of the tail moves, as opposed to an elevator, where the horizontal stabilizer remains stationary while just the elevator moves.

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Structure and properties of matter
- Interactions of energy and matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology



Reference Materials

Fig. 1 Airplane Diagram

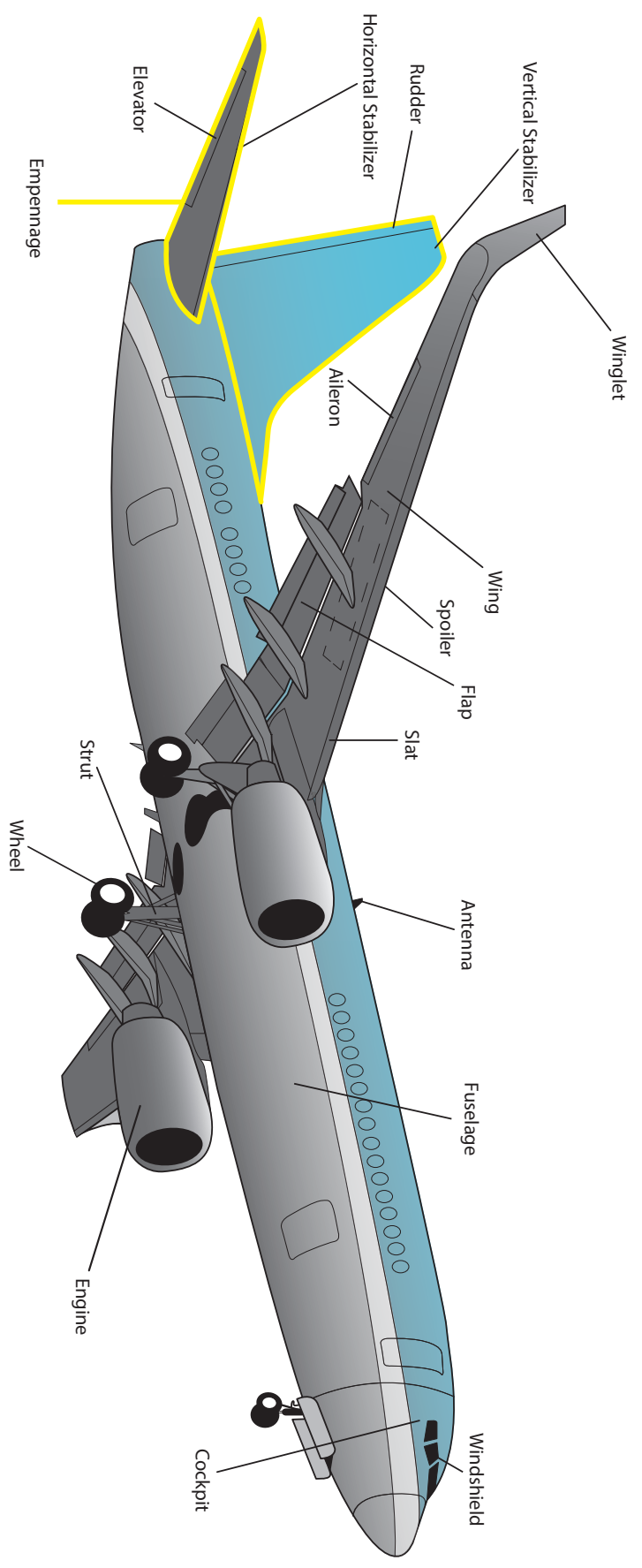


Fig. 2 Propeller Path

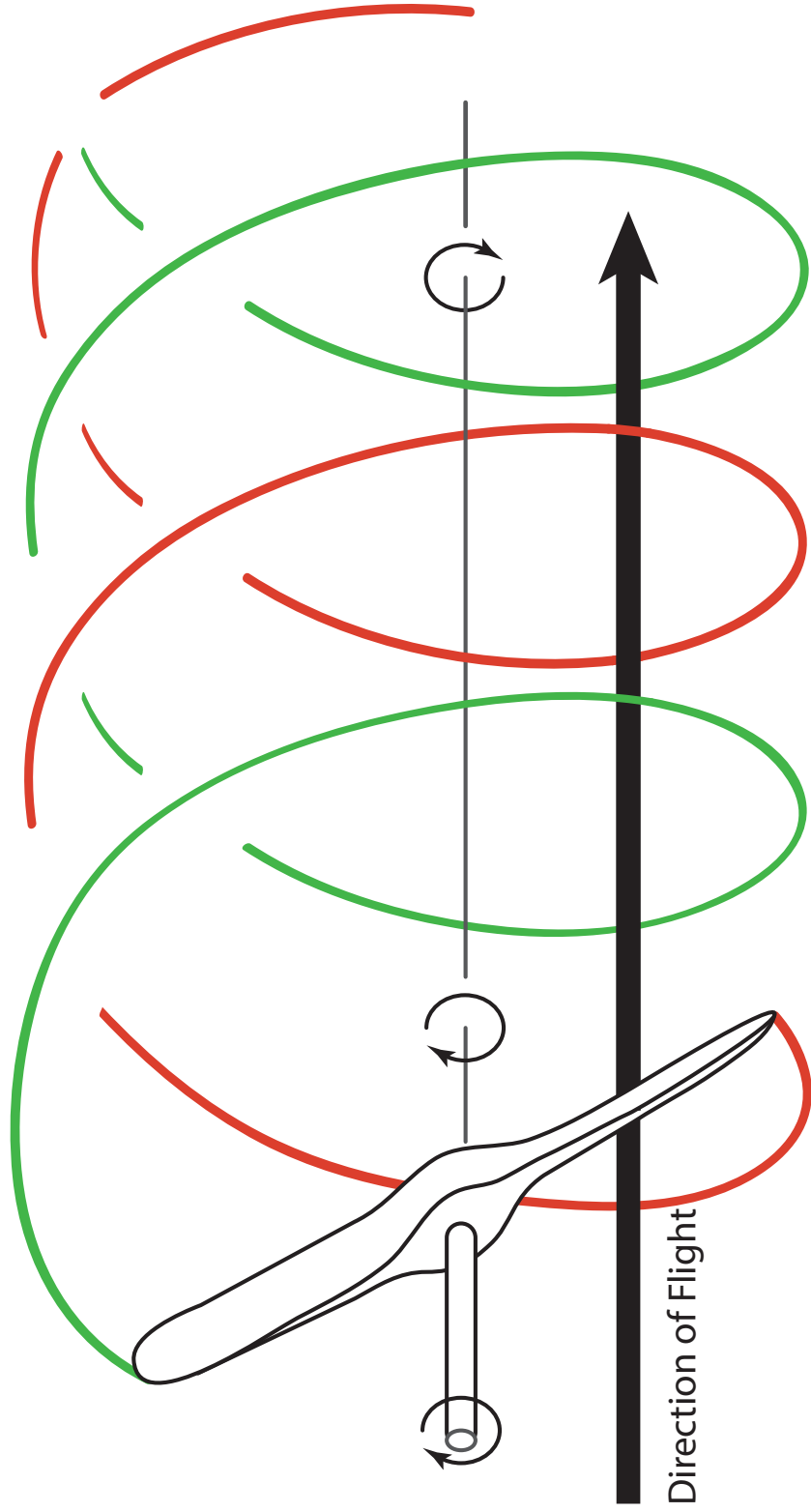
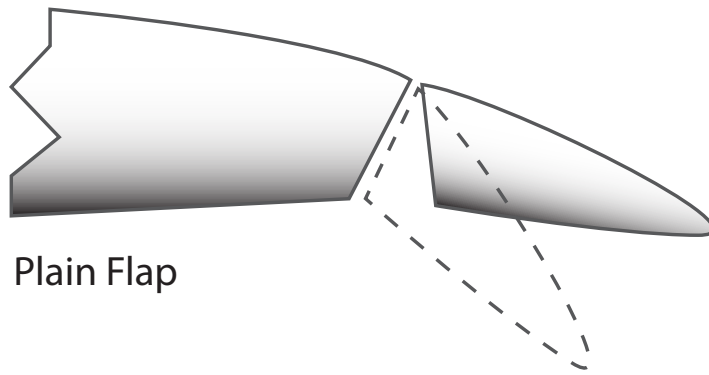
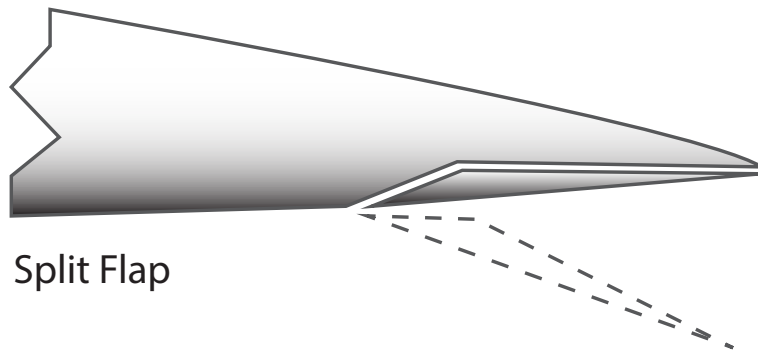


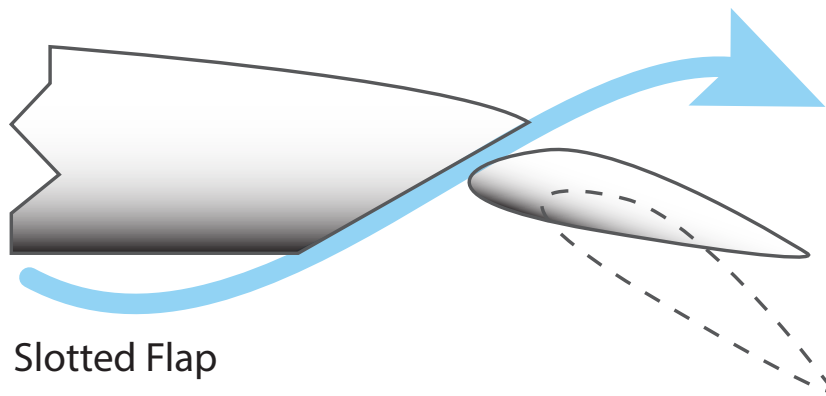
Fig. 3 Flaps



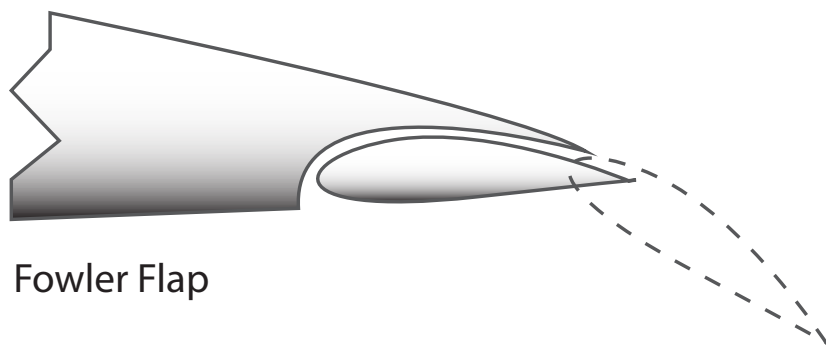
Plain Flap



Split Flap



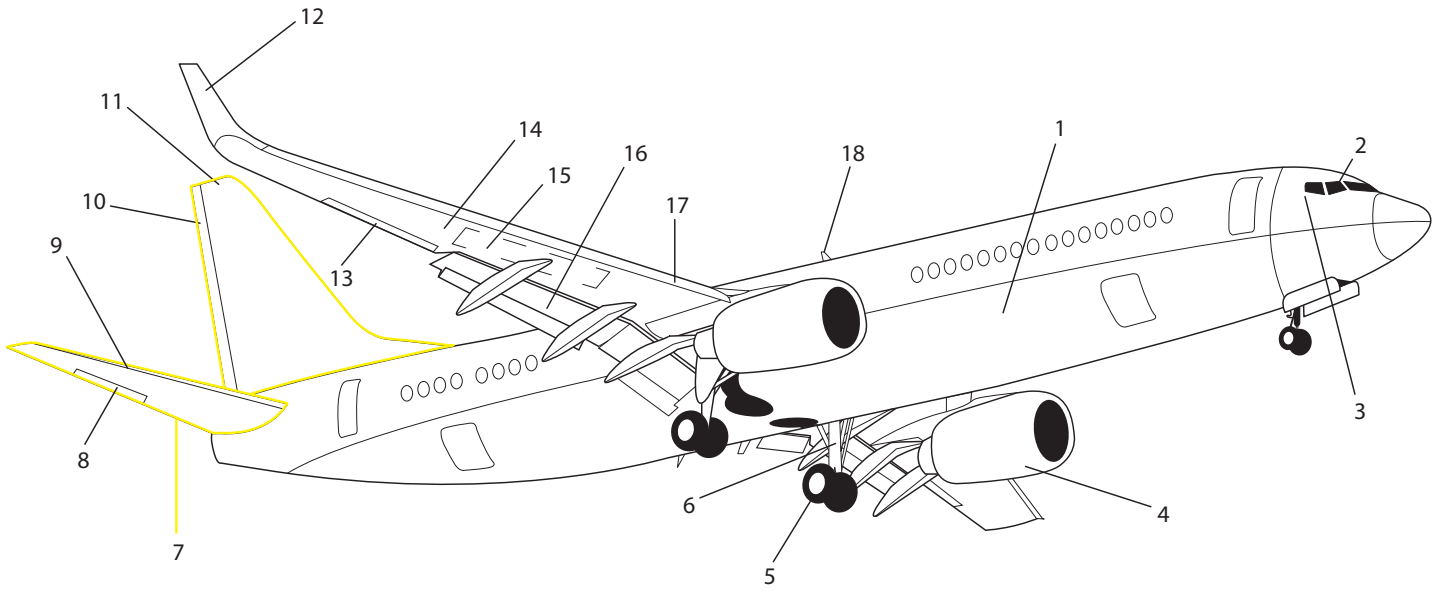
Slotted Flap



Fowler Flap



Student Worksheets



1. _____
2. _____
3. _____
4. _____
5. _____
6. _____
7. _____
8. _____
9. _____
10. _____
11. _____
12. _____
13. _____
14. _____
15. _____
16. _____
17. _____
18. _____

Word Bank	
Aileron	Rudder
Antenna	Slat
Cockpit	Spoiler
Elevator	Strut
Empennage	Vertical Stabilizer
Engine	Wheel
Flap	Windshield
Fuselage	Wing
Horizontal Stabilizer	Winglet

1. Describe the following aircraft motions.
Pitch:

Roll:

Yaw:
2. Which parts of an airplane are used to control lift at low speed for takeoff and landing?
3. Which aircraft component has two parts, installed one on each wing, that operate in opposite directions (i.e., one up and one down)?
4. If the component in question 3 is up on the right wing and down on the left, what will the aircraft do?
5. What language do the terms "fuselage" and "empennage" come from?
6. What is a spoiler and why would a pilot use it?
7. There are four main types of flaps; what are they and how does each design differ from each other?

8. If the pilot pushes forwards on the control column or control stick, what will the airplane do?
9. What is a Canard-style airplane?
10. What is the difference between a spoiler and a spoileron?
11. What is the difference between a stabilator and an elevator?



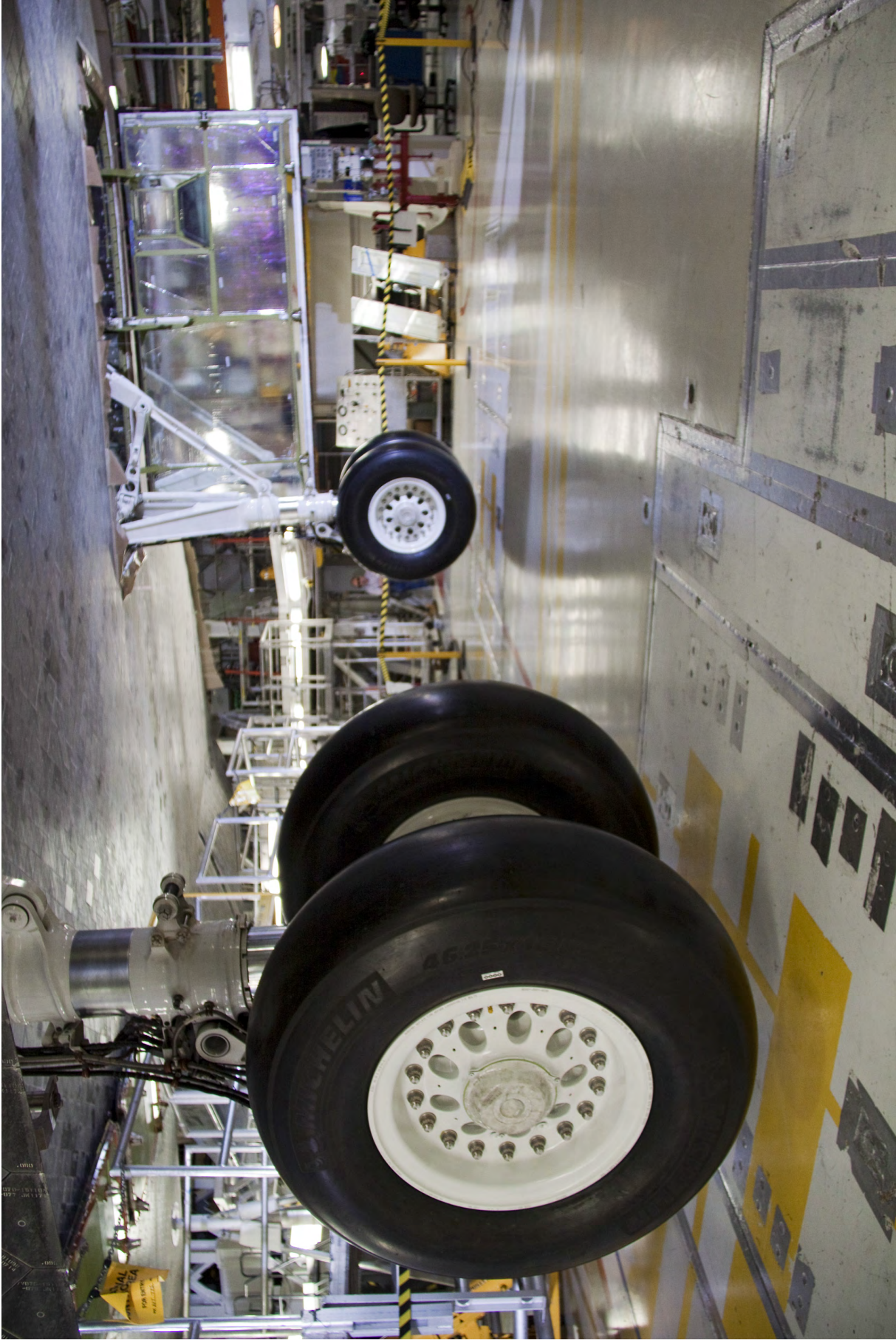
Images

Img. 1 Ground spoilers on an Airbus 320 aircraft



(Public Domain)

Img. 2 The straight leg landing gear of the Space Shuttle Atlantis



(Photo courtesy of NASA)

Img. 3 Trailing link landing gear



(Photo courtesy of Lost Tribe Media, Inc.)

Img. 4 A NASA modified essna 190



(Photo courtesy of NASA)

Img. 5 A Lockheed C-69 Constellation



(photo courtesy of The United States Air Force)

Img. 6 A modified Boeing 747 carrying the Space Shuttle Enterprise

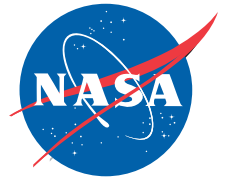


(Photo courtesy of www.NASAIMages.org)

Aeronautics
Research
Mission
Directorate



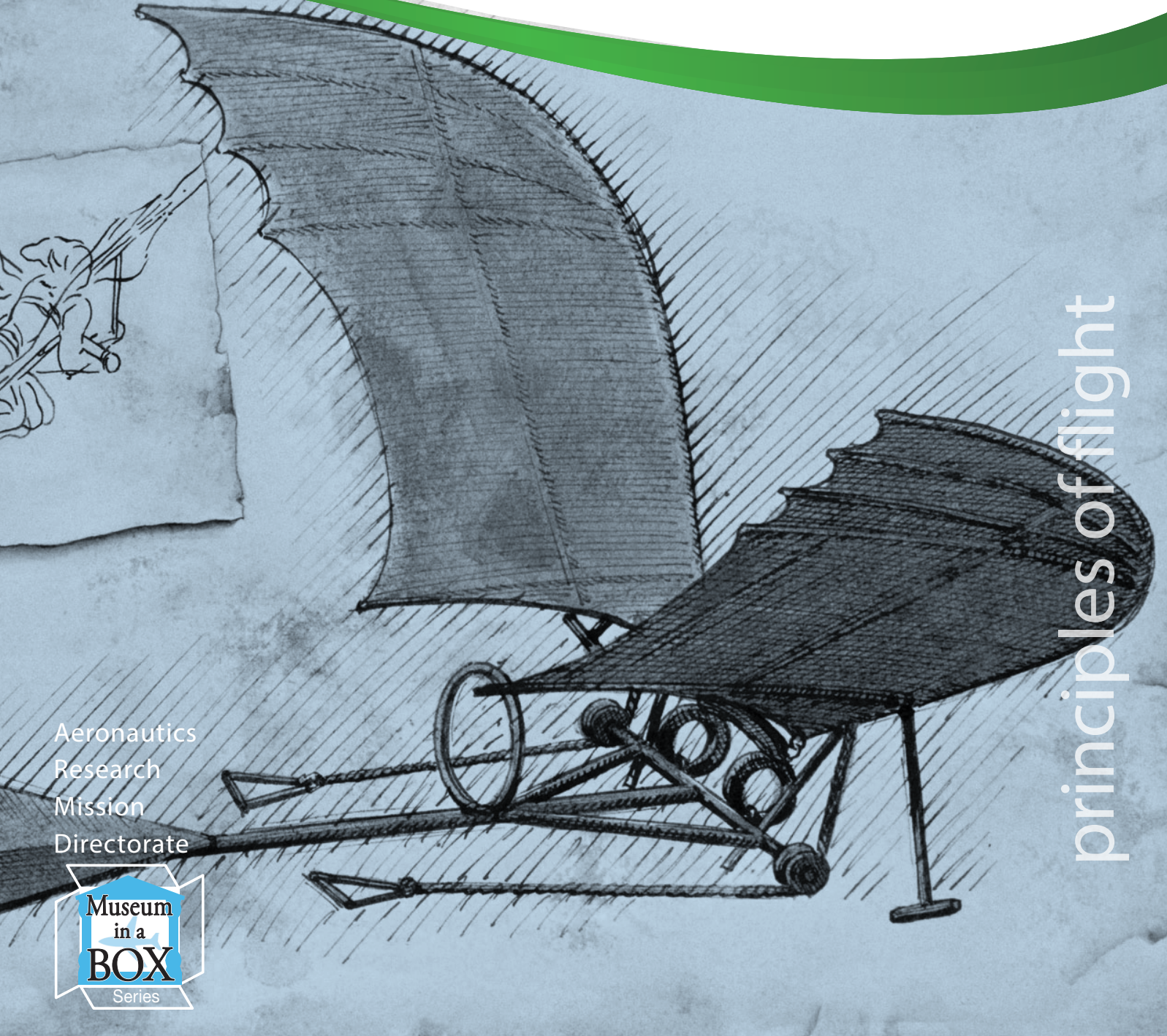
parts of an airplane



GRADES

K-12

Kites



principles of flight

Aeronautics
Research
Mission
Directorate



Kites

Lesson Overview

In this lesson, students will learn about position and motion of object, changes in earth and sky, abilities to distinguish between natural objects and objects made by humans, and abilities of technological design as they learn about one of the forces of nature and how it impacts objects in the air. The force of nature we will focus on is “air” or “wind.” Students will comment on how the wind acts on various objects. They will make observations based on what they see and learn how to identify the direction the wind is blowing. Students will also learn to gauge approximately how fast the wind is moving based on objects in nature and their movements. Students will learn about the Beaufort Wind Scale and why it was developed. Students will be able to make educated estimates about how many knots the wind is moving outside by observing objects in nature and their movements.

Students will follow directions to create simple kites and draw conclusions from their understanding of the power of wind as it applies to the activity of flying. By understanding that animals and humans can use nature’s power of wind to accomplish different activities, students will learn how the forces of nature can impact our daily lives.

Objectives

Students will:

1. Understand that wind is a force of nature.
2. Explain how wind impacts objects in the air.
3. Be able to identify the direction the wind is blowing.
4. Be able to identify approximately how fast the wind is moving.
5. Create simple kites.
6. Identify man-made objects that fly.
7. Identify objects in nature that fly.
8. Identify different shapes of kites.
9. Identify different types of kites.

Materials:

In the Box

Fan
Balloons
Large ball of string
Scissors
Store-bought kites
Clear tape
Glue sticks
Crayons
Colored pencils
Markers
Small foam plates (dessert size)
Unsharpened pencils
Paper-hole puncher
Fan (optional)
Small plastic bags
Large plastic bags
Ruler
Compass
Stencils

Provided by User

Quarter
Pre-cut shapes for students (quantity based on group size)
Paper towel dowels

GRADES

K-4

Time Requirements: 2 ¾ - 4 hours

Background

Kites have dazzled our skies for over 2,000 years. Using silk and bamboo, the Chinese were the first to fly kites. The Japanese flew kites mostly for religious reasons. Often times kites were fitted with whistles or strings in order to make musical sounds while in flight. Kites were decorated with mythological themes or legendary figures to show respect as well. It was not until the 18th century that kites were used and taken seriously in Europe. Kites became more than just important religious symbols; they had become instruments of scientific research. The "Golden Age of Kiting," is said to have occurred from 1860 to 1910. Kites were used for meteorology, aeronautics, wireless communication and photography. After the Wright Brothers flew their "Wright Flyer," in 1903, interest in kites diminished and by WWII, kites had become a toy used primarily for recreation.



Img. 1 Children flying kites



Img. 2 Cody manlifter

While we are not exactly sure when the first kite was flown, it has been documented that Chinese General Han Hsin flew a kite over the wall of a city he was attacking around the year 200 B.C. He wanted to measure how far his army would have to tunnel underneath the city in order to reach past its defenses. Another story recounts that nearly 300 years ago a thief used a large kite to carry himself to the top of a castle so he could steal a golden statue from the roof.

Kites also were used to carry cameras and meteorological instruments. The British, French, Italian, and Russian armies utilized kites during World War I for immediate observations and signaling. During World War II however, the United States Navy found other uses for kites. For example, kites were flown to prevent airplanes from flying too low over targets, used for target practice, and if a pilot was lost at sea they would raise a kite so they could be found.

Samuel Cody came to the attention of the English War Office after he crossed the English Channel in a boat drawn by a kite. He continued his experiments with passenger kites and lifted a person to a new record high of 1600 feet. Cody's design was adopted in 1906, and his war kites were used for observation until they were later replaced by aircraft.

Eventually Cody's interest turned to gliders, which was based largely on his kite designs. Cody and his kite had a profound impact on the British Army. He became the chief instructor in kiting at the balloon school in Aldershot, England. It was also during this period of time that Cody built a motorized kite. He wanted to develop one of his motorized kites into a man-carrying airplane. However, the British Army was more interested in airships during 1907 than they were in airplanes.

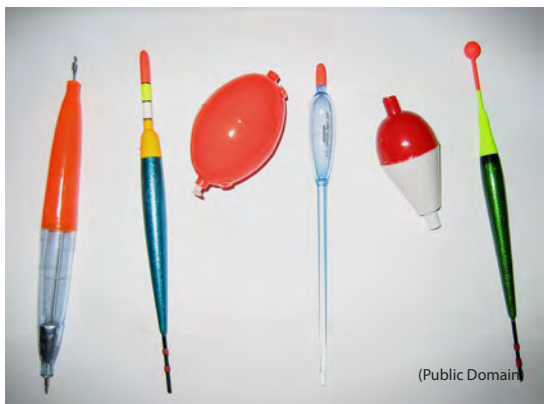
Perhaps one of the most interesting kites in history was one constructed by Alexander Graham Bell. His kite was specifically designed to carry people. Bell believed that the best type of kite to do this was a tetrahedron kite. A tetrahedron is essentially a triangular pyramid: a three-dimensional figure with four equilateral triangles.

His first kite, called the Frost King, was comprised of 256 cells or tetrahedrons. Bell was determined to build a kite that could carry a man, and therefore, increased his tetrahedron kite structure from 256 cells to 1300. In 1907, Bell built another kite which he called the Cygnet. It was the first kite he had ever designed, manned with a person and then flew. The kite contained 3,393 cells and had floats attached to the bottom so it could land on water. Just imagine how it must have felt to fly that kite! Graham's kite flew for 7 minutes and went as high as 168 feet.

When we think of kites today, we usually think of them as recreational. For example, something a family would do at a park on a windy day. Interestingly, kites have had many useful purposes in the past and continue to, even to this day. Fisherman today use something called a "bobber," to help them determine when a fish bites their line.



Img. 4 Bell's tetrahedron kite



Img. 5 Fishing bobbers

Imagine fishing from the beach; what can a kite do that a regular fishing pole could not? The kite can take a fishing line far offshore where larger fish are located. The normal distance a fisherman can cast his pole cannot reach the same distance that a kite could be flown. Long-ago Chinese fishermen actually used kites in the same manner. They would tie fishing line to the end of their kite, and when the fish took the bait, the kite would move.



Img. 3 Samuel Cody

Today, farmers use scarecrows to keep birds away that would eat their crops. Chinese farmers would use kites in their fields in much the same manner. Kites were also used for testing the wind, measuring distances, and signaling. During WWII, kites were used by Navy anti-aircraft gunners for target practice. The military used kites because they



Img. 6 Kite fishin

maneuver in the air in a similar fashion to the fighter aircraft that the gunners were responsible for defending their battleships against. Kites are still used today by the military for target practice. Scientists use kites as well to conduct experiments and to gather meteorological readings. Competitions are held for stunt kites and for recreational use. Their design has expanded beyond the known diamond and box kites.

There are many types of kites, and over the years the materials used to build kites has changed. Materials have included silk, bamboo, string, plastic, nylon, wood and more. NASA has classified five different types of kites. Reviewing the different kites will help you as the teacher, and will help prepare your students for this lesson. The five types of kites discussed in this lesson are the Winged Box, the Sled, the Delta, the Box Kite, and finally the Diamond.



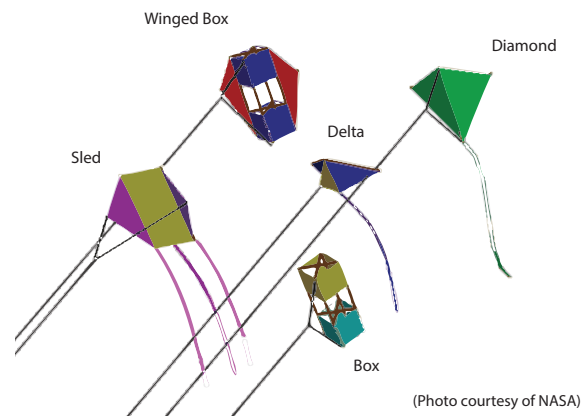
Img. 7 Scarecrow

All kites must be lightweight and strong to endure powerful winds. A solid frame made usually of wood or plastic serves as the base of the kite, while paper, plastic, or cloth serve as the kite's skin. Kites will range in abilities based on

their construction. Some kites are very stable while others are extremely maneuverable. Kites also can soar to high altitudes and others can perform magnificent stunts.



Img. 8 A modern kite



Img. 9 Types of kites



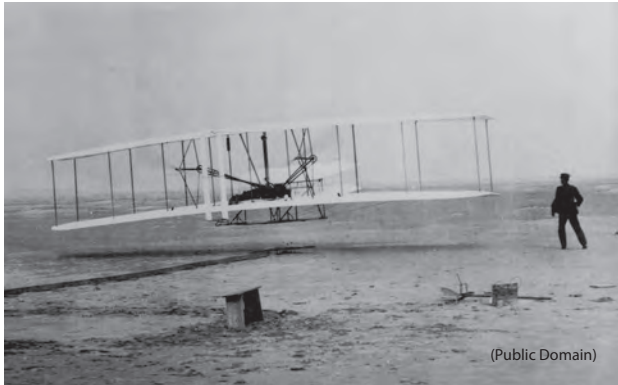
Img. 10 Leonardo da Vinci's Ornithopter

Many of us have seen the famous picture of Benjamin Franklin and his kite (Img. 5). However, Franklin was not the first one to use kites in a scientific fashion. During the late 1400s, Leonardo da Vinci began to study flight by observing birds. Later he flew kites which inspired him to design flying machines.



Img. 11 Benjamin Franklin flyin his kite

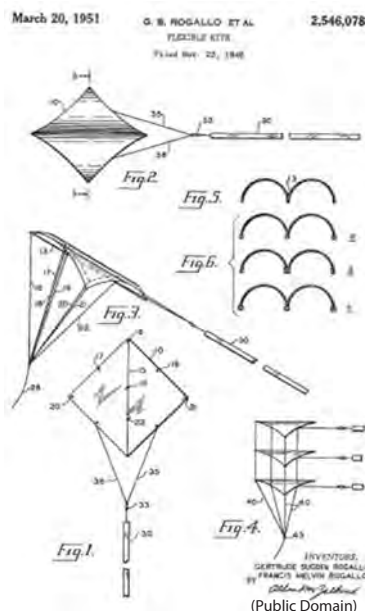
In 1899, the Wright Brothers built a bi-plane kite, which was the kite that was used to invent wing warping, a significant discovery. The Wright Brothers gained further insight about how to create the world's first working flying machine by learning that the wings of a kite could be twisted or warped. By



Img. 12 Wright fl er

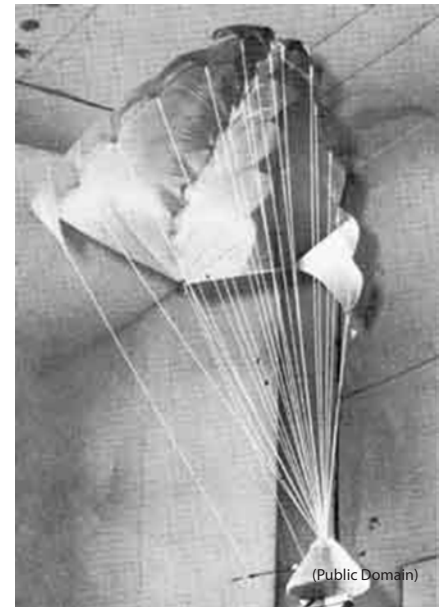
finding a way to twist the wings, it gave them greater control of their kite. This led to their creation of gliders, which then led to their invention of the Wright Flyer

Created by Gertrude and Francis Rogallo in 1948, the Rogallo wing or parawing is a flexible type of airfoil. This flexible wing was considered by NASA to be an alternate recovery system for the Gemini space capsule. Composed of two partial conic surfaces, both cones point forward and is considered to be a simple and inexpensive

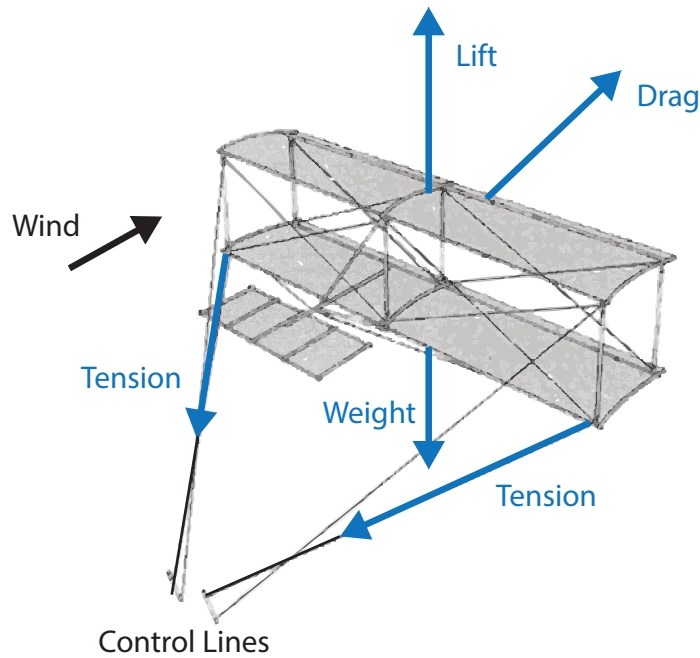


Img. 14 Rogallo patent

flying wing that has many remarkable properties. The Rogallo wing itself cannot be classified as a powered aircraft glider or kite. The way in which the wing is attached and manipulated does not allow it to be classified as a kite or glider. It has been used in toy kites, spacecraft parachutes, ultralight powered air craft, gliders, and in sport parachutes. What makes the wings so special is that it is designed to bend and flex in the wind. This provides favorable dynamics which can be compared to a spring suspension in an automobile.



Img. 13 Rogallo's wing



(Photo courtesy of NASA)

Img. 15 Forces on a kite

Similar to airplanes, kites are affected by wind and the four forces of flight; weight or gravity, lift, drag, and thrust. When a kite flies, it overcomes the force of gravity because the force of the wing and its pressure on the kite's surfaces helps to push it upward. Since kites are heavier than air, they weigh more than the volume of the air they displace. The air pressure increases as the wind hits the face or front surface of the kite.

The air blowing onto the face of the kite, traveling around its sides and down the kite's backside creates a low pressure area above the kite. When the wind hits the front of the kite, the wind is deflected downward, and there is a force in the opposite direction, which pushes the kite upward. This action depicts Newton's Third Law of Motion, which states that for every action there is an equal and opposite reaction. The shape of the kite affects the distribution of the aerodynamic forces. All of these things come into play when flying a kite, whether for fun or for scientific experimentation.



Without wind, it is very hard to fly a kite. Some days the wind is too calm for a kite to take flight or to conduct kite experiments. Other times flying a kite would not be optimal, for example, during a thunderstorm. Today, we have a variety of meteorological instruments that can measure the wind, weather, and temperature. However, prior to the 1800s, we had to guess the wind speed. That changed when Sir Francis Beaufort, who was serving on the HMS Woolwich in 1805, devised a scale to measure wind speed based on his observations of nature and man-made objects. His sea-based wind observation system, now referred to as the Beaufort Scale (Fig. 1), standardized the measurement of wind using a 0-12 rating scale. The ratings were based on the estimated wind knots through observation of what could be seen from the ocean to trees on land. Eventually, the scale was adapted from sea to land which is what we will learn about in this lesson.

Using the Beaufort scale while at sea is a tool that most boat captains still use today. In addition, the BBC radio in the United Kingdom uses it for shipping forecasts, as does the Irish Meteorological Service. China, Greece, Hong Kong and Taiwan also use this scale.

Humans have always been fascinated with flying. Before we could wrap our heads around something like Leonardo da Vinci's Orinopter, we managed to fly high in the sky aboard man-carrying kites. Kites have dazzled our skies and our imagination for over 2,000 years. We have learned that kites were made of different materials and that over the years these materials have become more advanced as technology in construction has improved. The creativity of those who have been involved in designing kites is remarkable. Their purposes range from fishing, to farming, to military intelligence and scientific experiments which show just how diverse kites have been and continue to be to this day.

Fig. 1 The Beaufort scale

Beaufort number	Description	Wind speed	Wave height	Sea conditions	Land conditions
0	Calm	< 1 km/h (< 0.3 m/s)	0 m	Flat.	Calm. Smoke rises vertically.
		< 1 mph			
		< 1 kn	0 ft		
		< 0.3 m/s			
1	Light air	1.1–5.5 km/h (0.3-2 m/s)	0–0.2 m	Ripples without crests.	Smoke drift indicates wind direction and wind vanes cease moving.
		1–3 mph	0–1 ft		
		1–2 kn			
		0.3–1.5 m/s			
2	Light breeze	5.6–11 km/h (2-3 m/s)	0.2–0.5 m	Small wavelets. Crests of glassy appearance, not breaking.	Wind felt on exposed skin. Leaves rustle and wind vanes begin to move.
		4–7 mph	1–2 ft		
		3–6 kn			
		1.6–3.4 m/s			
3	Gentle breeze	12–19 km/h (3-5 m/s)	0.5–1 m	Large wavelets. Crests begin to break; scattered whitecaps.	Leaves and small twigs constantly moving, light flags extended.
		8–12 mph	2–3.5 ft		
		7–10 kn			
		3.4–5.4 m/s			
4	Moderate breeze	20–28 km/h (6-8 m/s)	1–2 m	Small waves with breaking crests. Fairly frequent whitecaps.	Dust and loose paper raised. Small branches begin to move.
		13–17 mph	3.5–6 ft		
		11–15 kn			
		5.5–7.9 m/s			
5	Fresh breeze	29–38 km/h (8.1-10.6 m/s)	2–3 m	Moderate waves of some length. Many whitecaps. Small amounts of spray.	Branches of a moderate size move. Small trees in leaf begin to sway.
		18–24 mph	6–9 ft		
		16–20 kn			
		8.0–10.7 m/s			
6	Strong breeze	39–49 km/h (10.8-13.6 m/s)	3–4 m	Long waves begin to form. White foam crests are very frequent. Some airborne spray is present.	Large branches in motion. Whistling heard in overhead wires. Umbrella use becomes difficult. Empty plastic garbage cans tip over.
		25–30 mph	9–13 ft		
		21–26 kn			
		10.8–13.8 m/s			

Fig. 1 The Beaufort scale (cont.)

Beaufort number	Description	Wind speed	Wave height	Sea conditions	Land conditions
7	High wind, Moderate gale, Near gale	50–61 km/h (13.9-16.9 m/s)	4–5.5 m	Sea heaps up. Some foam from breaking waves is blown into streaks along wind direction. Moderate amounts of airborne spray.	Whole trees in motion. Effort needed to walk against the wind.
		31–38 mph			
		27–33 kn	13–19 ft		
		13.9–17.1 m/s			
8	Gale, Fresh gale	62–74 km/h (17.2-20.6 m/s)	5.5–7.5 m	Moderately high waves with breaking crests forming spindrift. Well-marked streaks of foam are blown along wind direction. Considerable airborne spray.	Some twigs broken from trees. Cars veer on road. Progress on foot is seriously impeded.
		39–46 mph			
		34–40 kn	18–25 ft		
		17.2–20.7 m/s			
9	Strong gale	75–88 km/h (20.8-24.4 m/s)	7–10 m	High waves whose crests sometimes roll over. Dense foam is blown along wind direction. Large amounts of airborne spray may begin to reduce visibility.	Some branches break off trees, and some small trees blow over. Construction/temporary signs and barricades blow over.
		47–54 mph			
		41–47 kn	23–32 ft		
		20.8–24.4 m/s			
10	Storm Whole gale	89–102 km/h (24.7-28.3 m/s)	9–12.5 m	Very high waves with overhanging crests. Large patches of foam from wave crests give the sea a white appearance. Considerable tumbling of waves with heavy impact. Large amounts of airborne spray reduce visibility.	Trees are broken off or uprooted, saplings bent and deformed. Poorly attached asphalt shingles and shingles in poor condition peel off roofs.
		55–63 mph			
		48–55 kn	29–41 ft		
		24.5–28.4 m/s			
11	Violent storm	103–117 km/h (28.6-32.5 m/s)	11.5–16 m	Exceptionally high waves. Very large patches of foam, driven before the wind, cover much of the sea surface. Very large amounts of airborne spray severely reduce visibility.	Widespread damage to vegetation. Many roofing surfaces are damaged; asphalt tiles that have curled up and/or fractured due to age may break away completely.
		64–72 mph			
		56–63 kn	37–52 ft		
		28.5–32.6 m/s			
12	Hurricane force	≥ 118 km/h (≥ 32.8 m/s)	≥ 14 m	Huge waves. Sea is completely white with foam and spray. Air is filled with driving spray, greatly reducing visibility.	Very widespread damage to vegetation. Some windows may break; mobile homes and poorly constructed sheds and barns are damaged. Debris may be hurled about.
		≥ 73 mph			
		≥ 64 kn	≥ 46 ft		
		≥ 32.7 m/s			

Activity 1a

Diamond Kite Construction 101

GRADES

K-2

Time Requirements: 90 minutes

Materials:

In the Box

- Kite Template on Legal Size paper (1 per student)
- Scotch Tape (enough for a class, 2-3 rolls)
- Large lightweight paper bag from supermarket used to pack groceries (1 per student)
- Writing implement for purpose of tracing on paper bag (1 per student)
- Scissors (1 per student)
- Non-flexible straws at least 8 inches long (4 per student)
- Ribbon (2-3 inches wide and enough for at least 12 feet per student)
- Yard stick or tape for measuring purposes (2-4 for the class)
- Pre-cut string for kite flying purposes (25-30 feet per student)
- Unsharpened pencils or firm elongated item to wrap kite flying string (1 per student)

Provided by User

None

Worksheets

None

Objective:

Through experimentation, students will:

1. Understand that wind is a force of nature.
2. Explain how wind impacts objects in the air.
3. Use prior knowledge and new information gained through the activity to construct their own diamond kite.

Activity Overview:

Students will create and fly their diamond kite by following the directions and using the materials provided.

Activity: Preparation for Teacher (or skillful students working in pairs, i.e., 3rd or 4th graders):

Additional help will be needed to assist the children with building their kites, i.e., older students or other adults.

Be sure it is a windy day to test-fly the kites. Otherwise, students will be disappointed when their kites do not fly due to lack of wind. Have students stand with their back to the wind before releasing the kite.

It is recommended for the younger students that the teachers not only prepare the kite sails, but cut pieces of pre-measured tape, string, and ribbon as well.

Preparation of kite template on legal size paper:

1. Copy the number of kite templates per number of students in your class.
2. Either the teacher or student cuts along the two black lines from corner edge to corner edge of the kite template copied on legal size paper.

Preparation of four 8-inch straws as kite-frame structure:

1. Take one straw and pinch one end. Insert that pinched end into a second straw so that they overlap 1 ½ inches.
2. Do the same with the other two straws so they, too, overlap 1 ½ inches.
3. Set aside.

Reference Materials

Kite Template
(Figure 2)

Key Terms:

- Bridle
- Cover
- Flying line
- Kite frame
- Spar
- Spine
- Tail

Preparation of four 8-inch straws as kite-frame structure:

1. Open the empty paper grocery bag and place it upright on a hard surface.
2. Choose any corner of the bottom of the bag, and with your scissors punch a hole in that corner.
3. Using that hole as your starting point, cut around the edges and cut off the bottom of the bag.
4. Flatten the bag on a hard surface along one of the creases.
5. Place one kite template (Fig. 2) with line A-C along each of the folded creases.
(2 kite templates should fit on each creased side of the grocery bag.)
6. Trace the kite templates.

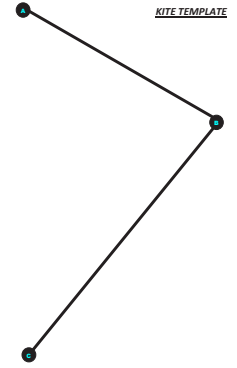
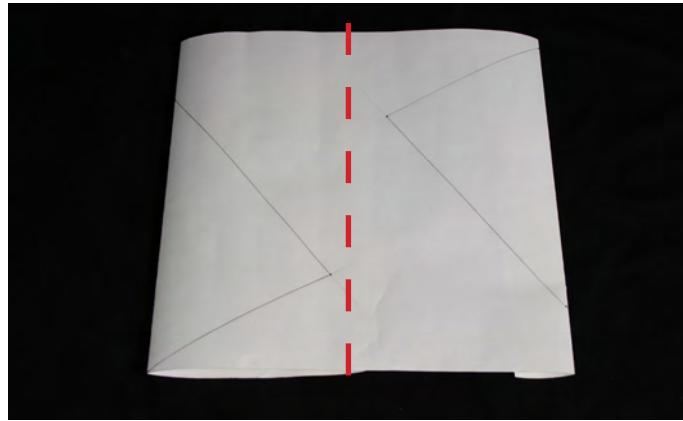
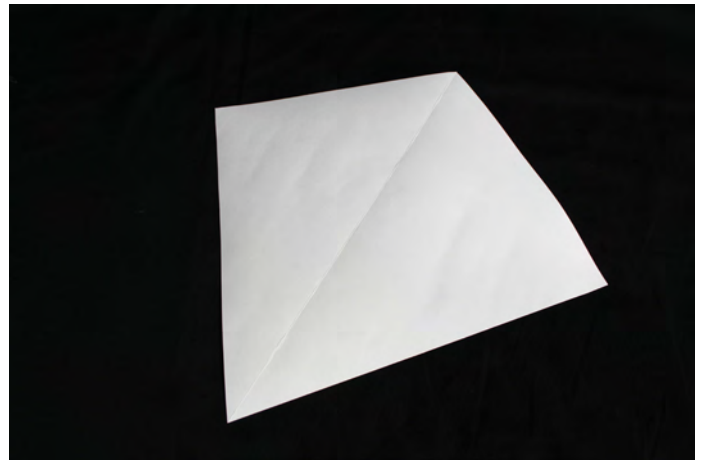


Fig. 2 Kite Template



7. Cut the paper bag vertically through the center to separate the two traced-kite templates.
(A teacher can cut the bag or one student of the paired 3rd or 4th graders can cut the bag to provide two kites.)

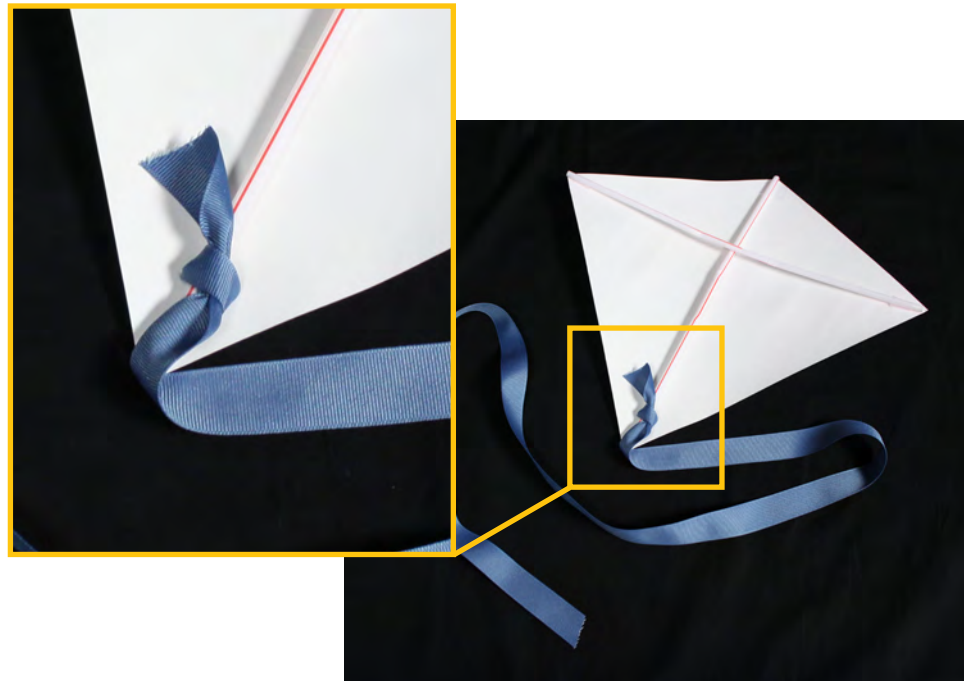
8. Cut out the templates and unfold to reveal a diamond-shaped kite.



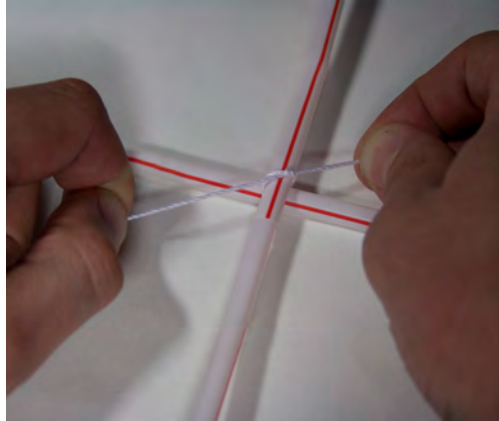
9. OPTIONAL – decorate/color kite.

Kite Construction:

1. Place one set of "joined" straws vertically across the kite from one point to the other.
2. Tape the straw ends onto the top and bottom "corner" ends of the paper kite.
3. Place the other set of "joined" straws horizontally along the kite from one point to the other.
4. Tape the straw onto the other "corner" ends of the paper kite.
5. Cut a piece of ribbon measuring 60 inches in length.
6. Tie one end of the ribbon to the end of the vertical kite dowel.



7. Measure and cut 25 feet of string for the kite.
8. Take one end of the 25 feet of string and tie it with a double knot where the two straws cross in the center of the kite.



9. Tie the other end of the 25 feet of string around the un-sharpened pencil.
10. Take a piece of scotch tape and secure the knot you just made to the pencil.
11. Wrap the string around the pencil until there is about 3 to 4 feet left.



12. Your kite is prepared for flight!

Ensure it is a windy day to fly the kite and students have their back to the wind before releasing the kite!

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials
- Position and motion of objects
- Science as human endeavor

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL MATH STANDARDS K-4

MEASUREMENT

- Understand how to measure using nonstandard and standard units
- Select an appropriate unit and tool for the attribute being measured
- Understand the need for measuring with standard units and become familiar with standard units in the customary and metric systems;
- Use tools to measure
- Select and apply appropriate standard units and tools to measure length, area, volume, weight, time, temperature, and the size of angles

Activity 1b

Diamond Kite Construction 101

GRADES

3-4

Time Requirements: 2 hours

Materials:

In the Box

- Kite string
- Scotch Tape and glue
- Knife or small saw)
- Sheet of strong paper or garbage bag (102 cm x 102 cm) (40 in x 40 in)
- 2 strong, straight wooden sticks (wooden doweling) 90 cm (35 in) and 102 cm (40 in)
- Different colored markers, paint or crayons to decorate your kite
- Strips of cloth

Provided by User

None

Worksheets

None

Reference Materials

None

Key Terms:

- Bridle
- Cover
- Flying line
- Kite frame
- Spar
- Spine
- Tail

Objective:

Through experimentation, students will:

1. Build a diamond kite and fly it.

Activity Overview:

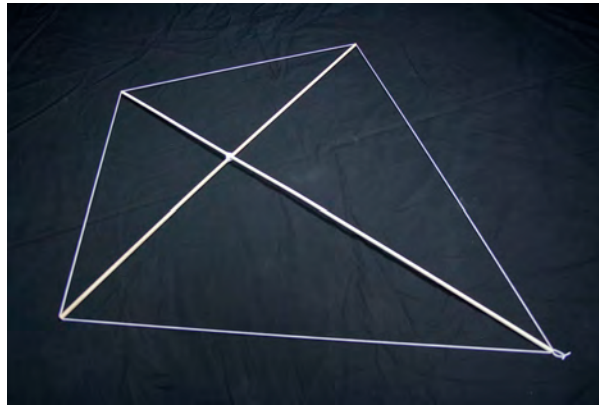
Students will build and fly their own basic diamond kite by following the directions and using the materials provided.

Activity: Preparation for Teacher

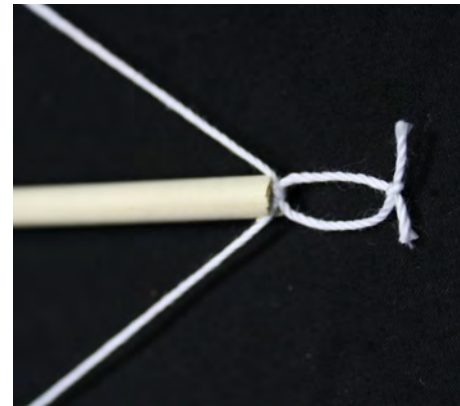
1. **The first thing to do is to make a cross with the two sticks.** The 102 cm (40 in) stick is the spine and the 90 cm (35 in) stick is the spar. It is important to ensure that both sides of the cross piece are equal in length.
2. **Next, tie the two sticks together with string where the two sticks cross.** Make sure the sticks are securely lashed together. A dab of glue can also be used with the string to ensure a stronger bond between the sticks. Tie the two sticks together with the string in such a way as to make sure that they are at right angles to each other.



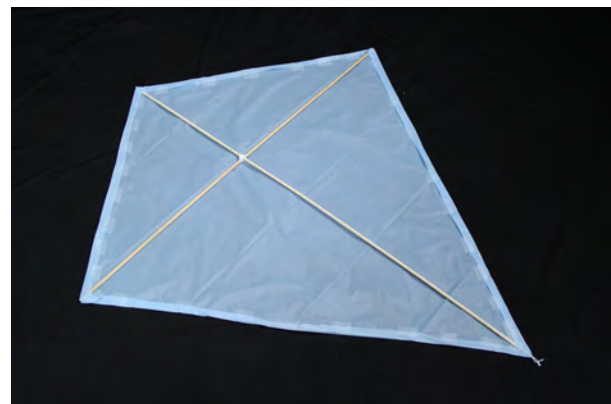
3. Use a knife or small saw to cut a V shaped notch at each end of both sticks. The notch must be large enough to allow for the string to fit into it. Then cut a piece of string to stretch around each end of the sticks.



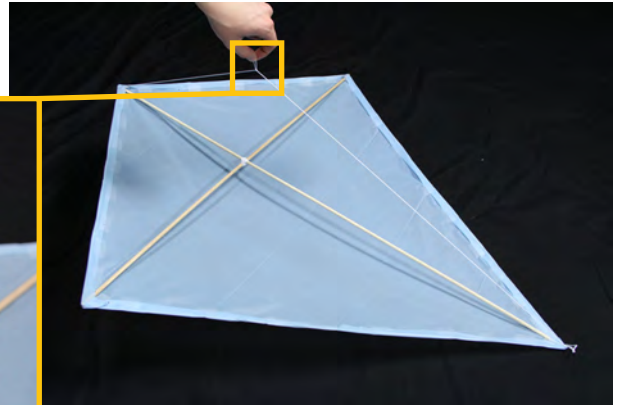
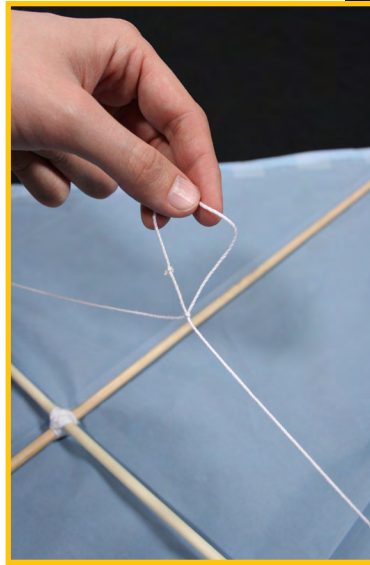
When the string has been stretched around the kite make a loop and tie both ends of the string together. The string should be taut, but not so tightly fitted as to warp the sticks. This is the kite frame.



4. Lay the kite frame flat and place the stick frame face down on top of the paper or garbage bag (102 cm x 102 cm) (40 in x 40 in). Carefully, cut around the kite frame and do not cut the string. Leave about 2-3 cm (3/4 in – 1 in) for a margin beyond the string. Fold these edges over the string frame and tape or glue it down so that the material is tight.



- Next, cut a piece of string about 125 cm (50 in) long. On the front side of the kite, tie one end of the string on the top of the spine and then tie the other end to the bottom of the spine.



Tie a small loop in the string just above the intersection of the spine and spar. This is the kite's bridle. The string to fly the kite is to be attached to the loop in the bridle.

- Make a tail by tying small pieces of cloth together. Attach the tail to the loop at the bottom of the kite.



Further suggestions

- Sometimes it is helpful to put a slight bow in the kite. To do this stretch a piece of string from one end of the spar to the other end and gently pull to create a bow in the kite and then tie the string to one end of the spar.
- NEVER FLY A KITE NEAR A POWER LINE**
- NEVER FLY A KITE IN A THUNDERSTORM**

Experiment with your kite and have fun!

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials
- Position and motion of objects
- Science as human endeavor

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL MATH STANDARDS K-4

MEASUREMENT

- Understand how to measure using nonstandard and standard units
- Select an appropriate unit and tool for the attribute being measured
- Understand the need for measuring with standard units and become familiar with standard units in the customary and metric systems;
- Use tools to measure
- Select and apply appropriate standard units and tools to measure length, area, volume, weight, time, temperature, and the size of angles

Activity 2

Wind, Shapes, and Kites - Oh My!

GRADES**K-2****Time Requirements:** 75 minutes**Materials:**In the Box

Balloons
 Large ball of string
 Scissors
 Store-bought kites
 Clear tape
 Glue sticks
 Crayons
 Colored pencils
 Markers
 Small foam plates (dessert size)
 Unsharpened pencils
 Paper-hole puncher
 Fan (optional)

Provided by User

Pre-cut shapes for students (quantity based on group size)

Worksheets

Wind Observation
 (Worksheet 1)

Reference Materials

None

Objective:

Through experimentation, students will:

1. Understand that wind is a force of nature.
2. Explain how wind impacts objects in the air
3. Be able to identify direction wind is blowing
4. Be able to identify approximately how fast the wind is moving
5. Identify man-made objects that fl
6. Identify objects in nature that fl

Activity Overview:

Through observation and identification, students will learn about properties of objects and materials, position and motion of objects, abilities of technological design, and science as a human endeavor as they learn to recognize the direction and force of wind. They will discuss their observations as they relate to the force of wind and how it affects objects. Students will test materials and designs, creating kites from a set of supplies based on what they believe will fly the best.

Activity:

1. **Spend about 5 minutes brainstorming with your students.** Ask them to identify man-made objects and entities in nature that fl . *(Answers will include items such as planes, birds, bats, owls, jets and helicopters, etc.)*
2. **Ask the students why we can stay on the ground when we walk and we don't float away.** *(Answers should include weight or gravity.)*
3. **Now ask students what the man-made objects and entities in nature need to fl .** *(Answers could include wings, engines, and lift).* The students need to focus on lift. *Explain to students that lift is a force of flight that helps objects get off the ground. Tell the students that they are going to perform an experiment to show lift and gravity.*

Key Terms:

Beaufort Scale

Gravity

Kite

Observation

Ornithopter

Wind

4. **Ask two students to volunteer.** Give one student a balloon that has been blown up and give one student a pencil. Ask the students what item they believe will hit the ground first, the balloon or the pencil. After you have discussed what they believe will happen have the two students extend their arms out and drop the balloon and pencil at the same time. Have the class count to three together. (3-2-1 drop).
5. **Explain to the students that the experiment they just performed showed us about gravity and that gravity is a force of flight.** Another force of flight they will be learning about is lift. Ask the students what they think the word lift means. *Explain that lift is the opposite of gravity. Gravity is what keeps us on the ground and lift is what helps objects whether man-made like kites or things in nature like birds take off into the air and stay airborne.*
6. **Next, show the students the store-bought kites.** Ask them what shapes they see that are used in the store-bought kites. (*Shapes should include triangles, squares, rectangles, circles and pyramids*).
7. **Each student needs to have a group of shapes in order to create a template for their kite.** These shapes should include triangles, squares, rectangles, circles, pyramids, and trapezoids. Tell the students they need to assemble these shapes into their own unique design using tape or glue sticks. Also, students can decorate their kite with crayons, colored pencils and markers.
8. **Next, pass out a small foam plate to each student.**
9. **Let the students decorate their foam plate kites.** Once they are completed, you may need to help them assemble it. Punch two holes on either side of the plate so that they are of equal distance across on either side of the plate. Next, take the first piece of string and loop it through the hole and tie it off in a knot. Do this same step for the other hole. Now there should be two holes and two pieces of string hanging down from the plate.
10. **Next, take the two pieces of string and tie them at the bottom so they form a "v."** Take the knot and tape the knot to an unsharpened pencil they will use for their kite handle. Wrap the string around the pencil twice and tie into a double knot. The string should be secure and ready for flight.
11. **Now, the students are ready to fly their foam plate kites outside.** If there is not enough wind, you can use a fan for this step. Once the students have test-flown their kites, have them either talk to you about what they experienced (for the younger students) and/or fill out the Wind Observation Worksheet (K-2 and 3-4 students).
12. **The teacher or instructor should test fly the store-bought kites so that the students can compare and contrast their observations to the foam plate kites.** Once they have flown both sets of kites, students will need to complete the rest of the Wind Observation Worksheet.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials
- Position and motion of objects

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

Activity 3

Wind Scientists

GRADES

3-4

Time Requirements: 120 minutes

Materials:In the Box

Balloons
 Large ball of string
 Scissors
 Store-bought kites
 Fan
 Clear tape
 Glue Sticks
 Small foam plates (dessert size)
 Unsharpened pencils
 Paper-hole puncher
 Small plastic bags
 Large plastic bags
 Ruler
 Compass
 Stencils

Provided by User

Quarter
 Pre-cut shapes for students
 (quantity based on group size)
 Crayons
 Colored Pencils
 Markers
 Paper Towel Dowels

Objective:

Through experimentation, students will:

1. Understand that wind is a force of nature.
2. Explain how wind impacts objects in the air
3. Be able to identify direction wind is blowing
4. Be able to identify approximately how fast the wind is moving
5. Identify man-made objects that fl
6. Identify objects in nature that fl

Activity Overview:

Through observation and identification, students will learn about the changes in earth and sky, the abilities of technological design, and understanding about science and technology, and science as a human endeavor as they learn to recognize the direction and force of wind. They will talk about their observations as they relate to the force of wind and how it affects objects. They will create kites from a set of supplies based on what they believe will fly the best. Also, test their kite, materials and designs.

Activity:

1. **Pass out the Beaufort Scale Activity Worksheet.**
2. **Read over the Beaufort Scale Activity Worksheet with the students.** Go over each section and discuss how fast the wind is moving and what the environment looks like on the sea and on land. Ask the students if they have any questions.
3. **Explain to your students that over the course of this activity they will be going outside several times to observe the wind and to record their observations.** Students will need to take notes on what they see and hear outside and compare it to the Beaufort scale chart, indicating how fast they think the wind is blowing.
4. **Have the students go outside before they start the other kite activities.** They will be recording their first wind observation (1 of 3) on their chart. Tell them they will need to take their Wind Observation Worksheet with them so that they can estimate how fast the wind is blowing. They will also need to take their compass with them in order to determine the direction the wind is blowing.

Worksheets

Wind Observation
(Worksheet 1)

Beaufort Scale Activity
(Worksheet 2)

Kite Engineering
(Worksheet 3)

Reference Materials

Beaufort scale
(Figure 1)

Key Terms:

Beaufort Scale

Gravity

Kite

Observation

Ornithopter

Wind

Have the students use their observations and a compass to determine the direction of the wind. If the students are not able to identify the direction of the wind based on trees or smokestacks or other items in nature, have them pick up some grass from the ground and hold it above their head. Next tell them to release the grass and follow the direction that the grass blows away and use their compass to determine the direction of the wind.

5. **Ask them to come back inside and start the next phase of the activity.**
6. **Spend about 5 minutes brainstorming with your students.** Ask them to identify man-made objects and entities in nature that fly. (Answers will include items like planes, birds, bats, owls, jets and helicopters, etc.).
7. **Next ask the students why we can stay on the ground when we walk and we don't float away.** (Answers should include weight or gravity.)
8. **Now ask students what the man-made objects and entities in nature need to fly.** (Answers could include wings, engines, and lift). We need the students to focus on lift. Explain to students that lift is a force of flight that helps objects get off the ground. Tell the students that they are going to perform an experiment to show lift and gravity.
9. **Have the students gather into a circle.** Make sure you have your fan, two inflated balloons including one tied with a string and quarter for weight.
10. **Ask two students to volunteer.** Give them each a balloon, instruct them to stretch their arm out and drop the balloons at the same time on the count of three.
11. **The balloon that is weighted with the string and quarter should fall to the ground first.** Ask the students why they believed that happened. (Answers should include that the weighted balloon is heavier and gravity forced it to the ground faster.)
12. **Take the balloons and ask the students which one they believe will rise faster using only the fan.** Use the fan to send the balloons upward and suspend them there for a few seconds. Make sure the fan is underneath the balloons and pointed upward so that the fan can generate the lift necessary to keep the balloons floating in the air. (Students should conclude that the balloon that weighs less is able to get off the ground faster.)
13. **Explain to the students that this is "lift", another force of flight.**
14. **Have the students go outside to record their second wind observation using their compass and chart.** See step number four for specific instructions.
15. **Ask the students to come back inside and start the next phase of the activity.**
16. **Show your students the store-bought kites.** Ask them what shapes they see (The following shapes should be included: triangles, squares, rectangles, circles, pyramids).

17. **Give the students approximately 30 minutes to create their own kite designs using the store-bought kites and any other kites presented as examples.** Make sure the students fill out the Kite Engineering Student Worksheet which will help them as they build their kites.
18. **After 30 minutes, students should have created their own kite by following the directions on the Kite Engineering Student Worksheet and by using the materials given in the activity.** This will be the student's third and final recording of their wind observations. Have the students take their compass and their chart. Refer to step number four for further instructions.
19. **Now each student should have their own kite that they built completed and ready to fly.** Before the students fly their kites, ask the students to think about what makes the store-bought kites fly. *For example, is it their design? Is it the materials that were used in the construction of the kite? Does the person flying the kite have any control in the kite's flight performance? Have the teacher or instructor take the class outside so that the students can observe the teacher flying these store-bought kites.*
20. **Bring the class back inside and have them prepare their kites for flight.** Have the students estimate how long they think their kites will stay in the air. Students should now take their kites outside and fly them. *The teacher and/or instructor should be prepared to help students with their kites if questions or problems arise.*
21. **Based on the results from the students flying their kites tell them they are allowed 10 additional minutes to make any kind of modifications to their kite in order to produce better flying results.** They will need to explain what changes they made and why they made them. Make sure the students complete their kite engineering worksheet. They need to compare and contrast the store-bought kites with their own handmade kites and include suggestions for improvement to their own kite. The goal is for students to understand that when something is designed and created numerous test trials are conducted to improve design and functionality.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials
- Position and motion of objects

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology
- Science as a human endeavor



Reference Materials

Glossary

Beaufort scale:

The Beaufort scale named after Sir Francis Beaufort of England was created by him in 1805. This scale was developed to determine the force and velocity of wind based on what ships captains and crew observed at sea. Eventually it was translated to a land based scale. The Beaufort scale describes what the environment looks like both on the water and on land based on wind velocity.

Bridle:

The string that is attached to the kite that helps to control it and the line on which the flying line is attached

Cover:

The material that is used to cover the kite frame

Flying line:

The string that runs from the kite's bridle to the string to the person flying the kite

Gravity:

A natural force of attraction which is exerted by terrestrial bodies such as planets and moons where objects that are on or near its surface are drawn towards the center. This is why on the planet Earth objects in motion that are not kept in motion by nature or technology will fall back to the ground. It is also why human beings are able to walk on the grounds without fear of floating away

Kite:

A light framework that ranges in shape, covered with cloth, plastic, or paper, designed to be flown in the wind at the end of a long string

Kite frame:

The joined spine and spar with the string connecting each of the ends

Observation:

To watch, take note, or document a person, place or thing

Ornithopter:

A flying machine designed by Leonardo da Vinci that was propelled through the air by flapping its wings

Spar:

The horizontal stick on the kite. It is at a right angle to the spine. To improve flight the spar is often curved or bowed.

Spine:

The vertical stick on the kite. It is usually the longest stick on the kite.

Tail:

Used on a kite to help provide balance; the tail is often made of strips of cloth or ribbons. Not all kites need a tail.

Wind:

A force of nature. A natural, perceptible motion of air that moves along the earth's surface.

SUGGESTED ADDITIONAL READINGS:

We Like Kites by Stan Berenstain

The Kite Fighters by Linda Sue Park

The Emperor and the Kite by Jane Yolen

Kite Flying by Grace Lin

Henry and the Kite Dragon by Bruce Edward Hall

SUGGESTED INTERNET SEARCHES:

Kites

History of Kites

Chinese Fishing Kites

Wright Brothers and Kites

Alexander Graham Bell's Tetrahedron Kite

Benjamin Franklin and Kite Experiment

How Kites Are Used to Generate Energy

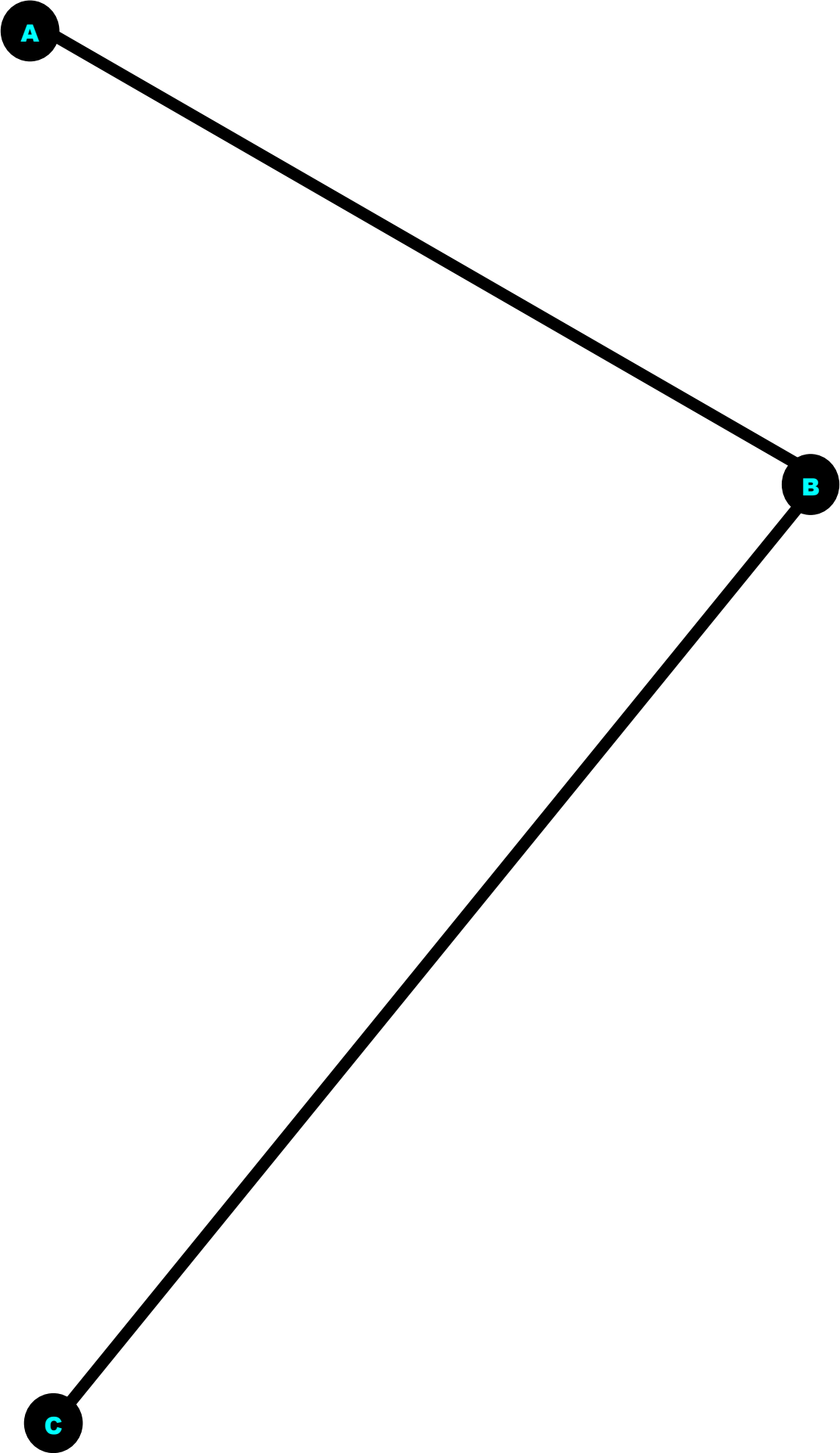
Fig. 1 The Beaufort Scale

Beaufort number	Description	Wind speed	Wave height	Sea conditions	Land conditions
0	Calm	< 1 km/h (< 0.3 m/s)	0 m	Flat.	Calm. Smoke rises vertically.
		< 1 mph			
		< 1 kn	0 ft		
		< 0.3 m/s			
1	Light air	1.1–5.5 km/h (0.3-2 m/s)	0–0.2 m	Ripples without crests.	Smoke drift indicates wind direction and wind vanes cease moving.
		1–3 mph			
		1–2 kn	0–1 ft		
		0.3–1.5 m/s			
2	Light breeze	5.6–11 km/h (2-3 m/s)	0.2–0.5 m	Small wavelets. Crests of glassy appearance, not breaking.	Wind felt on exposed skin. Leaves rustle and wind vanes begin to move.
		4–7 mph			
		3–6 kn	1–2 ft		
		1.6–3.4 m/s			
3	Gentle breeze	12–19 km/h (3-5 m/s)	0.5–1 m	Large wavelets. Crests begin to break; scattered whitecaps.	Leaves and small twigs constantly moving, light flags extended.
		8–12 mph			
		7–10 kn	2–3.5 ft		
		3.4–5.4 m/s			
4	Moderate breeze	20–28 km/h (6-8 m/s)	1–2 m	Small waves with breaking crests. Fairly frequent whitecaps.	Dust and loose paper raised. Small branches begin to move.
		13–17 mph			
		11–15 kn	3.5–6 ft		
		5.5–7.9 m/s			
5	Fresh breeze	29–38 km/h (8.1-10.6 m/s)	2–3 m	Moderate waves of some length. Many whitecaps. Small amounts of spray.	Branches of a moderate size move. Small trees in leaf begin to sway.
		18–24 mph			
		16–20 kn	6–9 ft		
		8.0–10.7 m/s			
6	Strong breeze	39–49 km/h (10.8-13.6 m/s)	3–4 m	Long waves begin to form. White foam crests are very frequent. Some airborne spray is present.	Large branches in motion. Whistling heard in overhead wires. Umbrella use becomes difficult. Empty plastic garbage cans tip over.
		25–30 mph			
		21–26 kn	9–13 ft		
		10.8–13.8 m/s			

Fig. 1 The Beaufort Scale (cont.)

Beaufort number	Description	Wind speed	Wave height	Sea conditions	Land conditions
7	High wind, Moderate gale, Near gale	50–61 km/h (13.9-16.9 m/s)	4–5.5 m	Sea heaps up. Some foam from breaking waves is blown into streaks along wind direction. Moderate amounts of airborne spray.	Whole trees in motion. Effort needed to walk against the wind.
		31–38 mph			
		27–33 kn	13–19 ft		
		13.9–17.1 m/s			
8	Gale, Fresh gale	62–74 km/h (17.2-20.6 m/s)	5.5–7.5 m	Moderately high waves with breaking crests forming spindrift. Well-marked streaks of foam are blown along wind direction. Considerable airborne spray.	Some twigs broken from trees. Cars veer on road. Progress on foot is seriously impeded.
		39–46 mph			
		34–40 kn	18–25 ft		
		17.2–20.7 m/s			
9	Strong gale	75–88 km/h (20.8-24.4 m/s)	7–10 m	High waves whose crests sometimes roll over. Dense foam is blown along wind direction. Large amounts of airborne spray may begin to reduce visibility.	Some branches break off trees, and some small trees blow over. Construction/temporary signs and barricades blow over.
		47–54 mph			
		41–47 kn	23–32 ft		
		20.8–24.4 m/s			
10	Storm Whole gale	89–102 km/h (24.7-28.3 m/s)	9–12.5 m	Very high waves with overhanging crests. Large patches of foam from wave crests give the sea a white appearance. Considerable tumbling of waves with heavy impact. Large amounts of airborne spray reduce visibility.	Trees are broken off or uprooted, saplings bent and deformed. Poorly attached asphalt shingles and shingles in poor condition peel off roofs.
		55–63 mph			
		48–55 kn	29–41 ft		
		24.5–28.4 m/s			
11	Violent storm	103–117 km/h (28.6-32.5 m/s)	11.5–16 m	Exceptionally high waves. Very large patches of foam, driven before the wind, cover much of the sea surface. Very large amounts of airborne spray severely reduce visibility.	Widespread damage to vegetation. Many roofing surfaces are damaged; asphalt tiles that have curled up and/or fractured due to age may break away completely.
		64–72 mph			
		56–63 kn	37–52 ft		
		28.5–32.6 m/s			
12	Hurricane force	≥ 118 km/h (≥ 32.8 m/s)	≥ 14 m	Huge waves. Sea is completely white with foam and spray. Air is filled with driving spray, greatly reducing visibility.	Very widespread damage to vegetation. Some windows may break; mobile homes and poorly constructed sheds and barns are damaged. Debris may be hurled about.
		≥ 73 mph			
		≥ 64 kn	≥ 46 ft		
		≥ 32.7 m/s			

Fig. 2 Kite Template





Worksheets

Worksheet 1

Wind Observation (K-2)

What happened when you flew our foam plate kite? Write your answer or draw a picture.

Did you notice any other objects in the air when you flew our kite? Write your answer or draw a picture.

What happened when you flew the store-bought kite? Write your answer or draw a picture.

Did you notice any other objects in the air when you flew the store-bought kite? Write your answer or draw a picture.

What happened when you flew our foam plate kite? Write your answer or draw a picture.

Answers will vary but students should discuss the kite flying, lift, the wind, how high it flew, how far it traveled etc.

Did you notice any other objects in the air when you flew our kite? Write your answer or draw a picture.

Answers will vary.

What happened when the teacher flew the store-bought kite? Write your answer or draw a picture.

Answers will vary but students should discuss the kite flying, lift, the wind, how high it flew, how far it traveled, etc.

Did you notice any other objects in the air when you flew the store-bought kite? Write your answer or draw a picture.

Answers will vary.

Worksheet 1

Wind Observation (3-4)

What happened when you flew our foam plate kite? Describe in detail the wind, how it interacted with your kite and any other observations. Please also include an illustration with your response below.

Did you notice any other objects in the air when you flew our kite? If so, what were they and did they behave in the same way your kite did in the air? Please also include an illustration with your response below.

What happened when you flew the store-bought kite? Describe in detail the wind, how it interacted with your kite and any other observations.

Did you notice any other objects in the air when you flew the store-bought kite? If so what were they and did they behave in the same way your kite did in the air?

What happened when you flew our foam plate kite? Describe in detail the wind, how it interacted with your kite and any other observations. Please also include an illustration with your response below.

Answers will vary but students should discuss the kite flying, lift, the wind, how high it flew, how far it traveled, etc.

Did you notice any other objects in the air when you flew our kite? If so, what were they and did they behave in the same way your kite did in the air? Please also include an illustration with your response below.

Answers will vary but students should discuss the kite flying, lift, the wind, how high it flew, how far it traveled, etc.

What happened when you flew the store-bought kite? Describe in detail the wind, how it interacted with your kite and any other observations.

Answers will vary but students should discuss the kite flying, lift, the wind, how high it flew, how far it traveled, etc.

Did you notice any other objects in the air when you flew our kite? If so, what were they and did they behave in the same way your kite did in the air?

Answers will vary but students should discuss the kite flying, lift, the wind, how high it flew, how far it traveled, etc.

Worksheet 2

Beaufort Scale Activity

Force	Wind (Knots)	WMO Classification	Appearance of Wind Effects on Land
0	Less than 1	Calm	Calm, smoke rises vertically
1	1-3	Light Air	Smoke drift indicates wind direction, still wind vanes
2	4-6	Light Breeze	Wind felt on face, leaves rustle, vanes begin to move
3	7-10	Gentle Breeze	Leaves and small twigs constantly moving, light flags extended
4	11-16	Moderate Breeze	Dust, leaves, and loose paper lifted, small tree branches move
5	17-21	Fresh Breeze	Small trees in leaf begin to sway
6	22-27	Strong Breeze	Larger tree branches moving, whistling in wires
7	28-33	Near Gale	Whole trees moving, resistance felt walking against wind
8	34-40	Gale	Whole trees in motion, resistance felt walking against wind
9	41-47	Strong Gale	Slight structural damage occurs, slate blows off roofs
10	48-55	Storm	Seldom experienced on land, trees broken or uprooted, "considerable structural damage"
11	56-63	Violent Storm	NO RANKING FOR LAND - PLEASE SKIP
12	64+	Hurricane	NO RANKING FOR LAND - PLEASE SKIP

Observation Number			
Observation Date			
Observation Time			
Direction of Wind			
Speed of Winds (Knots)			
Reasons for Wind Speed Conclusion			

Force	Wind (Knots)	WMO Classification	Appearance of Wind Effects on Land
0	Less than 1	Calm	Calm, smoke rises vertically
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12	64+	Hurricane	NO RANKING FOR LAND - PLEASE SKIP

Observation Number	Observation Date	Observation Time	Direction of Wind	Speed of Winds (Knots)	Reasons for Wind Speed Conclusion
#1	Will vary	Will vary	Based on wind direction and compass calculation	Deduction from students based on Beaufort Scale	Reasons for wind speed conclusion needs to be consistent with what is on Beaufort Scale.
#2	Will vary	Will vary	Based on wind direction and compass calculation	Deduction from students based on Beaufort Scale	Reasons for wind speed conclusion needs to be consistent with what is on Beaufort Scale.
#3	Will vary	Will vary	Based on wind direction and compass calculation	Deduction from students based on Beaufort Scale	Reasons for wind speed conclusion needs to be consistent with what is on Beaufort Scale.

Worksheet 3

Kite Engineering

Draw a design of your kite. Include the following information: dimensions, materials you will use, and reasons for your design. Please label your drawing.

After you have designed your kite you will need to build it. Once your kite is constructed, answer the following questions (include detailed observations and opinions):

1. How did your kite fly

2. How long do you think it took your kite to get into the air?

3. How long do you estimate your kite stayed in the air?

4. How high did your kite fly

5. If you could build your kite differently, what would you do? Explain your answer.

Worksheet 3 (cont.)

Kite Engineering (Teacher Version)

Draw a design of your kite. Include the following information: dimensions, materials you will use, and reasons for your design. Please label your drawing.

Students need to draw and label their kite. They need to list the materials they are using and label their drawing.

After you have designed your kite you will need to build it. Once your kite is constructed, answer the following questions (include detailed observations and opinions):

1. How did your kite fly

Student answers will vary, but they should consider lessons in observation from the previous activities.

2. How long do you think it took your kite to get into the air?

Student answers will vary, but they should consider lessons in observation from the previous activities.

3. How long do you estimate your kite stayed in the air?

Student answers will vary, but they should consider lessons in observation from the previous activities.

4. How high did your kite fly

Student answers will vary, but they should consider lessons in observation from the previous activities.

5. If you could build your kite differently, what would you do? Explain your answer..

Students should include ideas for improving their kites:

What they think they could make better on their kite and why (1-3 improvements are to be noted) If they do not believe they can make

their kite better, they need to discuss what they are curious about and what other changes they would make to experiment with their kite

in the future.



Images

Img. 1 Children flying kites



(Public Domain)

Img. 2 Cody manlifter



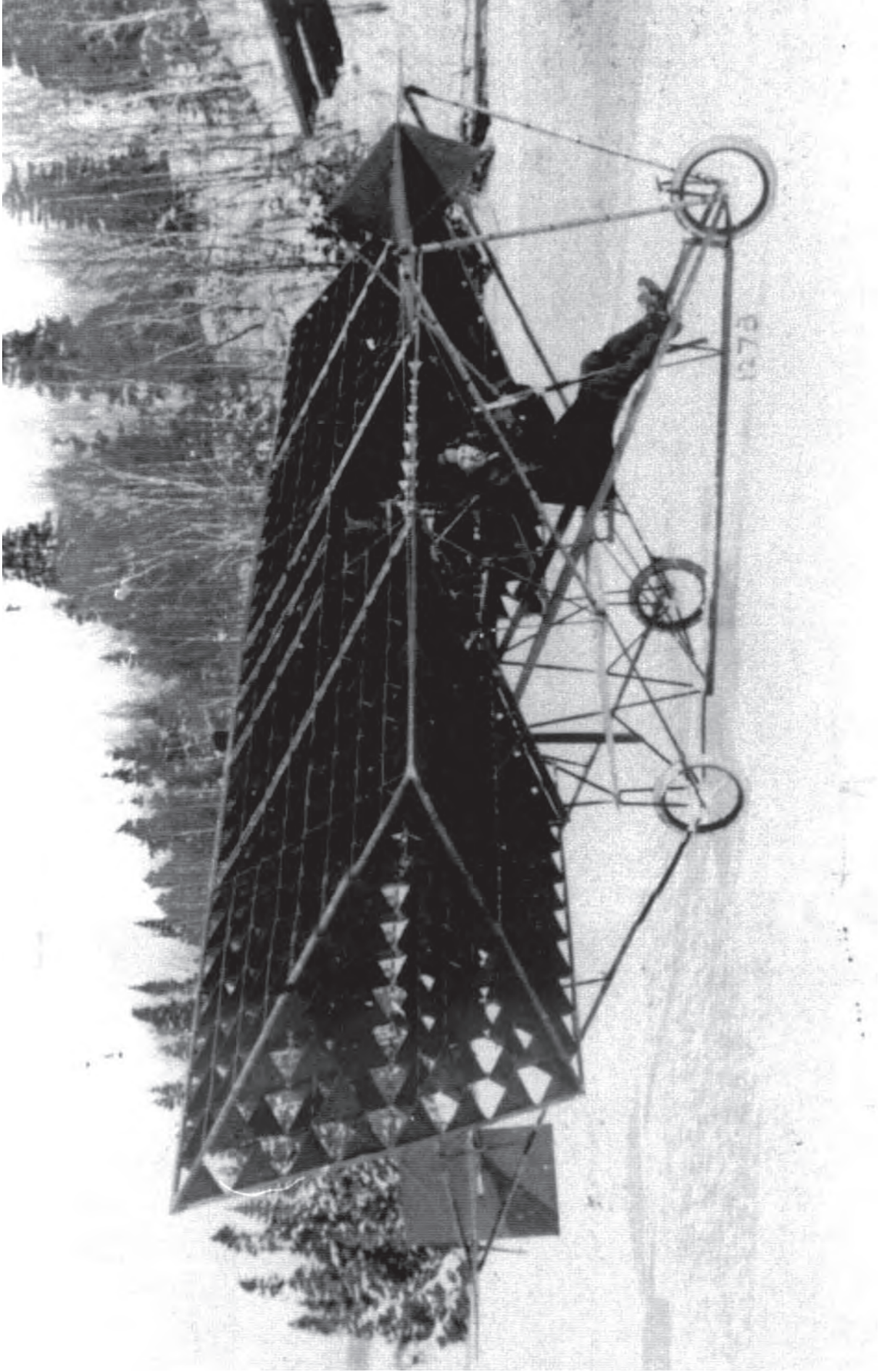
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Img. 3 Samuel Cody



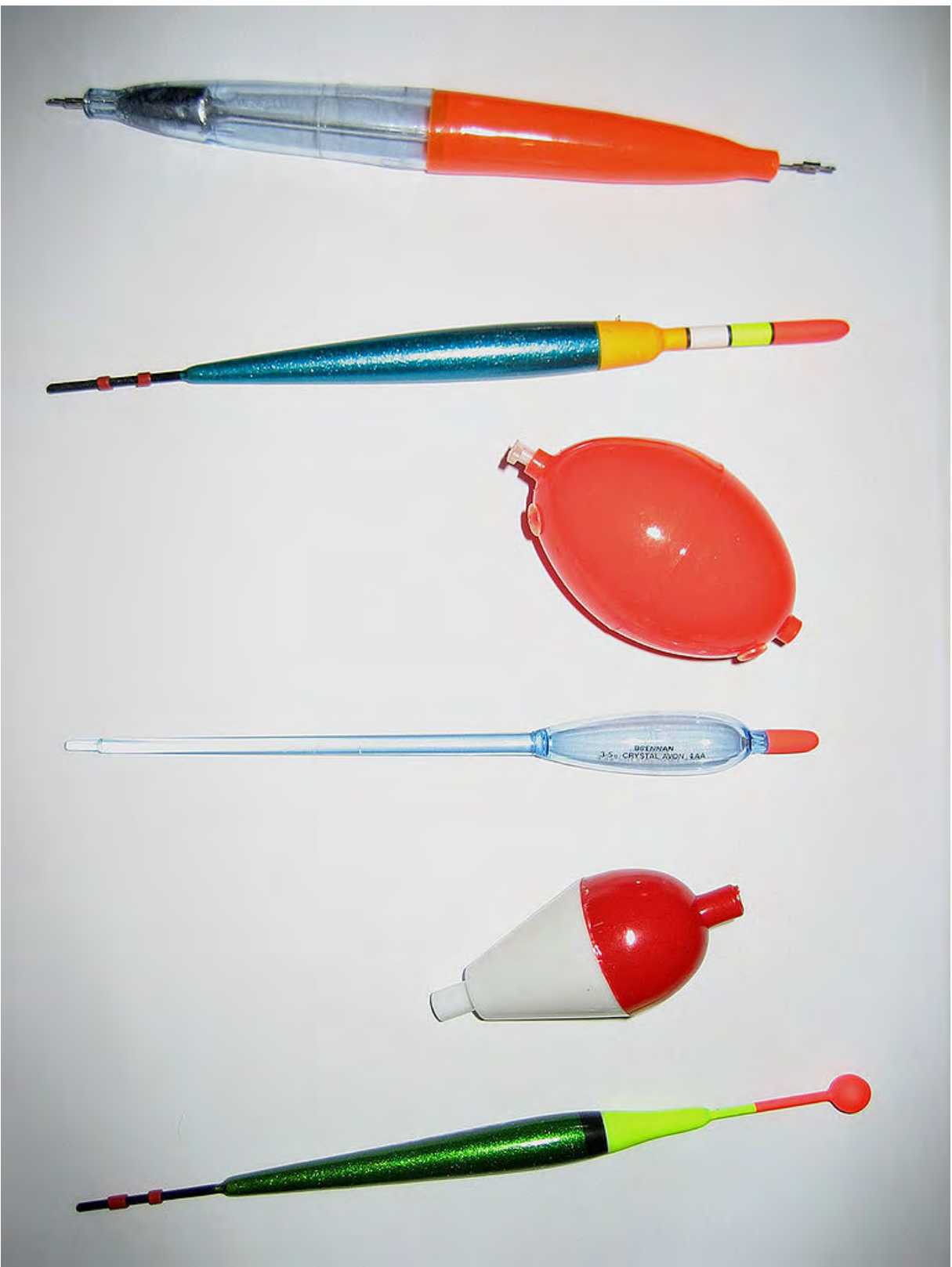
(Public Domain)

Img. 4 Bell's tetrahedron kite



(Photo courtesy of NASA)

Img. 5 Fishing bobbers



(Public Domain)

Img. 6 Kite fishin



(Public Domain)

Img. 7 Scarecrow



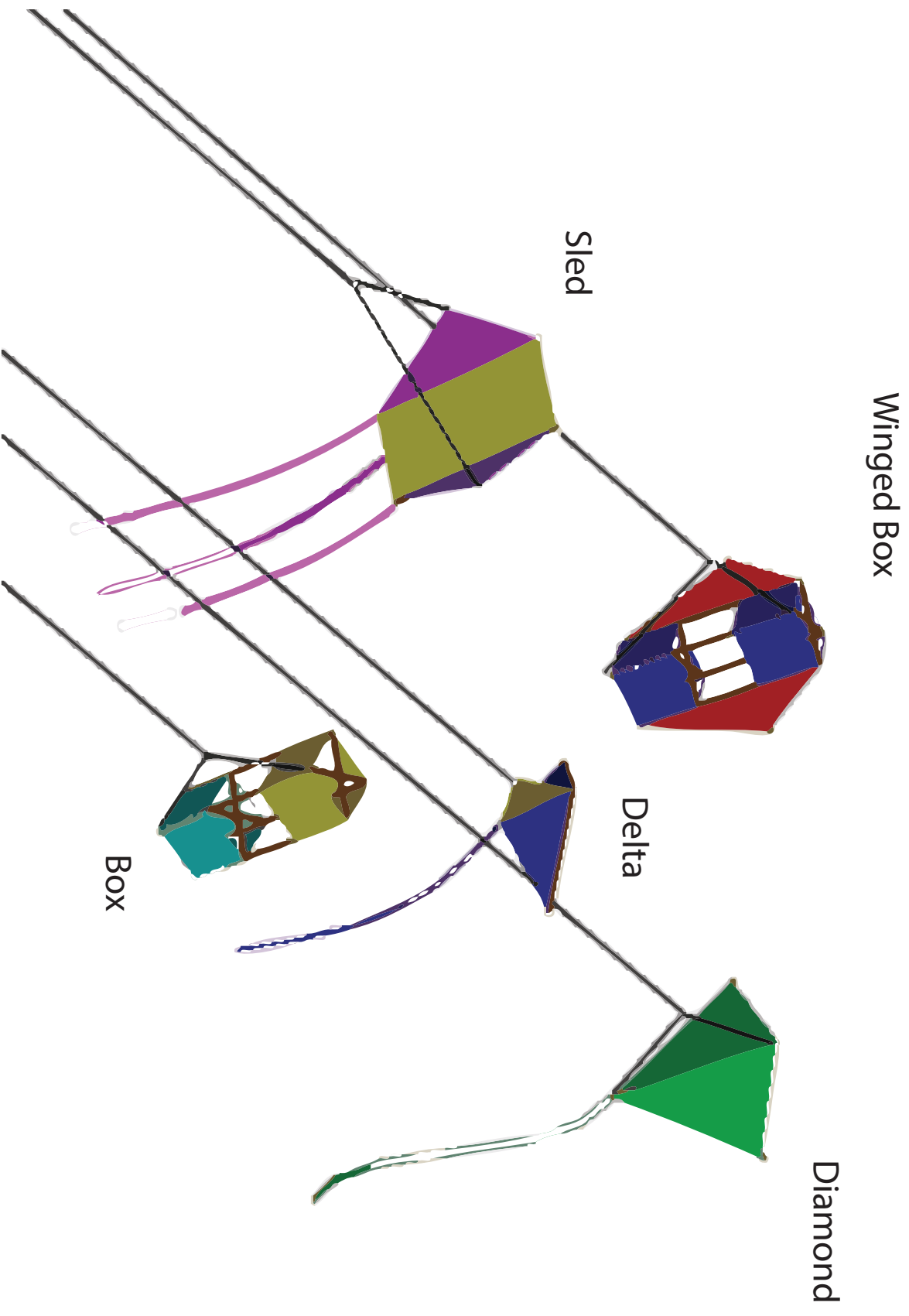
(Public Domain)

Img. 8 A modern kite



(Photo courtesy of NASA)

Img. 9 Types of kites



(Photo courtesy of NASA)

Img. 10 Benjamin Franklin flying his kite



(Public Domain)

Img. 11 Leonardo da Vinci's Ornithopter

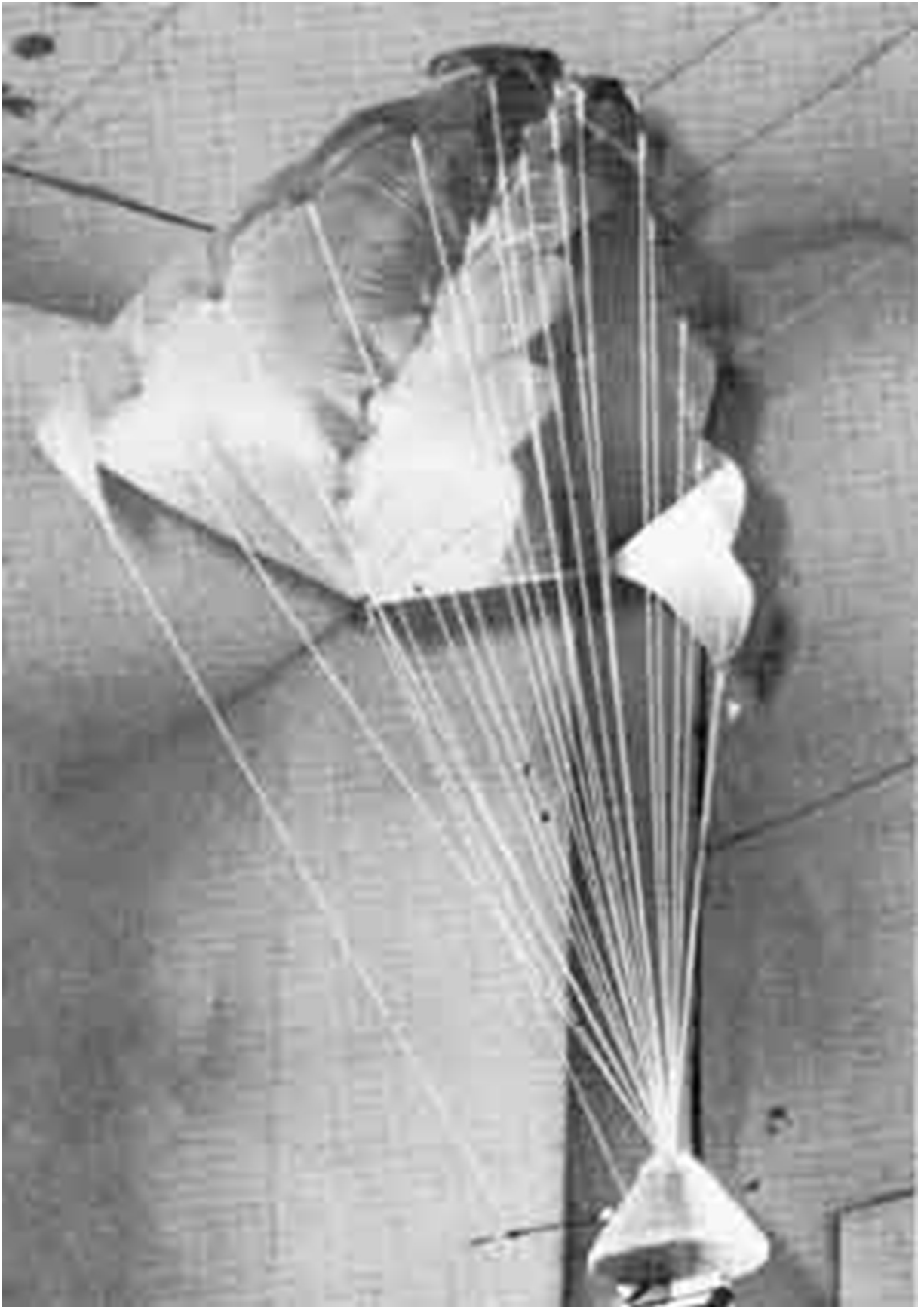


Img. 12 Wright fl er



(Public Domain)

Img. 13 Rogallo's wing



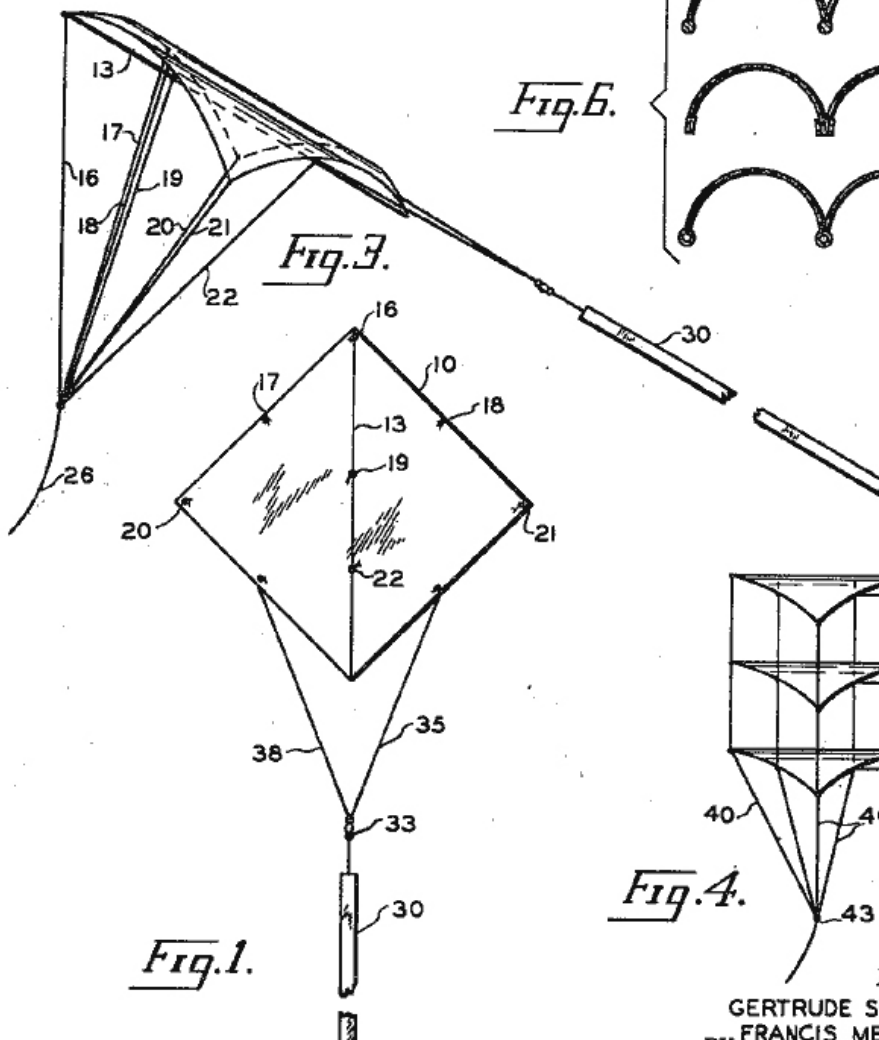
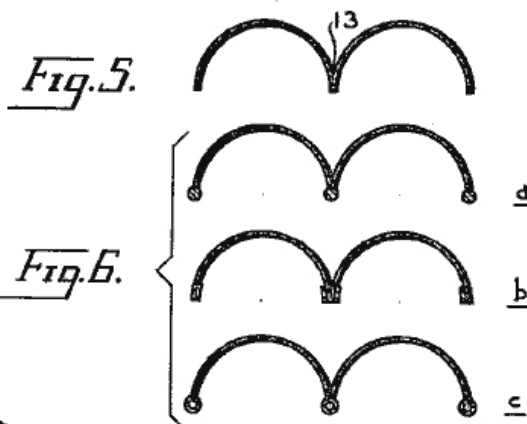
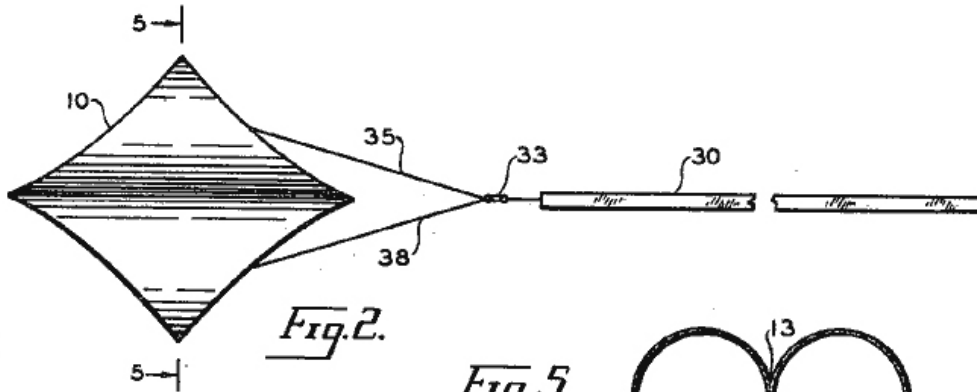
(Public Domain)

March 20, 1951

G. S. ROGALLO ET AL
FLEXIBLE KITE

2,546,078

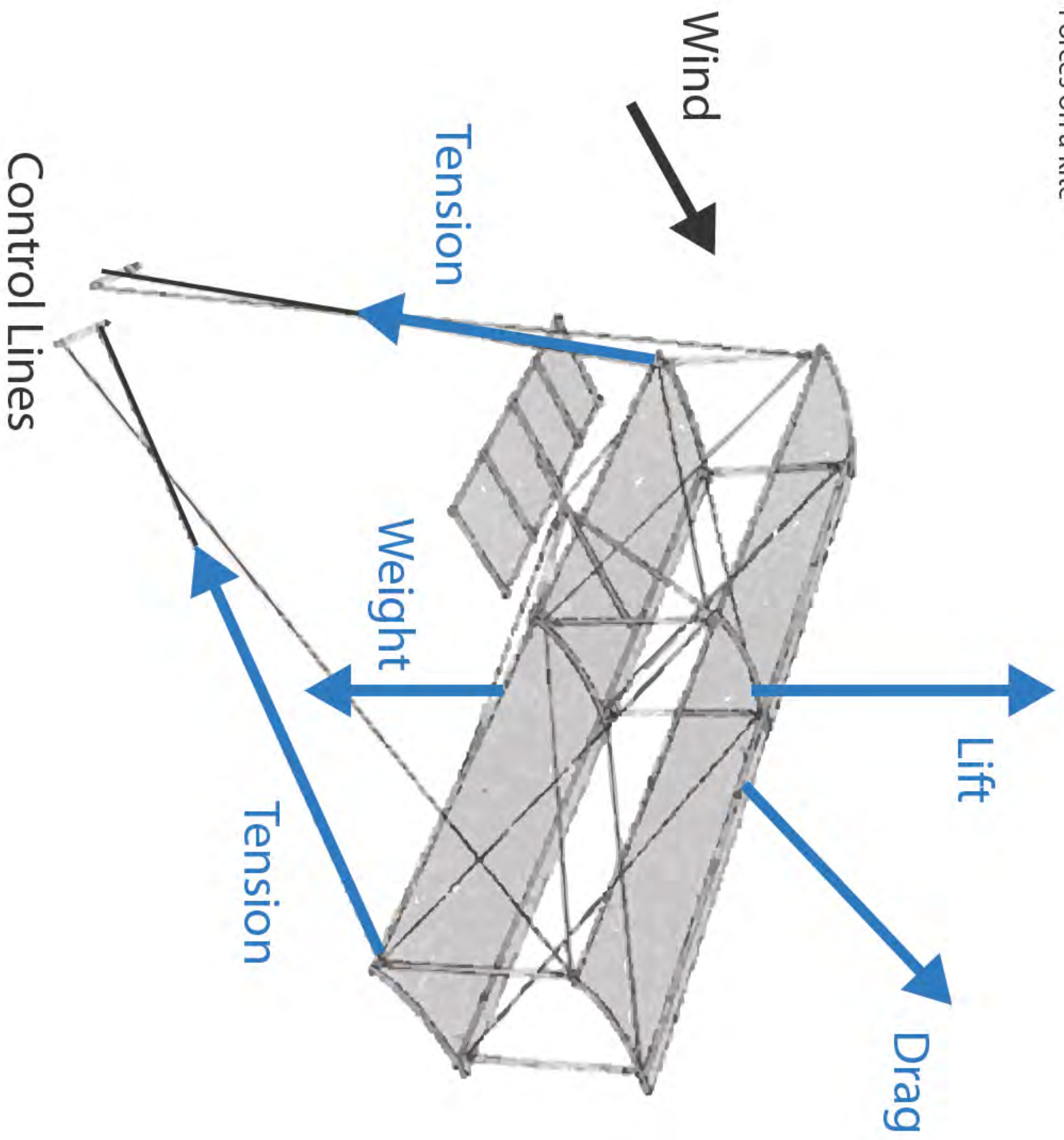
Filed Nov. 23, 1948



INVENTORS.
GERTRUDE SUGDEN ROGALLO
FRANCIS MELVIN ROGALLO

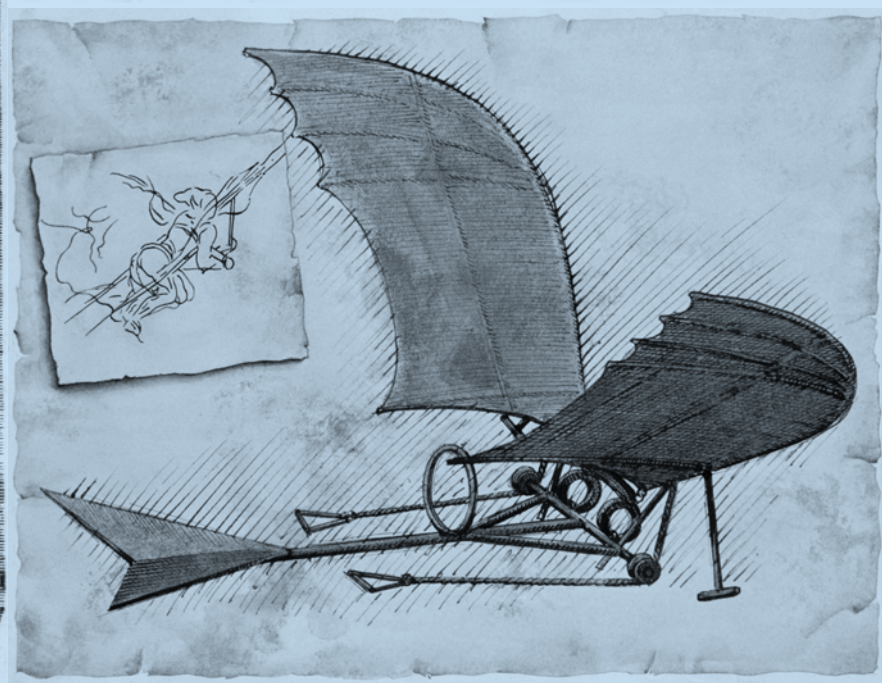
(Public Domain)

Img. 15 Forces on a kite

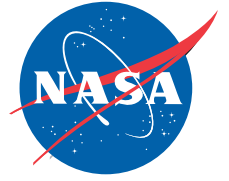


(Photo courtesy of NASA)

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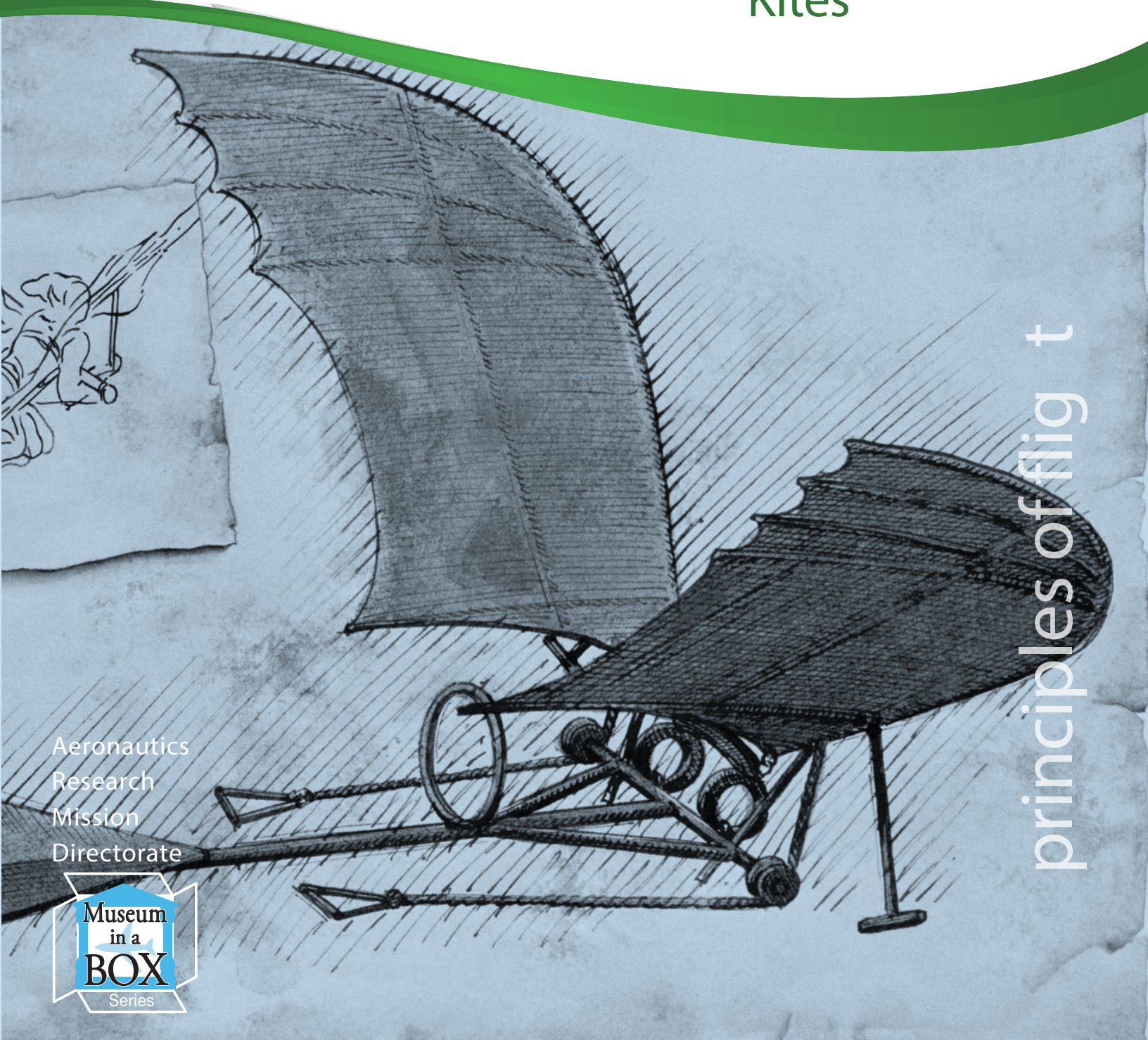
principles of flight



GRADES

5-12

Kites



principles of flight

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Kites

Lesson Overview

In this lesson, students will learn about the forces of nature such as wind and how they impact objects in the air. Students will discuss how wind acts on objects, how air moves, and how wind can be damaging (as in storms), but also helpful (wind power). They will make observations to identify the direction the wind is blowing and the approximate wind speed based on objects in nature and their movements.

Students will learn about motions and forces, transfer of energy, abilities of technological design, energy in the earth system, science as a human endeavor, and historical perspectives as they create their own kites and draw conclusions from their understanding of the power of wind as it applies to the activity of flying. By understanding that animals and humans can use nature's power of wind to accomplish different activities such as flying, students will learn how the forces of nature impact their daily lives.

Objectives

Students will:

1. Develop an understanding of certain geometric terms and use that understanding to build their kites.
2. Design and build a tetrahedron.
3. Visualize tetrahedrons in three dimensions.
4. Calculate how many tetrahedrons will be necessary to assemble a large kite.
5. Find number patterns from sequences.
6. Understand the four forces of flight and basic wind flow.
7. Be able to identify the direction wind is blowing.
8. Be able to approximate the speed of the wind using the Beaufort scale.

Materials:

In the Box

Sets of six (6) eight-inch straws for every team of 3-4 students

Sets of four (4) 3 x 5 cards for every team of 3-4 students

Sets of six (6) straws (no longer than 8 inches) for every team of 3-4 students. (*NOTE: The straws need to be straight and of uniform length. If only flexible straws are available, then they need to be cut to remove the flexible portion. Each tetrahedral cell needs 6 straws.*)

2-3 large spools of cotton string. (*NOTE: Consider cutting the string ahead of time. Each piece = 4 feet long*)

Scissors

Hot Glue Gun (recommended for instructors use only)

Hot Glue Gun Sticks (recommended for instructors use only)

Colored tissue paper

Ruler

Glue sticks

Store bought kites

Meter stick

Digital anemometer

Provided by User

Unsharpened pencils
(1 per team of students)

GRADES

5-12

Time Requirements: 5 - 5½ hours

Background

Kites have dazzled our skies for over 2,000 years. Using silk and bamboo, the Chinese were the first to fly kites. The Japanese flew kites mostly for religious reasons. Oftentimes kites were fitted with whistles or strings in order to make musical sounds while in flight. Kites were decorated with mythological themes or legendary figures to show respect as well. It was not until the 18th century that kites were used and taken seriously in Europe. Kites became more than just important religious symbols; they had become instruments of scientific research. The "Golden Age of Kiting," is said to have occurred from 1860 to 1910. Kites were used for meteorology, aeronautics, wireless communication and photography. After the Wright Brothers flew their "Wright Flyer," in 1903, interest in kites diminished and by WWII, kites had become a toy used primarily for recreation.



Img. 1 Children flying kites



Img. 2 Cody manlifter

While we are not exactly sure when the first kite was flown, it has been documented that Chinese General Han Hsin flew a kite over the wall of a city he was attacking around the year 200 B.C. He wanted to measure how far his army would have to tunnel underneath the city in order to reach past its defenses. Another story recounts that nearly 300 years ago a thief used a large kite to carry himself to the top of a castle so he could steal a golden statue from the roof.

Kites also were used to carry cameras and meteorological instruments. The British, French, Italian, and Russian armies utilized kites during World War I for immediate observations and signaling. During World War II however, the United States Navy found other uses for kites. For example, kites were flown to prevent airplanes from flying too low over targets, used for target practice, and if pilots were lost at sea they would raise a kite so they could be found.

Samuel Cody came to the attention of the English War Office after he crossed the English Channel in a boat drawn by a kite. He continued his experiments with passenger kites and lifted a person to a new record high of 1600 feet. Cody's design was adopted in 1906, and his war kites were used for observation until they were later replaced by aircraft.

Eventually Cody's interest turned to gliders, which was based largely on his kite designs. Cody and his kite had a profound impact on the British Army. He became the chief instructor in kiting at the balloon school in Aldershot, England. It was also during this period of time that Cody built a motorized kite. He wanted to develop one of his motorized kites into a man-carrying airplane. However, the British Army was more interested in airships during 1907 than they were in airplanes.

Perhaps one of the most interesting kites in history was one constructed by Alexander Graham Bell. His kite was specifically designed to carry people. Bell believed that the best type of kite to do this was a tetrahedron kite. A tetrahedron is essentially a triangular pyramid: a three-dimensional figure with four equilateral triangles.

His first kite, called the Frost King, was comprised of 256 cells or tetrahedrons. Bell was determined to build a kite that could carry a man, and therefore, increased his tetrahedron kite structure from 256 cells to 1300. In 1907, Bell built another kite which he called the Cygnet. It was the first kite he had ever designed, manned with a person and then flew. The kite contained 3,393 cells and had floats attached to the bottom so it could land on water. Just imagine how it must have felt to fly that kite! Graham's kite flew for 7 minutes and went as high as 168 feet.

When we think of kites today, we usually think of them as recreational. For example, something a family would do at a park on a windy day. Interestingly, kites have had many useful purposes in the past and continue to, even to this day. Fisherman today use something called a "bobber," to help them determine when a fish bites their line.



Img. 4 Bell's tetrahedron kite



Img. 5 Fishing bobbers

Imagine fishing from the beach. What can a kite do that a regular fishing pole could not? The kite can take a fishing line far offshore where larger fish are located. The normal distance a fisherman can cast his pole cannot reach the same distance that a kite could be flown. Long-ago Chinese fishermen actually used kites in the same manner. They would tie fishing line to the end of their kite, and when the fish took the bait, the kite would move.



Img. 3 Samuel Cody

Today, farmers use scarecrows to keep birds away that would eat their crops. Chinese farmers would use kites in their fields in much the same manner. Kites were also used for testing the wind, measuring distances, and signaling. During WWII, kites were used by Navy anti-aircraft gunners for target practice. The military used kites because they



Img. 6 Kite fishin

maneuver in the air in a similar fashion to the fighter aircraft that the gunners were responsible for defending their battleships against. Kites are still used today by the military for target practice. Scientists use kites as well to conduct experiments and to gather meteorological readings. Competitions are held for stunt kites and for recreational use. Their design has expanded beyond the known diamond and box kites.

There are many types of kites, and over the years the materials used to build kites has changed. Materials have included silk, bamboo, string, plastic, nylon, wood and more. NASA has classified five different types of kites. Reviewing the different kites will help you as the teacher, and will help prepare your students for this lesson. The five types of kites discussed in this lesson are the Winged Box, the Sled, the Delta, the Box Kite, and finally the Diamond. All kites must be lightweight and strong to endure powerful winds. A solid frame made usually of wood or plastic serves as the base of the kite, while paper, plastic, or cloth serve as the kite's skin. Kites will range in abilities based on their construction. Some kites

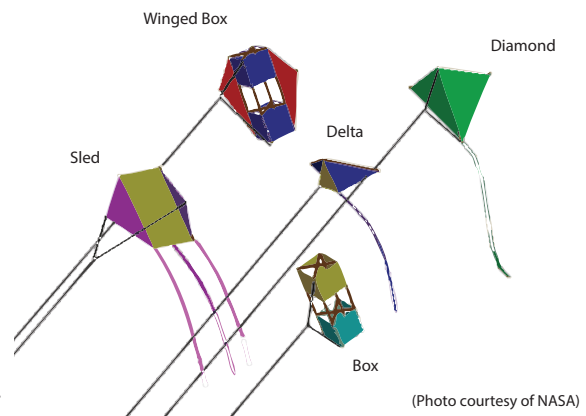


Img. 7 Scarecrow



Img. 8 A modern kite

are very stable while others are extremely maneuverable. Kites also can soar to high altitudes and others can perform magnificent stunts.



Img. 9 Types of kites



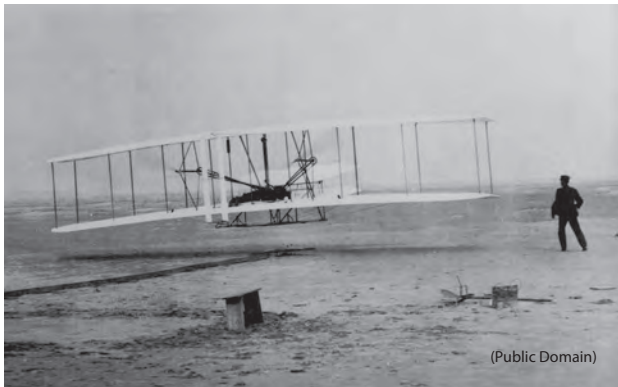
Img. 10 Leonardo da Vinci's Ornithopter

Many of us have seen the famous picture of Benjamin Franklin and his kite (Img. 5). However, Franklin was not the first one to use kites in a scientific fashion. During the late 1400s, Leonardo da Vinci began to study flight by observing birds. Later he flew kites which inspired him to design flying machines.



Img. 11 Benjamin Franklin flyin his kite

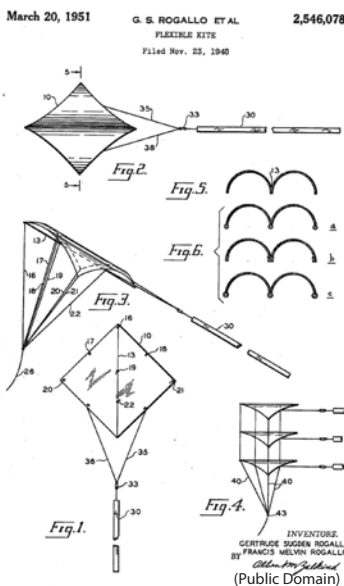
In 1899, the Wright Brothers built a bi-plane kite, which was the kite that was used to invent wing warping, a significant discovery. The Wright Brothers gained further insight about how to create the world's first working flying machine by learning that the wings of a kite could be twisted or warped. By finding a way to



Img. 12 Wright fl er

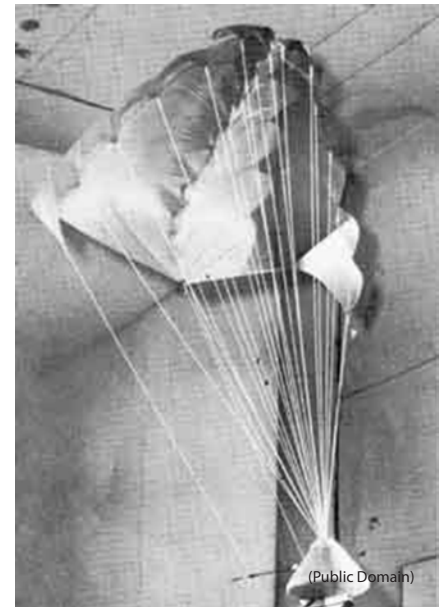
twist the wings, it gave them greater control of their kite. This led to their creation of gliders, which then led to their invention of the Wright Flyer.

Created by Gertrude and Francis Rogallo in 1948, the Rogallo wing or parawing is a flexible type of airfoil. This flexible wing was considered by NASA to be an alternate recovery system for the Gemini space capsule. Composed of two partial conic surfaces, both cones point forward and is considered to be a simple and inexpensive



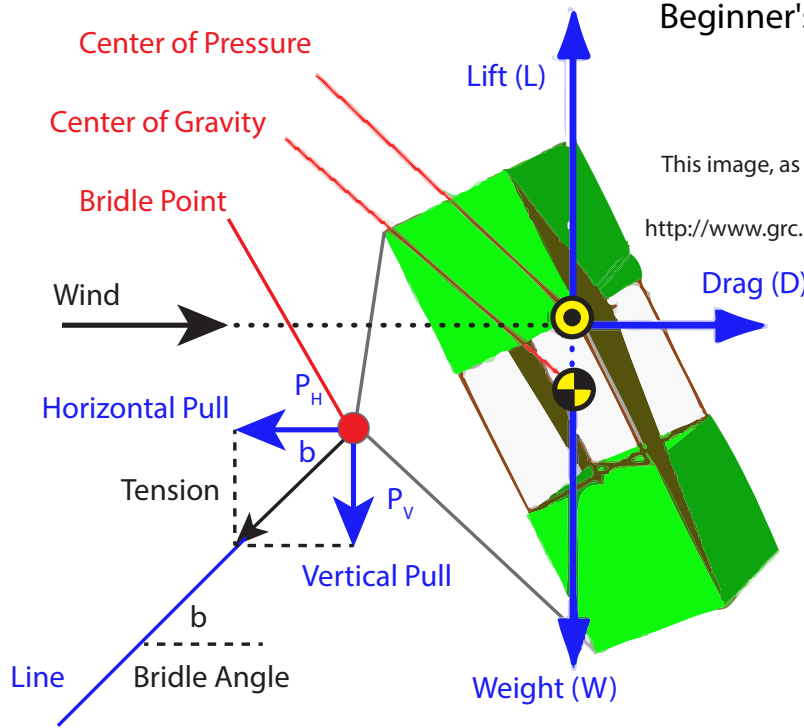
Img. 14 Rogallo patent

flying wing that has many remarkable properties. The Rogallo wing itself cannot be classified as a powered aircraft glider or kite. The way in which the wing is attached and manipulated does not allow it to be classified as a kite or glider. It has been used in toy kites, spacecraft parachutes, ultralight powered air craft, gliders, and in sport parachutes. What makes the wings so special is that it is designed to bend and flex in the wind. This provides favorable dynamics which can be compared to a spring suspension in an automobile.



Img. 13 Rogallo's wing

Beginner's Guide to Aeronautics



This image, as well as additional information on kites, can be found on the following web page: <http://www.grc.nasa.gov/WWW/k-12/airplane/kitefor.html>.

In Stable Flight:

$$P_V + W - L = 0$$

$$P_H - D = 0$$

$$\tan b = \frac{P_V}{P_H}$$

(Photo courtesy of NASA)

Img. 15 Forces on a kite

Similar to airplanes, kites are affected by wind and the four forces of flight; weight or gravity, lift, drag, and thrust. When a kite flies, it overcomes the force of gravity because the force of the wing and its pressure on the kite's surfaces helps to push it upward. Since kites are heavier than air, they weigh more than the volume of the air they displace. The air pressure increases as the wind hits the face or front surface of the kite.



The air blowing onto the face of the kite, traveling around its sides and down the kite's backside creates a low pressure area above the kite. When the wind hits the front of the kite, the wind is deflected downward, and there is a force in the opposite direction, which pushes the kite upward. This action depicts Newton's Third Law of Motion, which states that for every action there is an equal and opposite reaction. The shape of the kite affects the distribution of the aerodynamic forces. All of these things come into play when flying a kite, whether for fun or for scientific experimentation.

When we describe the four forces interacting with an airplane, we think of the airplane surrounded by a bubble of those four forces. You also can think of the four forces acting on a kite in the same manner, especially when imagining aircraft gliders. The Wright Brothers were well aware of these evident similarities and therefore, engaged in a series of kite experiments to investigate the aerodynamics of unpowered or glider aircraft in the early 1900s. Kites also taught them about the basics of flight control.

As previously mentioned, the four forces of flight are weight or gravity, lift, drag and thrust. On an airplane, thrust works against drag to keep the airplane moving forward. However, the tension in a kite's string works against the drag. This will be explained in greater detail later in the lesson. Weight (caused by gravity) is a force that is always directed toward the center of the earth. Gravity is what keeps us grounded, literally, on the planet. Gravity gives us the perfect balance necessary to perform our daily tasks, whether it is walking, driving, working, or playing.

An airplane rotates around the center of gravity, which is the average location of the weight of the airplane. However, a kite rotates around the connection point of its control wires or kite strings. The weight of the kite is always directed toward the center of the earth.

In order to make anything fly, a force must be generated to overcome its weight. The same idea applies to a kite. This force is called lift. For the kite, lift is generated by the motion of air around the kite. When air moves past a kite, there is some resistance, which causes a force on the kite known as drag. While lift is an upward force (perpendicular to the wind), drag is a force that acts in the same direction as the wind.

Tension on a kite is used to overcome drag, and is created through the string attached to the kite which keeps it in a fixed location. Without the string to anchor it, the kite would drift in the direction of the wind. For a kite to generate lift, the wind must be moving past it. If the kite is drifting with the wind, the wind is not blowing past it, so the kite will eventually fall to the ground because of gravity.

It is important to note that tension can be broken down into two different components: vertical and horizontal. Once the kite is stable in flight, the lift of the kite is equal to the weight plus the vertical component of the tension. The drag is equal to the horizontal tension. If we want to compare an airplane and a kite, the horizontal pull of the string tension on a kite is similar to the role of the thrust on an airplane.

Without wind, it is very hard to fly a kite. Some days the wind is too calm for a kite to take flight or to conduct kite experiments. Other times flying a kite would not be optimal, for example, during a thunderstorm. Today, we have a variety of meteorological instruments that can measure the wind, weather, and temperature. However, prior to the 1800s, we had to guess the wind speed. That changed when Sir Francis Beaufort, who was serving on the HMS Woolwich in 1805, devised a scale to measure wind speed based on his observations of nature and man-made objects. His sea-based wind observation system, now referred to as the Beaufort Scale (Fig. 1), standardized the measurement of wind using a 0-12 rating scale. The ratings were based on the estimated wind knots through observation of what could be seen from the ocean to trees on land. Eventually, the scale was adapted from sea to land which is what we will learn about in this lesson.

Using the Beaufort scale while at sea is a tool that most boat captains still use today. In addition, the BBC radio in the United Kingdom uses it for shipping forecasts, as does the Irish Meteorological Service. China, Greece, Hong Kong and Taiwan also use this scale.

Humans have always been fascinated with flying. Before we could wrap our heads around something like Leonardo da Vinci's Orinopter, we managed to fly high in the sky aboard man-carrying kites. Kites have dazzled our skies and our imagination for over 2,000 years. We have learned that kites were made of different materials and that over the years these materials have become more advanced as technology in construction has improved. The creativity of those who have been involved in designing kites is remarkable. Their purposes range from fishing, to farming, to military intelligence and scientific experiments which show how diverse kites have been and continue to be to this day.

Fig. 1 The Beaufort scale

Beaufort number	Description	Wind speed	Wave height	Sea conditions	Land conditions
0	Calm	< 1 km/h (< 0.3 m/s)	0 m	Flat.	Calm. Smoke rises vertically.
		< 1 mph			
		< 1 kn	0 ft		
		< 0.3 m/s			
1	Light air	1.1–5.5 km/h (0.3–2 m/s)	0–0.2 m	Ripples without crests.	Smoke drift indicates wind direction and wind vanes cease moving.
		1–3 mph	0–1 ft		
		1–2 kn			
		0.3–1.5 m/s			
2	Light breeze	5.6–11 km/h (2–3 m/s)	0.2–0.5 m	Small wavelets. Crests of glassy appearance, not breaking.	Wind felt on exposed skin. Leaves rustle and wind vanes begin to move.
		4–7 mph	1–2 ft		
		3–6 kn			
		1.6–3.4 m/s			
3	Gentle breeze	12–19 km/h (3–5 m/s)	0.5–1 m	Large wavelets. Crests begin to break; scattered whitecaps.	Leaves and small twigs constantly moving, light flags extended.
		8–12 mph	2–3.5 ft		
		7–10 kn			
		3.4–5.4 m/s			
4	Moderate breeze	20–28 km/h (6–8 m/s)	1–2 m	Small waves with breaking crests. Fairly frequent whitecaps.	Dust and loose paper raised. Small branches begin to move.
		13–17 mph	3.5–6 ft		
		11–15 kn			
		5.5–7.9 m/s			
5	Fresh breeze	29–38 km/h (8.1–10.6 m/s)	2–3 m	Moderate waves of some length. Many whitecaps. Small amounts of spray.	Branches of a moderate size move. Small trees with leaves begin to sway.
		18–24 mph	6–9 ft		
		16–20 kn			
		8.0–10.7 m/s			
6	Strong breeze	39–49 km/h (10.8–13.6 m/s)	3–4 m	Long waves begin to form. White foam crests are very frequent. Some airborne spray is present.	Large branches in motion. Whistling heard in overhead wires. Umbrella use becomes difficult. Empty plastic garbage cans tip over.
		25–30 mph	9–13 ft		
		21–26 kn			
		10.8–13.8 m/s			

Fig. 1 The Beaufort scale (cont.)

Beaufort number	Description	Wind speed	Wave height	Sea conditions	Land conditions
7	High wind, Moderate gale, Near gale	50–61 km/h (13.9-16.9 m/s)	4–5.5 m	Sea heaps up. Some foam from breaking waves is blown into streaks along wind direction. Moderate amounts of airborne spray.	Whole trees in motion. Effort needed to walk against the wind.
		31–38 mph			
		27–33 kn	13–19 ft		
		13.9–17.1 m/s			
8	Gale, Fresh gale	62–74 km/h (17.2-20.6 m/s)	5.5–7.5 m	Moderately high waves with breaking crests forming spindrift. Well-marked streaks of foam are blown along wind direction. Considerable airborne spray.	Some twigs broken from trees. Cars veer on road. Progress on foot is seriously impeded.
		39–46 mph			
		34–40 kn	18–25 ft		
		17.2–20.7 m/s			
9	Strong gale	75–88 km/h (20.8-24.4 m/s)	7–10 m	High waves whose crests sometimes roll over. Dense foam is blown along wind direction. Large amounts of airborne spray may begin to reduce visibility.	Some branches break off trees, and some small trees blow over. Construction/temporary signs and barricades blow over.
		47–54 mph			
		41–47 kn	23–32 ft		
		20.8–24.4 m/s			
10	Storm Whole gale	89–102 km/h (24.7-28.3 m/s)	9–12.5 m	Very high waves with overhanging crests. Large patches of foam from wave crests give the sea a white appearance. Considerable tumbling of waves with heavy impact. Large amounts of airborne spray reduce visibility.	Trees are broken off or uprooted, saplings bent and deformed. Poorly attached asphalt shingles and shingles in poor condition peel off roofs.
		55–63 mph			
		48–55 kn	29–41 ft		
		24.5–28.4 m/s			
11	Violent storm	103–117 km/h (28.6-32.5 m/s)	11.5–16 m	Exceptionally high waves. Very large patches of foam, driven before the wind, cover much of the sea surface. Very large amounts of airborne spray severely reduce visibility.	Widespread damage to vegetation. Many roofing surfaces are damaged; asphalt tiles that have curled up and/or fractured due to age may break away completely.
		64–72 mph			
		56–63 kn	37–52 ft		
		28.5–32.6 m/s			
12	Hurricane force	≥ 118 km/h (≥ 32.8 m/s)	≥ 14 m	Huge waves. Sea is completely white with foam and spray. Air is filled with driving spray, greatly reducing visibility.	Very widespread damage to vegetation. Some windows may break; mobile homes and poorly constructed sheds and barns are damaged. Debris may be hurled about.
		≥ 73 mph			
		≥ 64 kn	≥ 46 ft		
		≥ 32.7 m/s			

Activity 1

As the Wind Blows

GRADES**5-12****Time Requirements:** 30 minutes**Materials:**In the Box

Digital anemometer

Provided by User

None

WorksheetsBeaufort Wind Scale
(Worksheet 2)Reference MaterialsBeaufort Wind Scale
(Figure 1)**Key Terms:**

Beaufort Wind Scale

Objective:

Through experimentation, students will:

1. Understand the Beaufort Wind Scale.
2. Estimate and measure the wind outside

Activity Overview:

Students will work together to fill out instructional worksheets to measure the wind speed outside.

Activity:

1. **Discuss with the students that before there were instruments to measure the wind, people estimated the wind speed based on observations of nature and the environment outside.** This is called the Beaufort Wind Scale. Pass out the Beaufort Wind Scale Student Worksheet.
2. **Invite students to use their powers of deduction to fill out the blank Beaufort Wind Scale Student worksheet based on discussions and critical thinking within their group.**
3. **When the students are finished filling out their Beaufort Wind Scale student worksheet take the class outside and used to digital anemometer to take wind readings and discuss the class.**
4. **Once the students are finished, distribute copies of a complete Beaufort Wind Scale. Give students an opportunity to make any changes necessary to align their chart with the original Beaufort Scale.**

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

EARTH AND SPACE

- Energy in the earth system

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

Activity 2

The Great Straw Pyramid

GRADES**5-12****Time Requirements:** 45 minutes**Materials:**In the Box

None

Provided by User

Sets of six (6) straws (no longer than 8 inches) for every team of 3-4 students

Sets of four (4) 3 x 5 cards for every team of 3-4 students

Worksheets

Shape Define and Design (Worksheet 1)

Clue Cards (if needed)

Reference Materials

None

Key Terms:

Apex

Equilateral

Equilateral Triangle

Pyramid

Tetrahedron

Triangle

Vertices

Objective:

Through experimentation, students will:

1. Be able to explain the various shapes learned in this activity, including equilateral triangle, pyramid, tetrahedron, and triangle.
2. Build a tetrahedral pyramid using 6 straws.
3. Work in teams to develop designs, test theories, and construct a final build.

Activity Overview:

Students will be given definitions of the shapes that they will be working with, including equilateral triangle, pyramid, tetrahedron, and triangle. They will be asked to rewrite the definition in their own words and to draw a picture of the shape based on their definition. Once students grasp the shapes and their concepts, 6 straws will be passed out to each team and the students will be asked to create four equilateral triangles with the 6 straws. Students may not cut nor bend the straws to complete this task. They may not use glue or tape of any kind. The only items allowed will be the straws. The Shape, Design, and Define Worksheet will be provided for students to work in a two-dimensional environment (if they feel drawing will help them complete the task) before attempting to build the three-dimensional version.

Activity:

1. **Divide the students into groups of 3-4 students per team.**
2. **Pass out one set of six straws to each team.**
3. **Pass out the Shape, Define, and Design Worksheets.**
4. **Explain to the students that they will need to complete the worksheets together as a team first.** Once that step is completed, they will then need to assemble four equilateral triangles with the straws. Remind them that they may not cut or bend the straws or use any type of adhesive.
5. **Give the students approximately 20 minutes to complete the worksheets, and an additional 10-15 minutes to arrange the straws once the worksheet is finished.** The goal is to see if the students can devise a solution that will create four equilateral triangles with as little help from the teacher as possible.

6. **After about 10-15 minutes, if the teams have not been able to assemble the four equilateral triangles, tell them they can approach you and ask for a clue.**
7. **Give the students Clue #1 to take back to their team.** Based on the information given in the clue, they should be able to try and assemble the four equilateral triangles. If they are not able to do so, after a few minutes they can come up and get the next clue. Students may repeat these steps and acquire up to four clues in order to solve their puzzle.
8. **Write the following four clues each on 3 x 5 cards (One set of 4 clues per team).**
 - Clue #1** – *Another word for a triangular pyramid is a tetrahedron. Tetra means four and hedron means face.*
 - Clue #2** – *To build a tetrahedron, you need four equilateral triangles and four vertices. A vertex is a common point between two line segments. So in a regular triangle there would be three vertices. It may help to sketch your design.*
 - Clue #3** – *If sketching your design is two dimensional, then, when you build your tetrahedron it would be in terms of ____ dimensions. (The students should figure out the answer is 3.)*
 - Clue #4** – *Draw a picture of a tetrahedron or find a picture of one, and attach it to the clue card.*

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL MATH STANDARDS 5-12

NUMBER AND OPERATIONS

- Understand numbers, ways of representing numbers, relationships among numbers, and number systems
- Understand meanings of operations and how they relate to one another
- Compute fluently and make reasonable estimates

GEOMETRY

- Analyze characteristics and properties of two- and three-dimensional geometric shapes and develop mathematical arguments about geometric relationships
- Use visualization, spatial reasoning, and geometric modeling to solve problems

MEASUREMENT

- Understand measurable attributes of objects and the units, systems, and processes of measurement
- Apply appropriate techniques, tools, and formulas to determine measurements.

DATA ANALYSIS AND PROBABILITY

- Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them

PROCESS

- Problem Solving
- Communication
- Connections
- Representation

Activity 3

Triangular Numbers

GRADES 5-12**Time Requirements:** 45 minutes**Materials:**In the Box

None

Provided by User

None

WorksheetsTriangles in Numbers
(Worksheet 3)Reference Materials

None

Key Terms:

Triangular Numbers

Objective:

Through experimentation, students will:

1. Understand triangular numbers in order to build a tetrahedral kite.

Activity Overview:

Students will work together to complete instructional worksheets to better help them understand how a tetrahedral kite is constructed.

Activity:

1. **Pass out the Triangles in Numbers Worksheet.** Explain that a tetrahedron is represented mathematically on this sheet.
2. **Ask the students to fill out the mathematical representations through 10 levels.** The first five levels are done for them on the worksheet.
3. **When the students are done go over the answers with them.**

NATIONAL MATH STANDARDS 5-12

NUMBER AND OPERATIONS

- Understand numbers, ways of representing numbers, relationships among numbers, and number systems
- Understand meanings of operations and how they relate to one another
- Compute fluently and make reasonable estimates

GEOMETRY

- Analyze characteristics and properties of two- and three-dimensional geometric shapes and develop mathematical arguments about geometric relationships
- Use visualization, spatial reasoning, and geometric modeling to solve problems

MEASUREMENT

- Understand measurable attributes of objects and the units, systems, and processes of measurement
- Apply appropriate techniques, tools, and formulas to determine measurements.

DATA ANALYSIS AND PROBABILITY

- Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them

PROCESS

- Problem Solving
- Communication
- Connections
- Representation

Activity 4

Tetrahedral Kite Engineering

GRADES 5-12**Time Requirements:** 90-120 minutes**Materials:**In the Box

4 sets of 6 straws (8 inches or less) for every team of 3-4 students. (NOTE: The straws need to be straight and of uniform length. If only flexible straws are available, then cut them to remove the flexible portion OR tape the flexible portion. Each tetrahedral cell needs 6 straws.)

2-3 large spools of cotton string. (NOTE: Consider cutting the string ahead of time. Each piece = 4 feet long)

Scissors

Hot Glue Gun (recommended for instructors use only)

Hot Glue Gun Sticks (recommended for instructors use only)

Colored tissue paper

Ruler

Glue sticks

Store-bought kites

Meter stick

Provided by User

Unsharpened Pencils (1 per team)

Worksheets

Tetrahedral Kite Engineering (Worksheet 4)

Objective:

Through experimentation, students will:

1. Develop an understanding of numerous geometric terms including: base, edge, face, parallelogram, platonic solid, pyramid, quadrilateral, rhombus, tetrahedron, and vertex.
2. Create a tetrahedron kite.
3. Visualize a series of tetrahedrons in three dimensions to better understand how to construct it.

Activity Overview:

Working in teams, students will create and build a tetrahedral kite. Once students have completed their kite, they will have a chance to fly their kites outside.

Activity:

Caution: This is a highly engaging and hands-on activity. Extra assistance that day is advised.

Give each student the Tetrahedral Kite Engineering Student Worksheet. Prior to each step, read the directions aloud to the class and then allow them to proceed with the assembly. Also, circulate among the teams, so if students have questions, you are available.

Step One - Create a Tetrahedron Cell - Read these steps aloud to the class.

1. **You will need the following supplies for this step: string, 6 straws (no longer than 8 inches long), scissors, and a flat surface.**
2. **First, cut a length of yarn/string four (4) feet long. (If the cut string has not already been provided.)**
3. **Second, take 6 straws and place them flat on the surface.**
4. **Use your piece of string to join 3 straws together. One end of the "joined" 3 straws should have two strings extended, 1) approximately 20 inches long, and 2) approx. 4 inches long.**
5. **Tie these two ends of the string tightly together to make sure that there is no room for the triangle to "wiggle."**

Reference Materials

Figures 2 - 17

Key Terms:

Base
Edge
Face
Parallelogram
Pyramid
Rhombus
Tetrahedron
Vertex

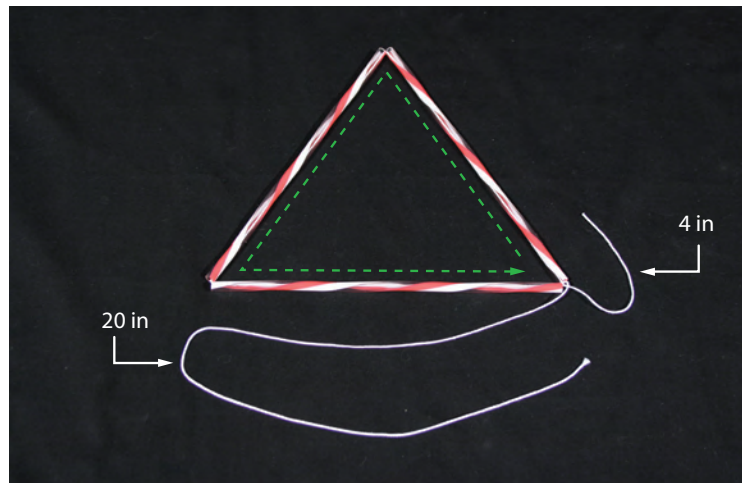


Fig. 2 Triangle

Step Two - Create a Rhombus - Read these steps aloud to the class.

1. The three “joined” straws should form a tight triangle.
2. Cut another 4-inch piece of string.
3. Take one end of the 4-inch string, and tie that end to any empty corner of the triangle.
4. Now, add 2 more straws onto the longest piece of string.

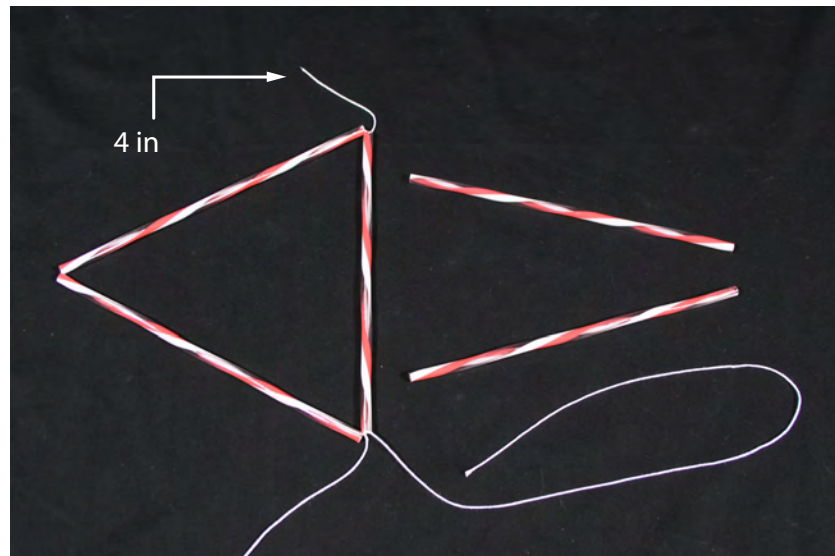


Fig. 3 Rhombus construction

- Next, take the string that holds the two additional straws and tie it to the end of the 4-inch string closest to the straw to make another tight triangle. See picture below:

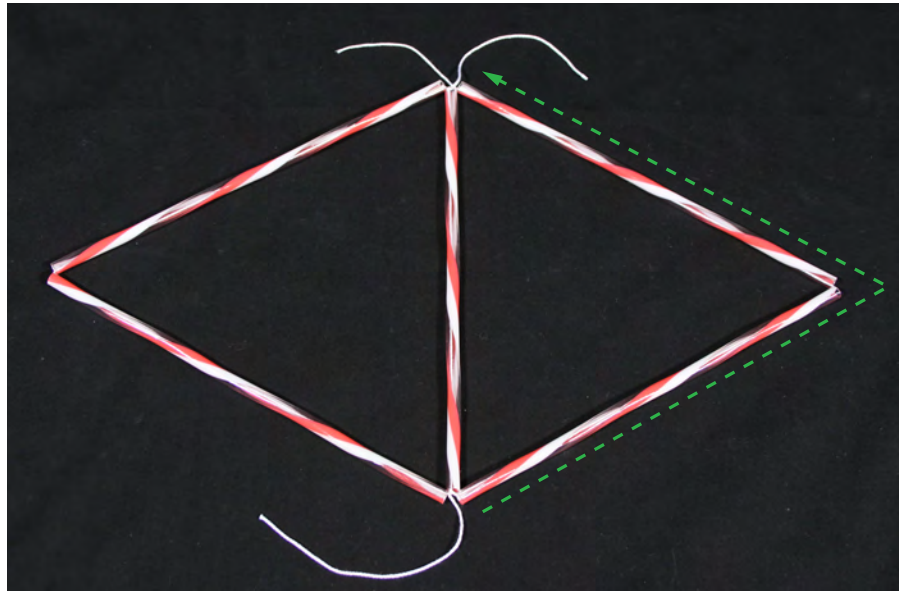


Fig. 4 Completed rhombus

Step Three - Create a Three Dimensional Tetrahedron - Read these steps aloud to the class.

- Cut another 4-inch piece of string.
- Take that 4-inch piece of string and tie one of its ends to one of the empty corners.
- Next, cut a piece of string that is double the length of one straw (or side of a tetrahedron).

4. Tie one end of that double-length string to the remaining empty corner. See picture below:

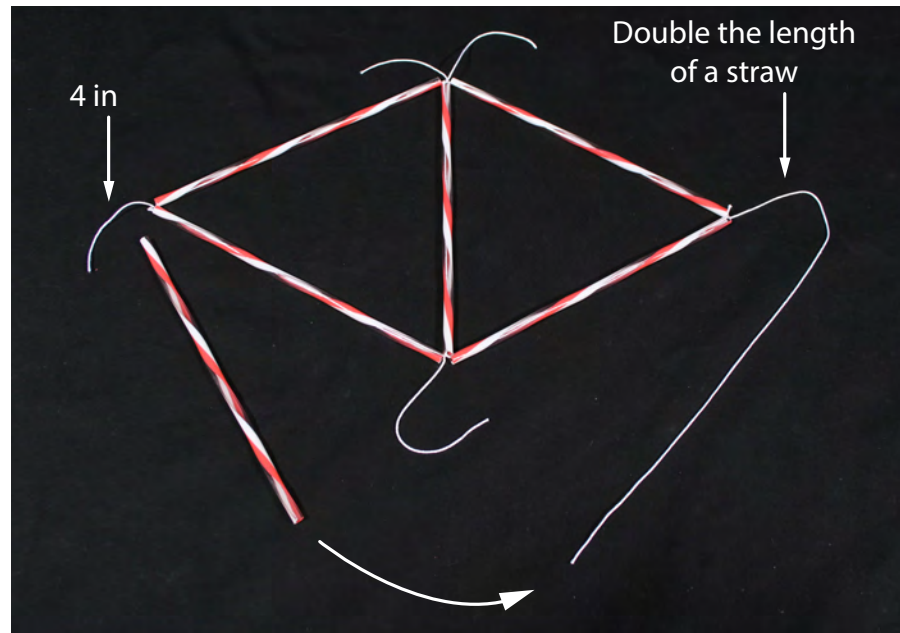


Fig. 5 Three dimensional tetrahedron construction

5. Now, add the last straw onto the double-length string.
6. Tie together the two opposite ends (the end of the 4-inch string and the end of the double-length string closest to the straws) to form a tight 3-dimensional tetrahedron (fig. 6).
7. Follow all numbered instructions in Steps 1, 2 and 3 to create a second tetrahedron. You will need two tetrahedrons to execute the Steps Four and Five.

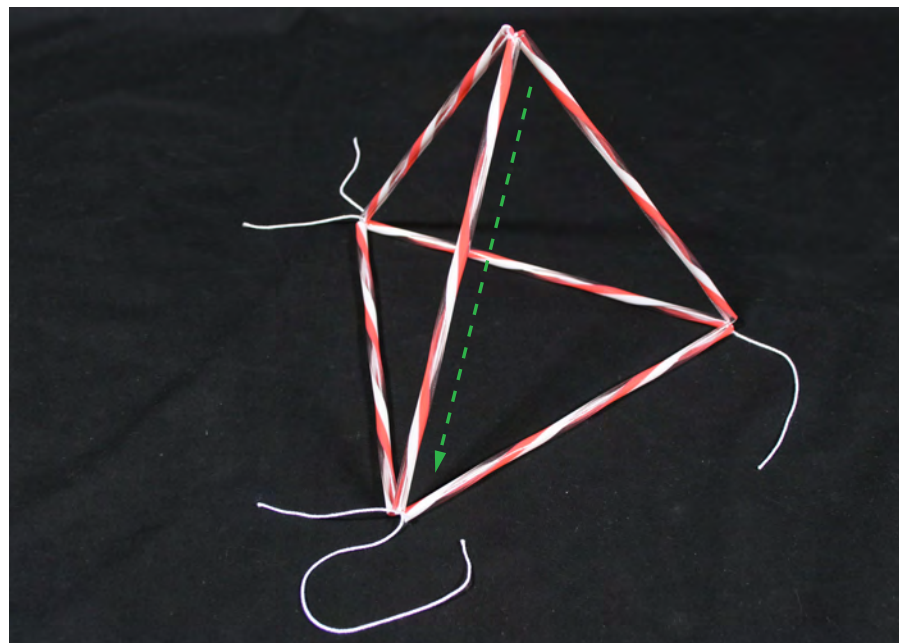


Fig. 6 Completed three dimensional tetrahedron

Step Four - Create a Tetrahedron Tissue Paper Cover - Read these steps aloud to the class.

1. Choose a piece of colored tissue approximately 24 inches x 18 inches.
2. Place two tetrahedrons side-by-side in the middle of the 24" x 18" tissue. (It might help to lightly place a piece of tape in the middle of the tetrahedrons to hold them in place for marking purposes.)
3. At each corner of the two "joined" tetrahedrons, measure one inch directly across from each of the four corners and mark with a dot. See picture below:

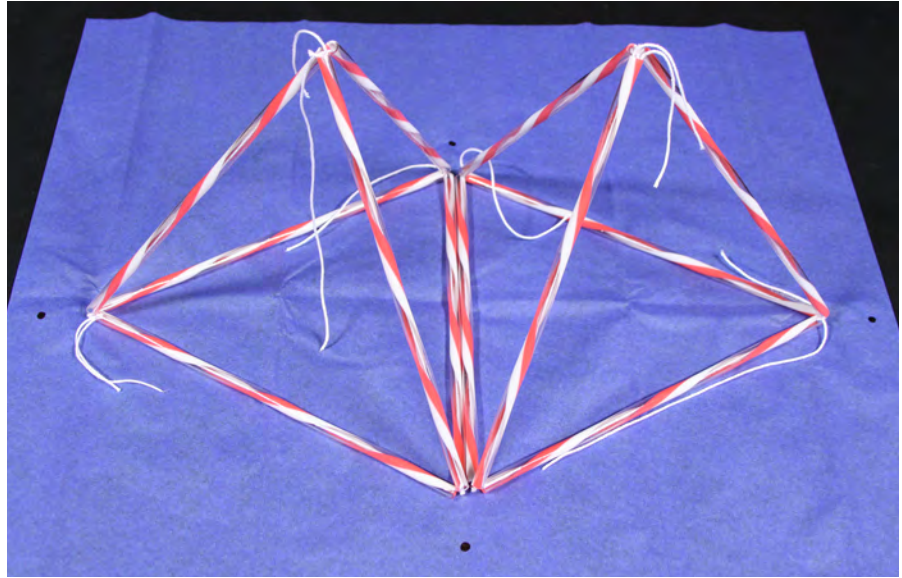


Fig. 7 One-inch marks to create template

4. Remove the tetrahedrons and connect the dots with a ruler. See picture below:

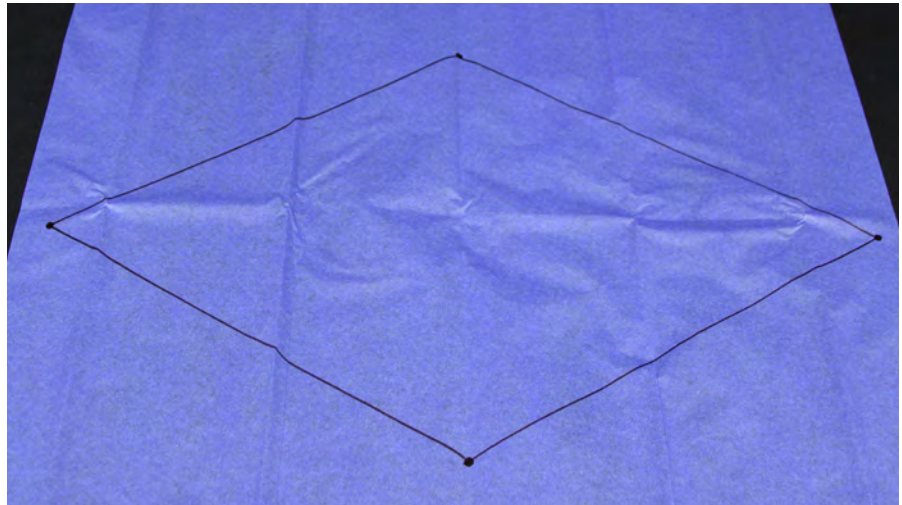


Fig. 8 Template construction

5. Next, measure two inches directly across from the vertex of one of the obtuse angles (obtuse = > 90 degrees) on the template, and make a mark.
6. Place any corner of a tetrahedron on the 2 inch mark so that the straws of the tetrahedron cross over the sides of the template and are equidistant from the vertex. See picture below:

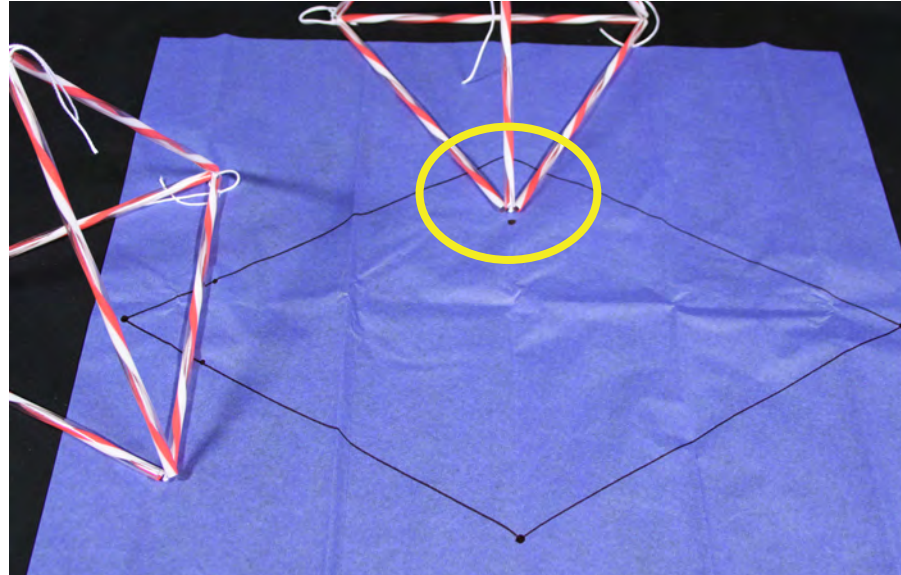


Fig. 9 Obtuse angle marking for template construction

7. Trace the inside of the side straws from the mark to the sides of the template.
8. Follow steps 5 – 7, and do the same to the other obtuse angle of the template.
9. Next, measure $1\frac{1}{2}$ inches directly across from the vertex of the acute angle (acute = < 90 degrees) on the template, and make a mark.
10. Place any side of the tetrahedron on the $1\frac{1}{2}$ inch mark so that the straws of the tetrahedron cross over the sides of the template and are equidistant from the vertex.

11. Trace along the side of the straw through the mark to each of the template sides.
See picture below (fig . 10):

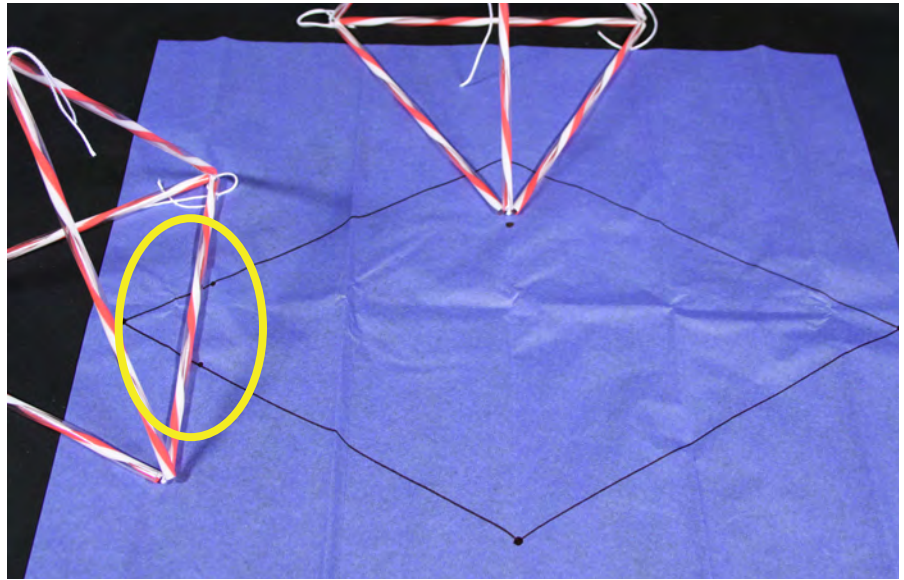


Fig. 10 Acute angle marking for template construction

12. Follow instructional steps 9 – 11, and do the same to the other acute angle of the template.
13. Your completed tissue paper tetrahedron template should look like fig . 11 below:

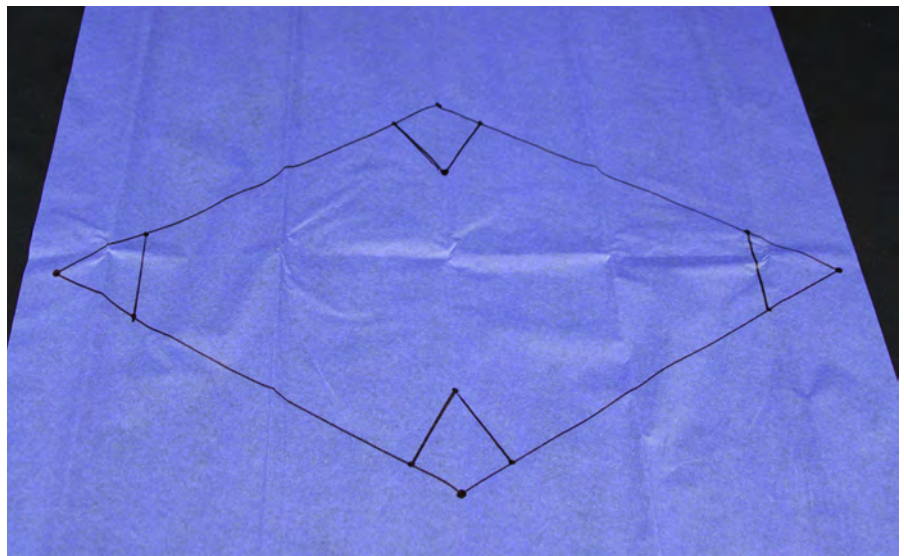


Fig. 11 Tissue paper template

14. Cut out the entire diamond-shaped template.
15. Next, cut out or cut off the tapered corners of the template so it looks like the picture below (figure 12):
16. Trace this template onto three sheets of tissue paper in preparation of covering three other tetrahedrons.

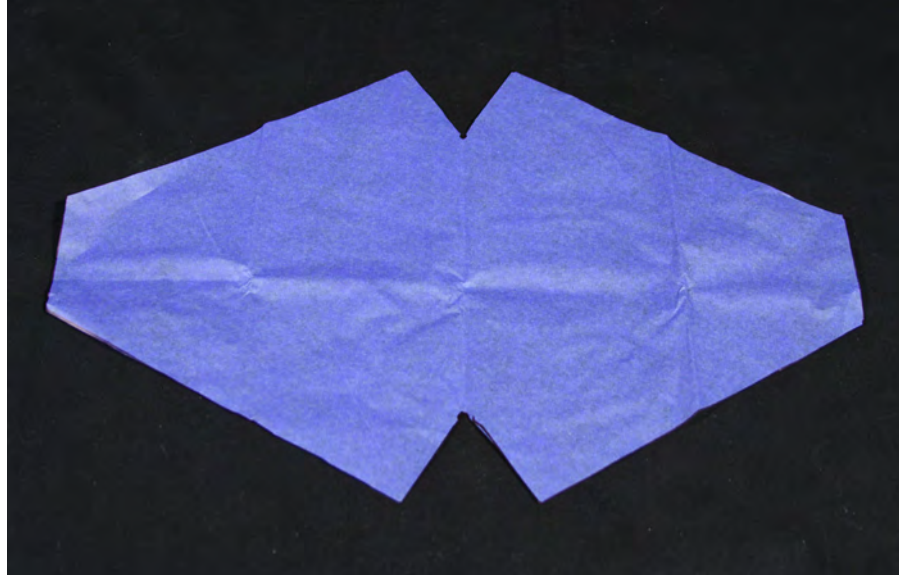


Fig. 12 Completed tissue paper template

Step Five - Cover the Tetrahedron - Read these steps aloud to the class.

1. Lay the one cut tissue paper template on your table.
2. Place one side of the tetrahedron in the middle of the template so there is enough tissue paper to wrap around the other two sides. See picture below (figure 13):

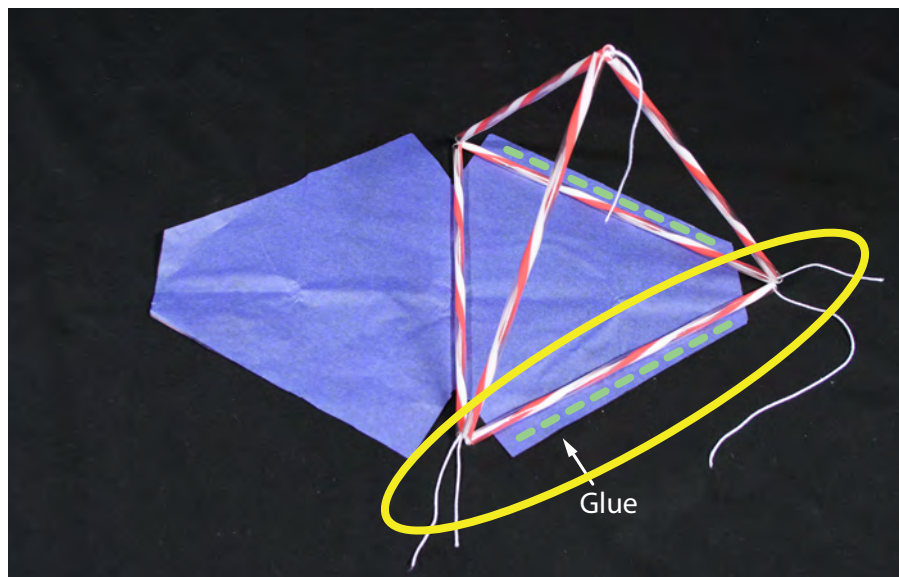


Fig. 13 Placement of tetrahedron on tissue paper template

3. Now spread the glue along the flaps and fold the flaps over the straws. (See yellow circle in figure 13). Make sure the tissue is wrapped tightly around the straws.
4. Flip the tetrahedron onto the other side of the tissue template.
5. Now, spread glue onto the flap .
6. Fold these flaps over the straws for a tight fit. See picture below (figure 14):

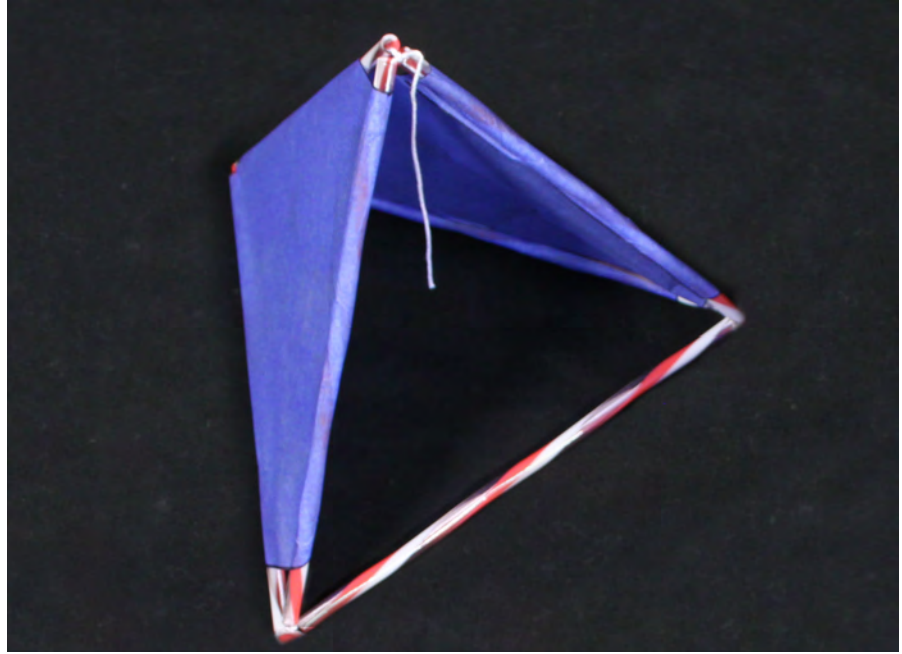


Fig. 14 Covered tetrahedron

Step Six - Add Levels to the Tetrahedron - Read these steps aloud to the class.

1. Now that you have successfully created and covered two tetrahedrons, you will need to repeat Steps One through Five to make an additional two tetrahedrons (four in total).
2. Once you have created the other two remaining tetrahedrons, select three of them and place the tetrahedrons on a flat surface or table to form one large triangle. All sides with the tissue paper should be facing away from you. See picture below (fig. 15).

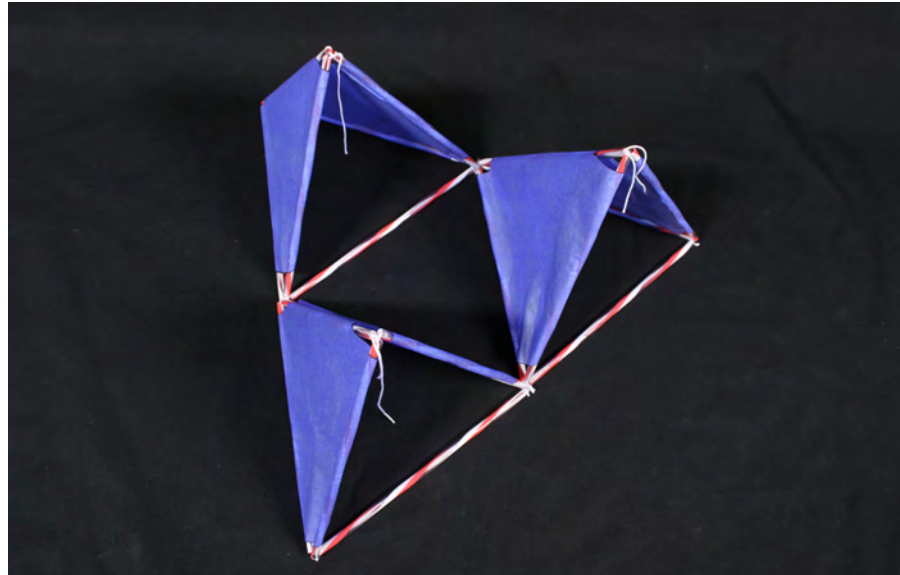


Fig. 15 Three tetrahedrons in the form of one large triangle

3. Each tetrahedron will have strings that are free. Use those free strings to tie one tetrahedron to another. This will tie the adjacent base vertices together.
4. Place the three tied tetrahedrons flat on the table in the same way they were tied together.

5. Now, take the fourth tetrahedron and place it on on the top of the three and secure each end. See picture below (fi . 16).
6. Be sure to fasten all ends tightly and securely so there is very little wiggle room among the tetrahedrons.

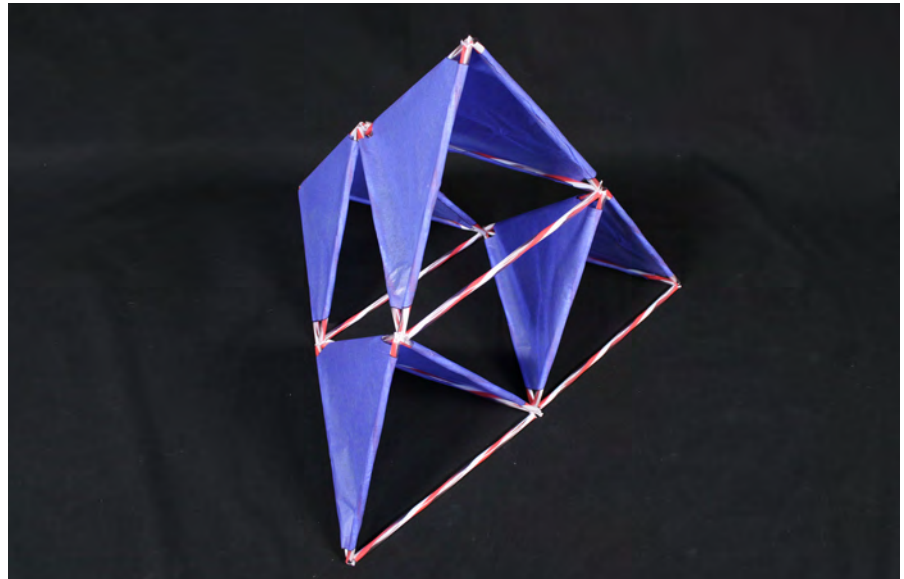


Fig. 16 Four tetrahedrons

7. **As a team, decide how many more tetrahedrons you want to add to your kite before you decide to fly it .** Repeat Step One through Step Five as necessary for your additions. Also, remember that when you add your additional tetrahedrons make sure the connections are tight.

Step Seven - Build Your Bridle - Read these steps aloud to the class.

1. Now that you have made your kite, you will need to create and attach your bridle in order to fly it .
2. Tie a string (approximately 15 feet long) to the ruler so it can serve as your bridle.
3. Take your ruler to your teacher and he or she will use the hot glue gun to make sure your string stays on the ruler.
4. **TEACHER:** Take the hot glue gun and insert a glue stick. Plug the glue gun into the wall giving it time to heat up. Once the glue gun is ready, apply glue (approximately the size of the quarter) to the ruler in order to fasten the string to the bridle. Only when glue has cooled, return the glued ruler and string to the students.
5. Place your kite on the table with the base touching the table.
6. Next, tie a 24-inch string firmly to the very top of the kite.
7. Tie the same piece of string again to the middle joint. This will be between the top section of the kite and the bottom toward the front. There should not be any slack in the string.
8. Next, tie a loop in the middle of your string. The loop should be about the size of a quarter.
9. Now, attach the string of your kite to the loop.
10. Your kite is finished and ready to fly .
11. Complete the questions on your Kite Engineering Worksheet before attempting to fly our kite.

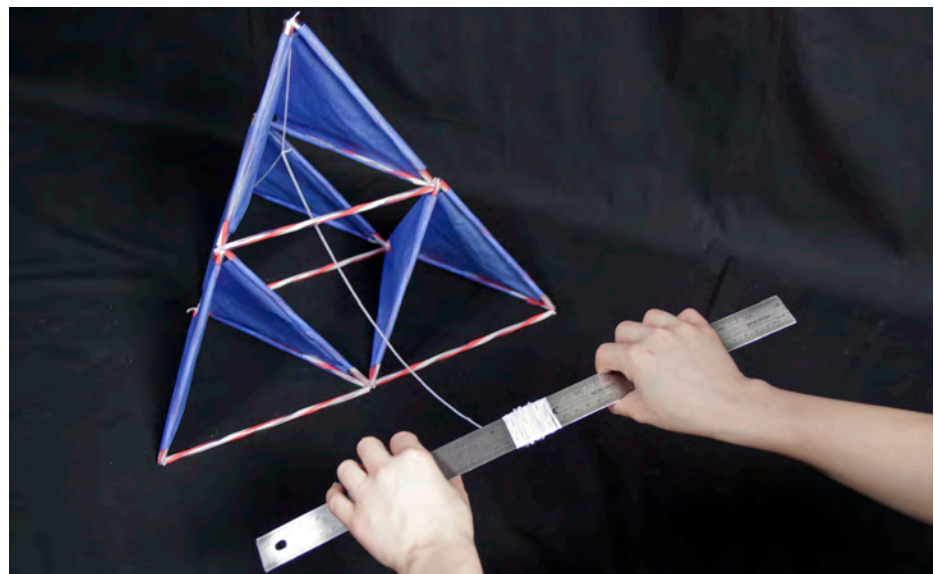


Fig. 17 Completed kite with bridle

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL MATH STANDARDS 5-12

NUMBER AND OPERATIONS

- Understand numbers, ways of representing numbers, relationships among numbers, and number systems
- Understand meanings of operations and how they relate to one another
- Compute fluently and make reasonable estimates

GEOMETRY

- Analyze characteristics and properties of two- and three-dimensional geometric shapes and develop mathematical arguments about geometric relationships
- Use visualization, spatial reasoning, and geometric modeling to solve problems

MEASUREMENT

- Understand measurable attributes of objects and the units, systems, and processes of measurement
- Apply appropriate techniques, tools, and formulas to determine measurements.

DATA ANALYSIS AND PROBABILITY

- Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them

PROCESS

- Problem Solving
- Communication
- Connections
- Representation

Activity 5

Box Kite Construction 101

GRADES 5-12**Time Requirements:** 90 minutes**Materials:**In the Box

None

Provided by User

Kite Template (1 per student)

Ruler (1 per student)

Wood Glue (3-4 bottles enough for 1 class)

Cellophane Tape (enough for a class 2-3 rolls)

Translucent 1 ply kitchen trash bag (1 per student)

Plastic grocery bag (1 per student)

Black magic marker (1 per student)

Scissors (1 per student)

Kite Making Dowels (4 twelve (12 inch) and 2 eight (8 in) per student)

Electrical Tape (enough for a class 1-2 rolls)

Yard Stick (2-4 for the class)

Sandpaper (1 per student)

Flying Line (1 roll per student)

Double-sided sticky tape

Worksheets

None

Objective:

Through experimentation, students will:

1. Understand that wind is a force of nature.
2. Explain how wind impacts objects in the air.
3. Use prior knowledge and new information gained through the activity to construct their own box kite.

Activity Overview:

Students will use this activity to build upon further kite building activities by constructing their own basic box kite. By following the directions and using the materials provided, students will create and fly their box kite.

Activity:**Part One - Constructing the Kite Sail**

You will need the following supplies to complete this portion of the activity:

- 4 (12 inch) kite dowels
- Kite Template (2 pages)
- Scissors
- Ruler
- Black magic marker
- Translucent kitchen or recyclable trash bag (single ply/1-ply)
- Tape

1. **Cut out Sections #1, #2 and #3 of the Kite Template. (Figure 18).**
2. **Lay Sections #1, #2 and #3 of the Kite Template on a flat surface and tape the bottom of Section #1 to the top of Section #2 and the bottom of Section 2 to the top of Section 3. Laid flat, this template represents one cell of the kite. (You will need two cells.)**
3. **Cut the translucent trash bag so it opens into a single layer and lay it flat on the table.**

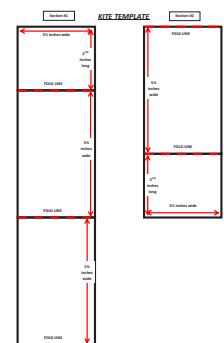


Fig. 18 Kite Template

Reference Materials

Kite Template
(Figure 18)

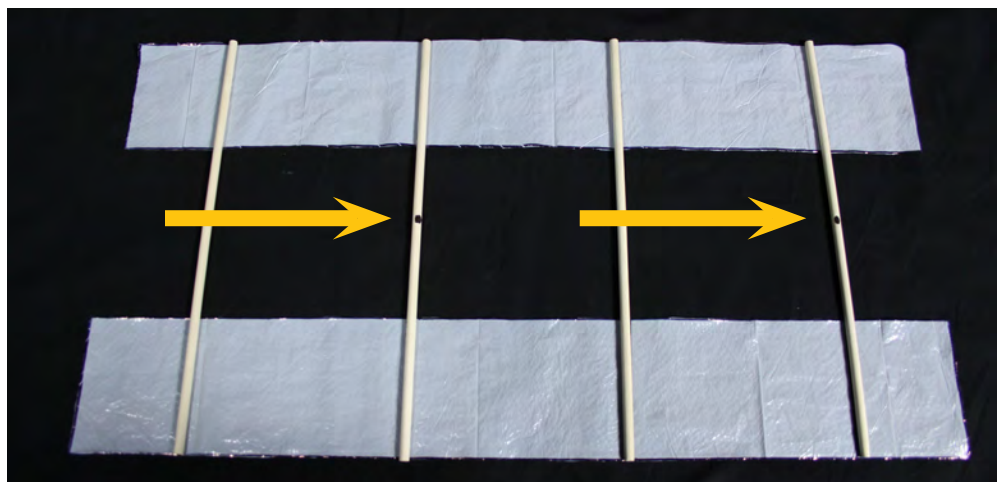
Key Terms:

None

4. Place the Box Kite Template (Sections #1, #2 and #3) on top of the trash bag with enough room to trace a second one.
5. Trace the outline of template. Be sure you are making a mark where the four (4) fold lines are located at the top and bottom of the template.
6. Place your ruler on the four sets of top and bottom marks, and connect the marks to identify the four fold lines. (See picture below.)



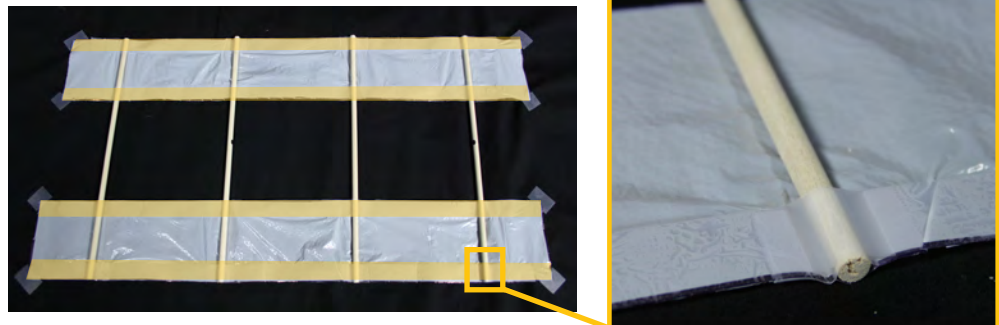
7. Repeat steps 4, 5 and 6 to trace a second Box Kite cell.
8. Cut out the two cells from the trash bag and lay them marked-side up on the table one above the other with the fold-lines aligned.
9. Take your 4 twelve-inch kite dowels and place them across both templates on the drawn fold-lines. Position the cells so that the 12-dowels' ends are at the top and bottom edges.
10. With your marker, measure the 2nd dowel and 4th dowels at 6 inches and make a dot. (See picture below.)



11. Take 4 small pieces of tape and tape down each corner (8) of both cell templates securing it to the table. (See picture below.)

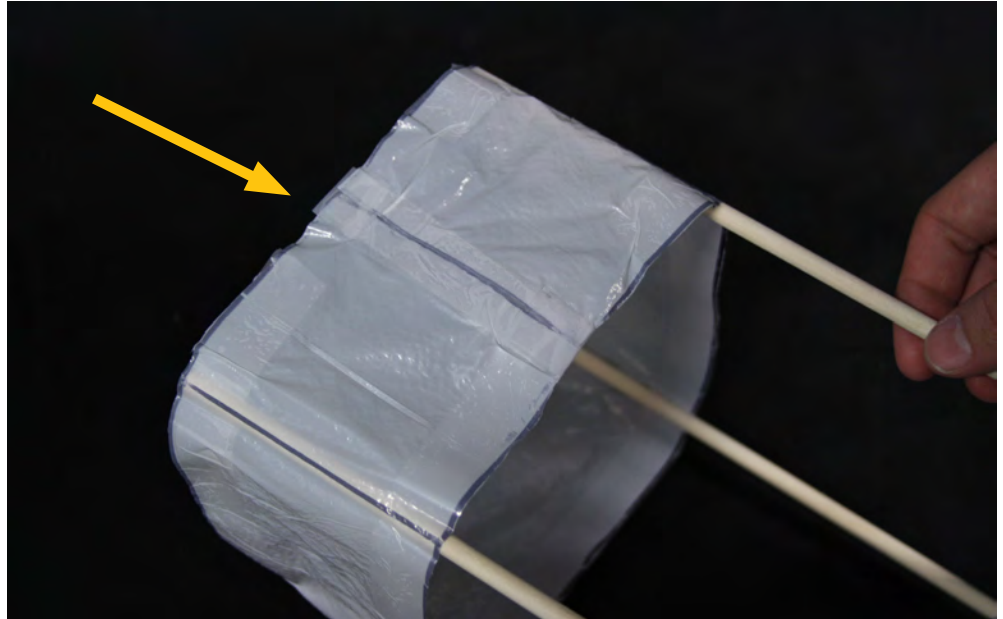


12. **Make sure your kite dowels are in place.** Take a roll of tape and release a few inches of tape. **DO NOT CUT** the tape. Place the tape on the bottom template along the bottom edge starting at the very left of the template.
13. **Very slowly pull more tape out while pressing down the tape onto the template.**
14. **Extend the tape and press down from left to right on the template, making sure the tape goes securely over each kite dowel.**
15. **Once you reach the end of the template cut the piece of tape and secure it to the right end of the bottom template.**
16. **Go back over the long piece of tape from left to right and smooth with your finger .**



17. **Repeat steps 12 thru 16 for the other three edges of cell templates.**
18. **Remove everything from your table except the kite template you just finished making.** Gently remove the 4 pieces of tape on the corners of each template. If you are having trouble removing them cut each edge of the piece of tape off.

19. Take the left end of the kite and gently pull it towards the right side.
20. Secure the outside of the two outer edges with a long piece of tape bringing the two joints together.
21. Measure another piece of tape similar to the one you just applied and tape the inside of the kite at the two joints. Both sides should have tape along them and be secured.

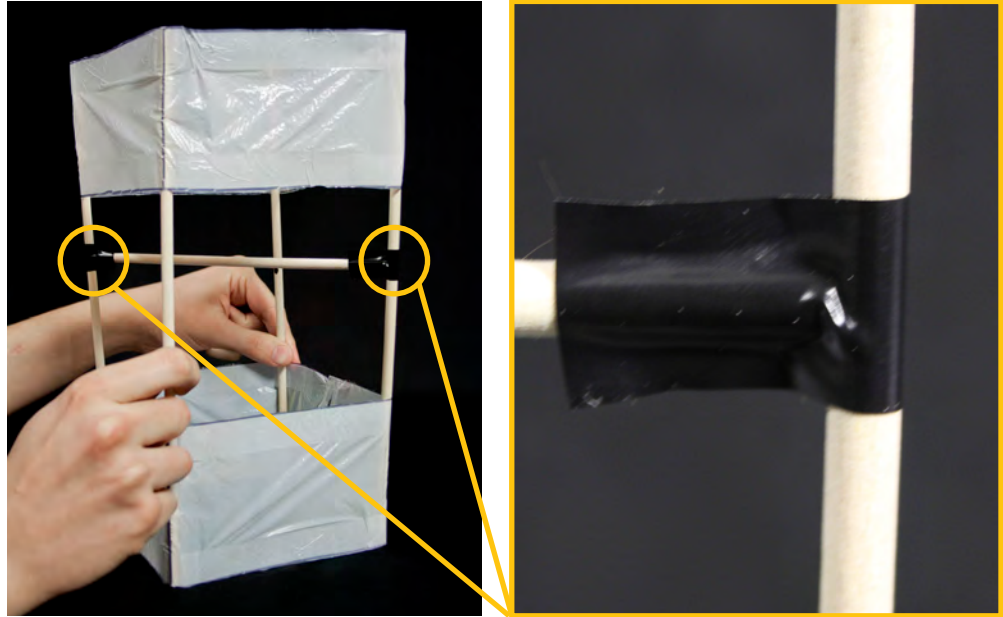


Part Two - Constructing the Cross Pieces

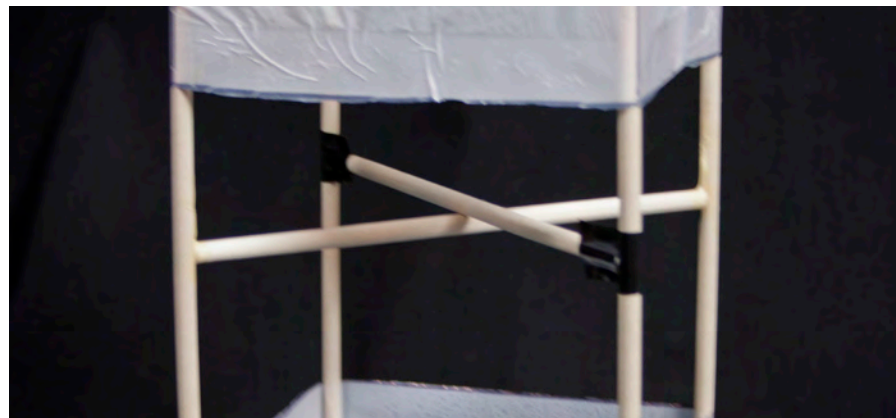
You will need the following supplies to complete Part Two and Three of the activity:

- Kite dowels
 - Scissors
 - Ruler
 - Black magic marker
 - Electrical tape
 - Cellophane tape
 - Sandpaper
 - Wood glue
 - Fly line
 - Plastic garbage bag for tail
1. Take a kite dowel and measure it to 8 inches in length. Mark that spot on your kite dowel with your marker.
 2. Take your scissors and gently cut your dowel at the 8 inch mark.
 3. Take your piece of sandpaper and gently smooth the end that was cut but be sure not to sand off enough to affect the length.

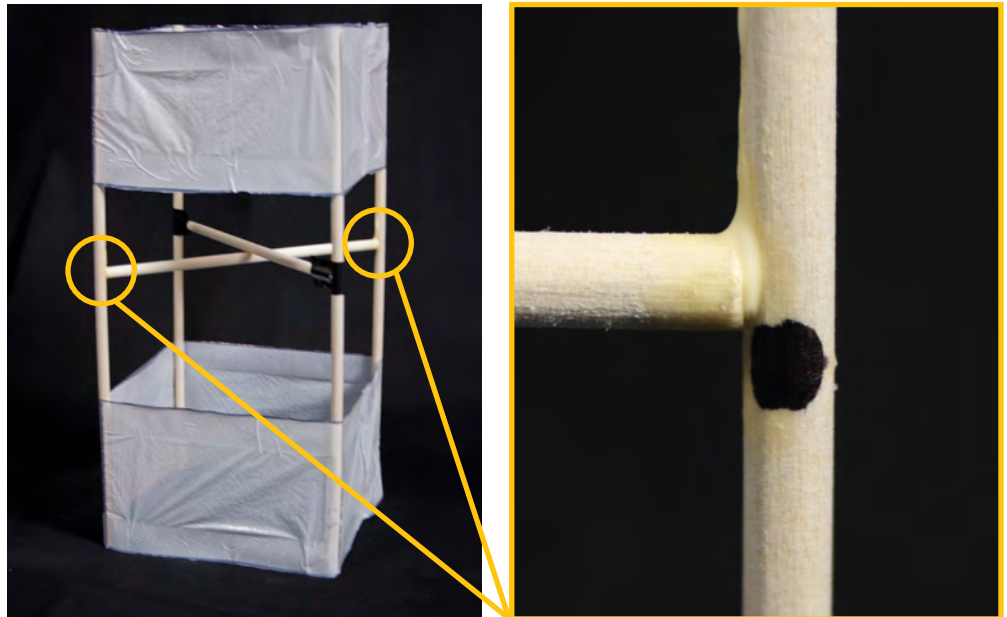
4. Take another kite dowel and measure it to 8 inches in length. Mark that spot on your kite dowel with your marker.
5. Take your scissors and gently cut your dowel at the 8 inch mark.
6. Take your piece of sandpaper and gently smooth the end that was cut but be sure not to sand enough off to affect the length.
7. Fit one 8 inch cross-piece between your unmarked kite dowels.
8. Take a small piece of electrical tape and wrap it around where each tip touches the kite dowel or spar.



9. Take the other 8 inch cross-piece and fit it between the two marked kite dowels. Note that you may need to gently cut and sand the top of your kite dowel little by little until it fits.



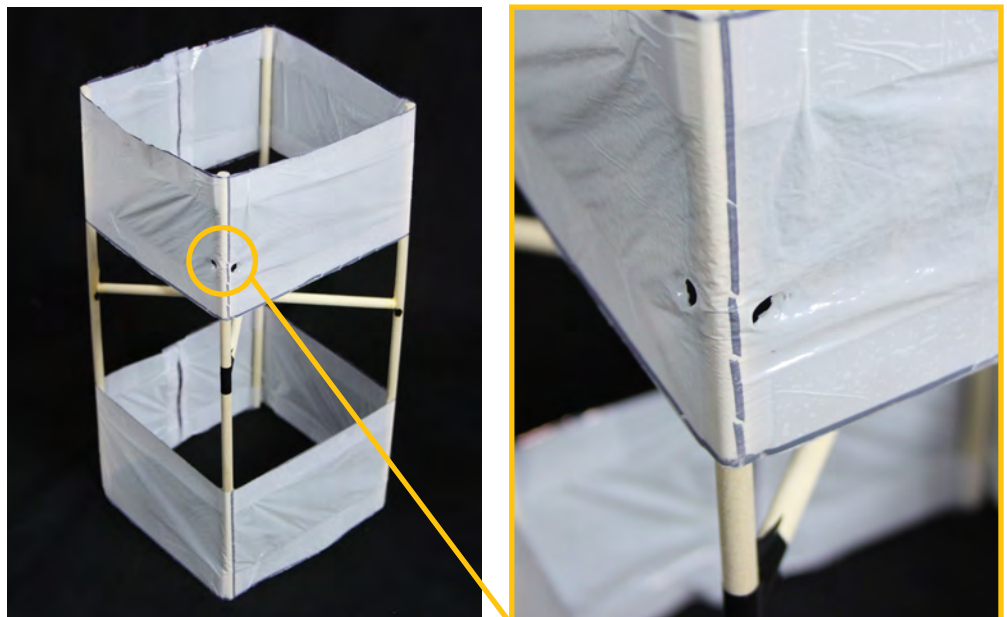
- Put 2 drops of wood glue at each end to secure it. Let the wood glue dry. This will take a few minutes. Now the 2 cross-pieces should be holding the kite open. Each plastic kite cell should show a little tension.



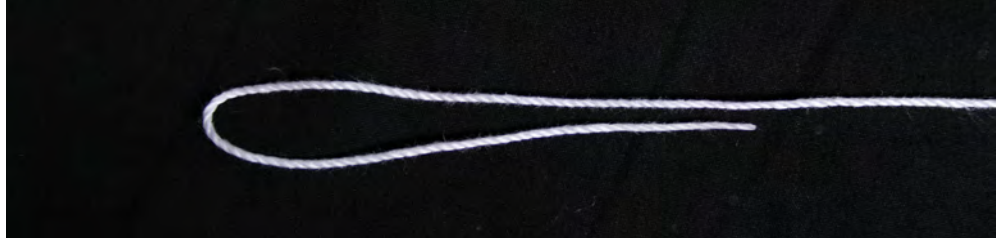
- When the glue has dried gently flip our kite over, peel back the tape, and add more wood glue to strengthen the joints on the other side.

Part Three - Attaching the Kite Sail

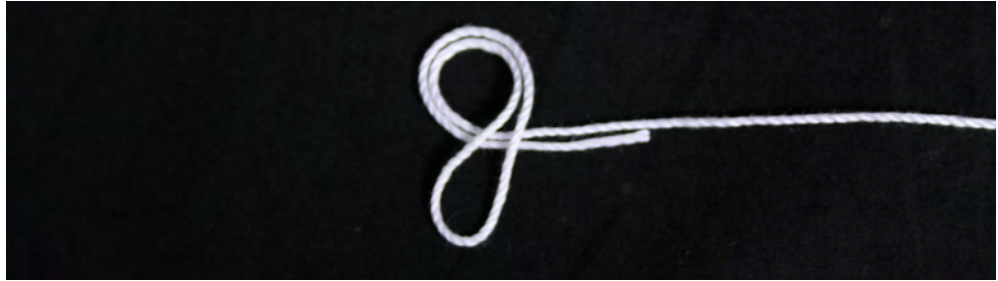
- Find one of your unmarked dowels. Take your ruler and measure on the left and right side of one unmarked dowel $2\frac{1}{4}$ inches from the top. Mark a dot on each side with your marker.
- Take a sharpened pencil and poke a hole into the marked dots on both sides of the kite dowel.



3. Measure and cut a 12 inch piece of flying line .
4. Form a loop.



5. Take the "u" shaped part of the line and bring it around and over.



6. Now bring the "u" shaped part of the line under and through.



7. Pull the string tightly.



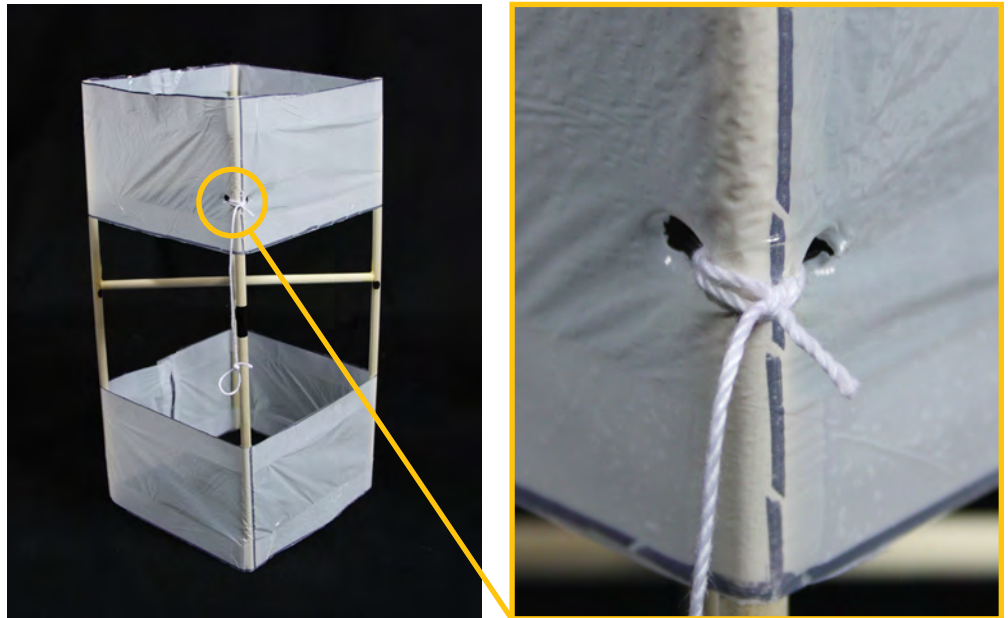
8. Make sure the loop is near one end of the string.

9. Repeat steps 4 through 7 to form another loop.

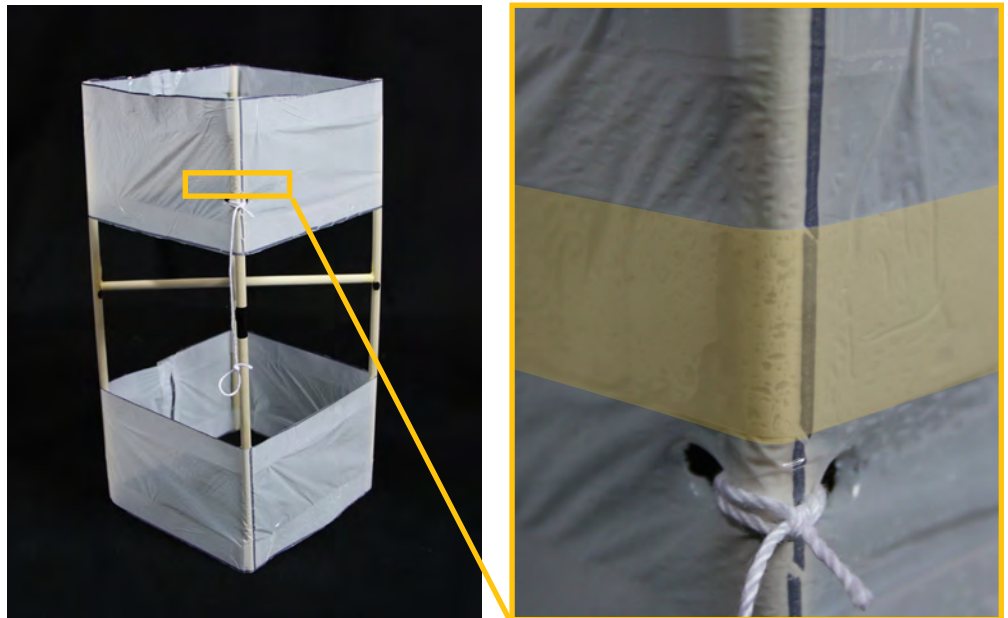
10. There should now be 2 loops, one near each end of the string.



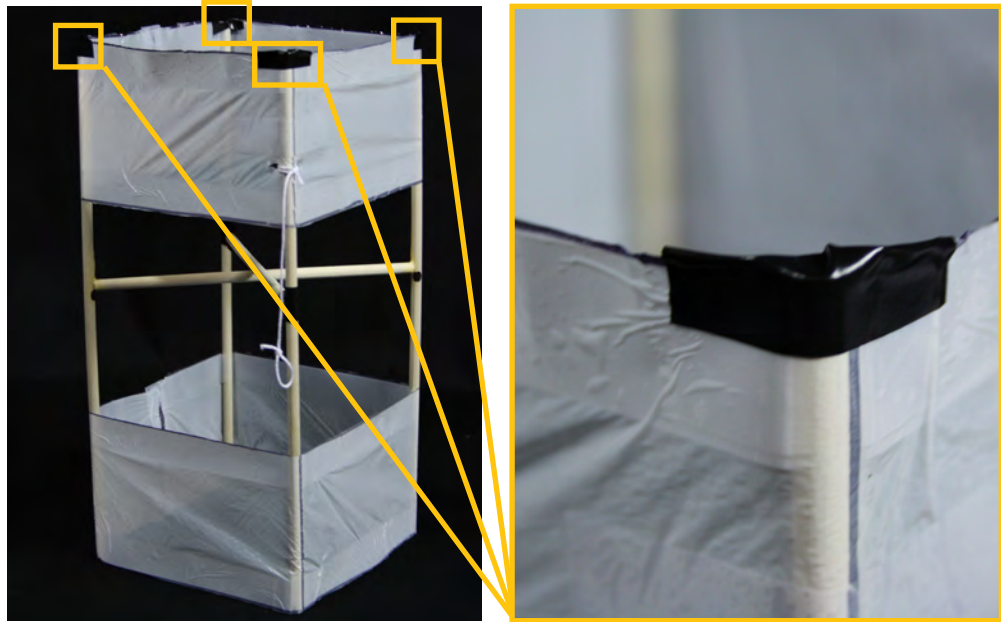
11. Attach one end of the double looped-string to the kite by passing it through the hole on the left, around the back of the dowel, and out the other hole on the right hand side. Now take the string and run it through the first loop . Pull the string tight.



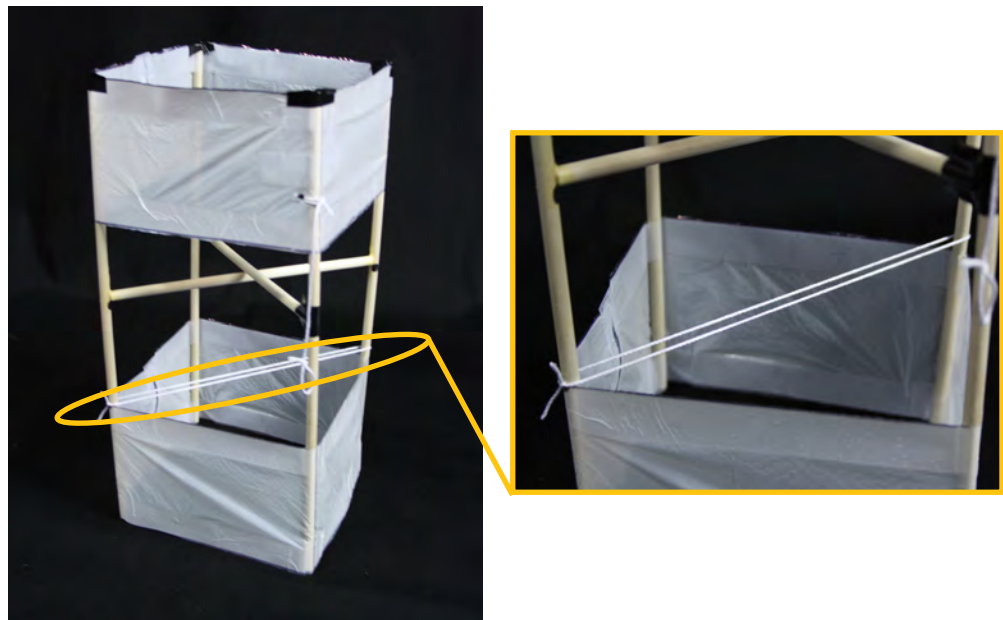
12. Cut a piece of 3-inch tape and wrap it around the sail, left to right, just above the holes where you put the string. (See picture below.)



13. Cut 4 pieces of electrical tape measuring 1 inch a piece.
14. Place 1 piece of tape over each dowel and cap each dowel. (See picture below.)



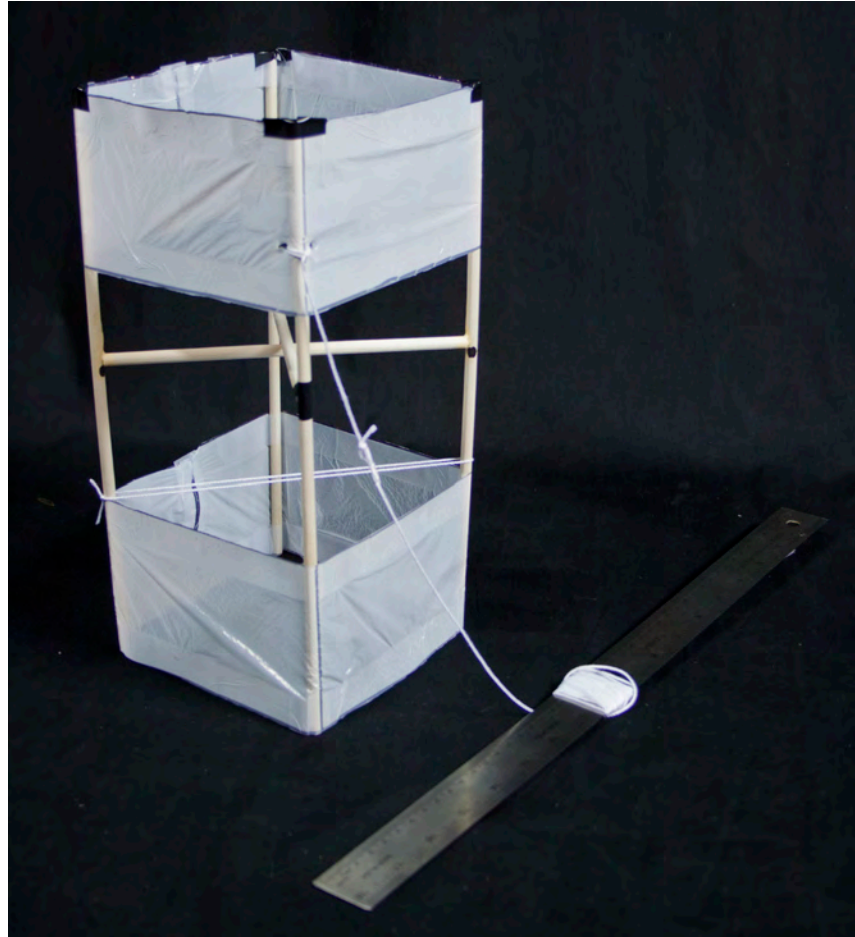
15. Cut another piece of fishing line measuring 12 inches in length.
16. Loop the string around the 2 marked dowels. Pull the string so that the string is straight and tie it off. This is called the tensioner.
17. Dab 2 drops of wood glue on the tensioner knot. (See picture below.)



18. Finally dab a few drops of glue in the center of the kite where the cross-pieces touch each other.

Part Four - Attaching the Kite Bridle

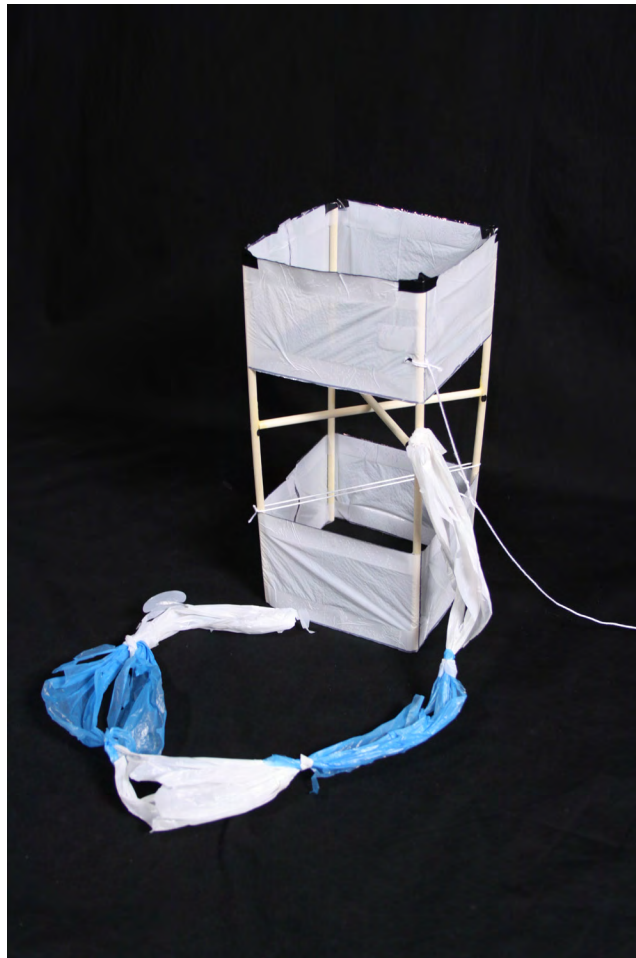
1. Measure a length of flying line approximately 60 feet long.
2. Attach the flying line to the bridle. (See picture below.)
3. Take the other end of the string and tie it around a ruler.
4. Wrap the string around the ruler one more time and secure on the back of the ruler with a 3 inch piece of electrical tape.
5. Now gently wrap the string tightly around the ruler until only about 3-5 feet are left between the kite and ruler. (See picture below.)



Part Four - Attaching the Kite Tail (Optional)

1. Cut off several loops of a closed, flat plastic grocery bag (or cut plastic strips from leftovers from kite cells). Loops or strips are approximately 2 inches or more in width.
2. Tie the loops or strips together to create a tail approximately 35 inches in length.
3. Lay a piece of double-sided sticky tape along the dowel that has the bridle attached, and press the tail securely on the dowel and sail.

NOTE: If the kite loops around in one direction, add more tail loops to one side of the lower cell.



NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

EARTH AND SPACE

- Energy in the earth system

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology



Reference Materials

Glossary

Apex:

The tip or point of an object.

Base:

The foundation of an object.

Edge:

A line where two surfaces of a solid meet.

Equilateral:

All sides of an object are equal.

Equilateral Triangle:

A triangle that has three equal sides and angles.

Face:

A flat surface of a 3-dimensional object

Parallelogram:

A quadrilateral that has both pairs of opposite sides parallel to each other.

Platonic Solid:

Classified as one of the five regular polyhedrons including the tetrahedron, octahedron, hexahedron, icosahedron, and dodecahedron.

Pyramid:

A solid geometric shape that has a polygonal base and triangular sides that meet in a singular point.

Quadrilateral:

A plane figure that has four sides and four angles otherwise known as a polygon that has four sides

Rhombus:

An angled equilateral parallelogram.

Triangle:

A closed plane figure that has three sides and three angles

Triangular Numbers:

The number of dots, mathematically represented by " n ", in an equilateral triangle evenly filled with dots; the successive sums of the first n natural numbers 1, 3, 6, 10, 15, ... representable by dots arranged in triangles.

Tetrahedron:

A solid triangular pyramid or a geometric shape comprised of four plane faces.

Vertex:

A point in a geometrical solid that is common to three or more sides.

Vertices:

Plural of vertex.

SUGGESTED ADDITIONAL READINGS:

None

SUGGESTED INTERNET SEARCHES:

Kites

History of Kites

Chinese Fishing Kites

Wright Brothers and Kites

Alexander Graham Bell's Tetrahedron Kite

Benjamin Franklin and Kite Experiment

How Kites are Used to Generate Energy

Beaufort Wind Scale

Future of Kites

Uses of Kites Today

Energy Producing Kites

Fig. 1 The Beaufort Scale

Beaufort number	Description	Wind speed	Wave height	Sea conditions	Land conditions
0	Calm	< 1 km/h (< 0.3 m/s)	0 m	Flat.	Calm. Smoke rises vertically.
		< 1 mph			
		< 1 kn	0 ft		
		< 0.3 m/s			
1	Light air	1.1–5.5 km/h (0.3-2 m/s)	0–0.2 m	Ripples without crests.	Smoke drift indicates wind direction and wind vanes cease moving.
		1–3 mph	0–1 ft		
		1–2 kn			
		0.3–1.5 m/s			
2	Light breeze	5.6–11 km/h (2-3 m/s)	0.2–0.5 m	Small wavelets. Crests of glassy appearance, not breaking.	Wind felt on exposed skin. Leaves rustle and wind vanes begin to move.
		4–7 mph	1–2 ft		
		3–6 kn			
		1.6–3.4 m/s			
3	Gentle breeze	12–19 km/h (3-5 m/s)	0.5–1 m	Large wavelets. Crests begin to break; scattered whitecaps.	Leaves and small twigs constantly moving, light flags xtended.
		8–12 mph	2–3.5 ft		
		7–10 kn			
		3.4–5.4 m/s			
4	Moderate breeze	20–28 km/h (6-8 m/s)	1–2 m	Small waves with breaking crests. Fairly frequent whitecaps.	Dust and loose paper raised. Small branches begin to move.
		13–17 mph	3.5–6 ft		
		11–15 kn			
		5.5–7.9 m/s			
5	Fresh breeze	29–38 km/h (8.1-10.6 m/s)	2–3 m	Moderate waves of some length. Many whitecaps. Small amounts of spray.	Branches of a moderate size move. Small trees in leaf begin to sway.
		18–24 mph	6–9 ft		
		16–20 kn			
		8.0–10.7 m/s			
6	Strong breeze	39–49 km/h (10.8-13.6 m/s)	3–4 m	Long waves begin to form. White foam crests are very frequent. Some airborne spray is present.	Large branches in motion. Whistling heard in overhead wires. Umbrella use becomes difficu . Empty plastic garbage cans tip over.
		25–30 mph	9–13 ft		
		21–26 kn			
		10.8–13.8 m/s			

Fig. 1 The Beaufort Scale (cont.)

Beaufort number	Description	Wind speed	Wave height	Sea conditions	Land conditions
7	High wind, Moderate gale, Near gale	50–61 km/h (13.9-16.9 m/s)	4–5.5 m	Sea heaps up. Some foam from breaking waves is blown into streaks along wind direction. Moderate amounts of airborne spray.	Whole trees in motion. Effort needed to walk against the wind.
		31–38 mph			
		27–33 kn	13–19 ft		
		13.9–17.1 m/s			
8	Gale, Fresh gale	62–74 km/h (17.2-20.6 m/s)	5.5–7.5 m	Moderately high waves with breaking crests forming spindrift. Well-marked streaks of foam are blown along wind direction. Considerable airborne spray.	Some twigs broken from trees. Cars veer on road. Progress on foot is seriously impeded.
		39–46 mph	18–25 ft		
		34–40 kn			
		17.2–20.7 m/s			
9	Strong gale	75–88 km/h (20.8-24.4 m/s)	7–10 m	High waves whose crests sometimes roll over. Dense foam is blown along wind direction. Large amounts of airborne spray may begin to reduce visibility.	Some branches break off trees, and some small trees blow over. Construction/temporary signs and barricades blow over.
		47–54 mph	23–32 ft		
		41–47 kn			
		20.8–24.4 m/s			
10	Storm Whole gale	89–102 km/h (24.7-28.3 m/s)	9–12.5 m	Very high waves with overhanging crests. Large patches of foam from wave crests give the sea a white appearance. Considerable tumbling of waves with heavy impact. Large amounts of airborne spray reduce visibility.	Trees are broken off or uprooted, saplings bent and deformed. Poorly attached asphalt shingles and shingles in poor condition peel off roofs.
		55–63 mph	29–41 ft		
		48–55 kn			
		24.5–28.4 m/s			
11	Violent storm	103–117 km/h (28.6-32.5 m/s)	11.5–16 m	Exceptionally high waves. Very large patches of foam, driven before the wind, cover much of the sea surface. Very large amounts of airborne spray severely reduce visibility.	Widespread damage to vegetation. Many roofing surfaces are damaged; asphalt tiles that have curled up and/or fractured due to age may break away completely.
		64–72 mph	37–52 ft		
		56–63 kn			
		28.5–32.6 m/s			
12	Hurricane force	≥ 118 km/h (≥ 32.8 m/s)	≥ 14 m	Huge waves. Sea is completely white with foam and spray. Air is filled with driving spray, greatly reducing visibility.	Very widespread damage to vegetation. Some windows may break; mobile homes and poorly constructed sheds and barns are damaged. Debris may be hurled about.
		≥ 73 mph	≥ 46 ft		
		≥ 64 kn			
		≥ 32.7 m/s			

Fig. 2 Triangle

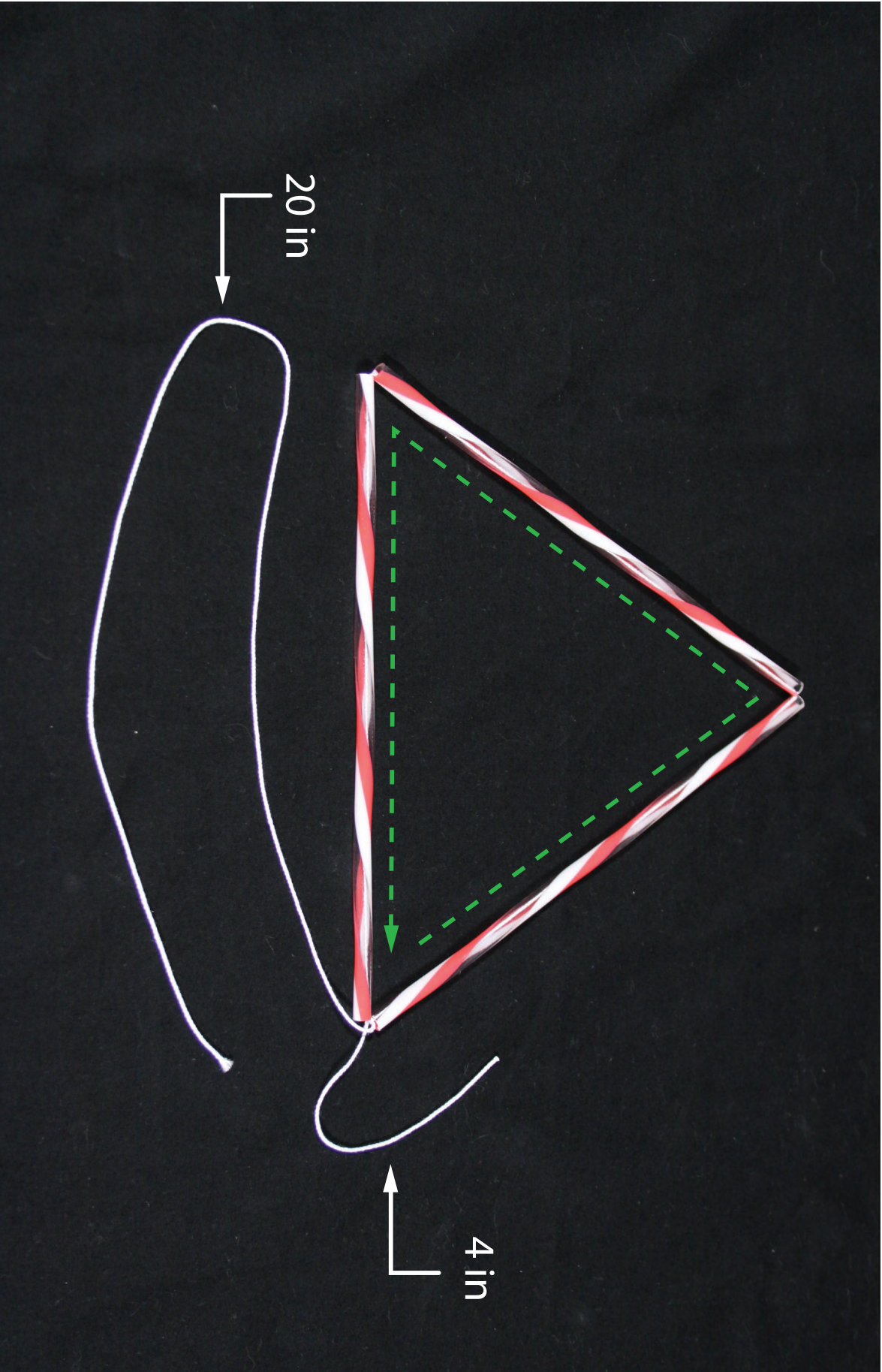


Fig. 3 Rhombus construction

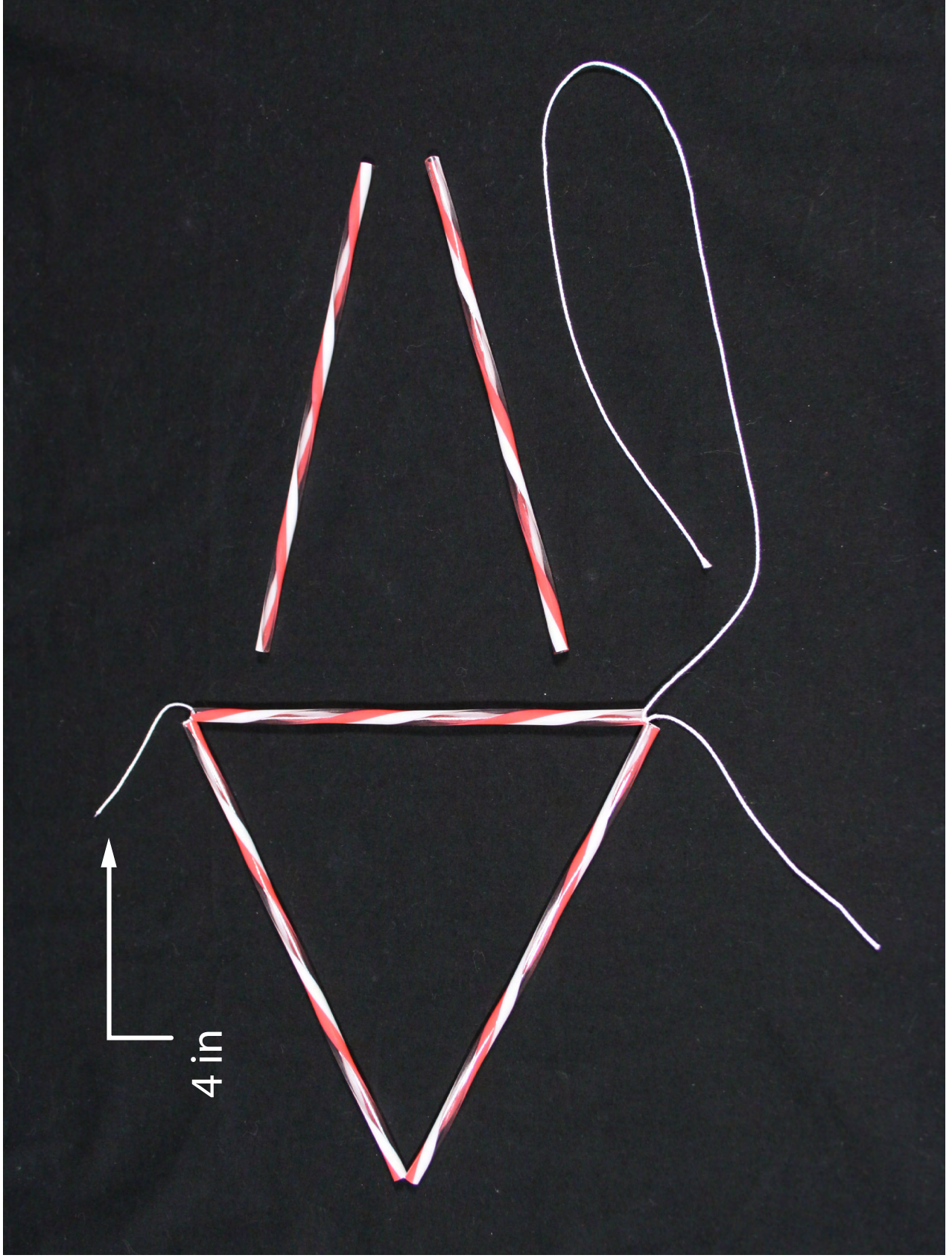


Fig. 4 Completed rhombus

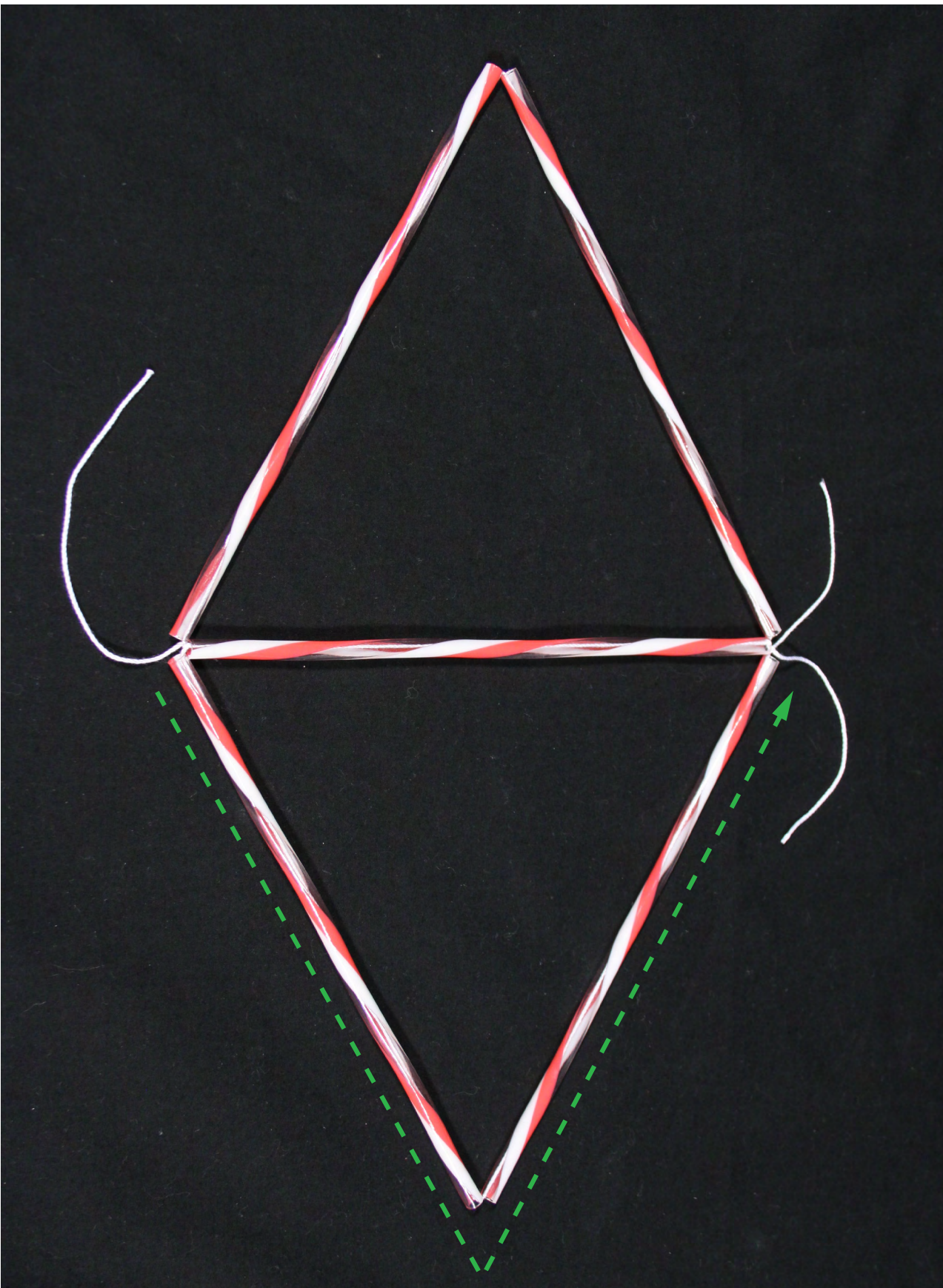


Fig. 5 Three dimensional tetrahedron construction

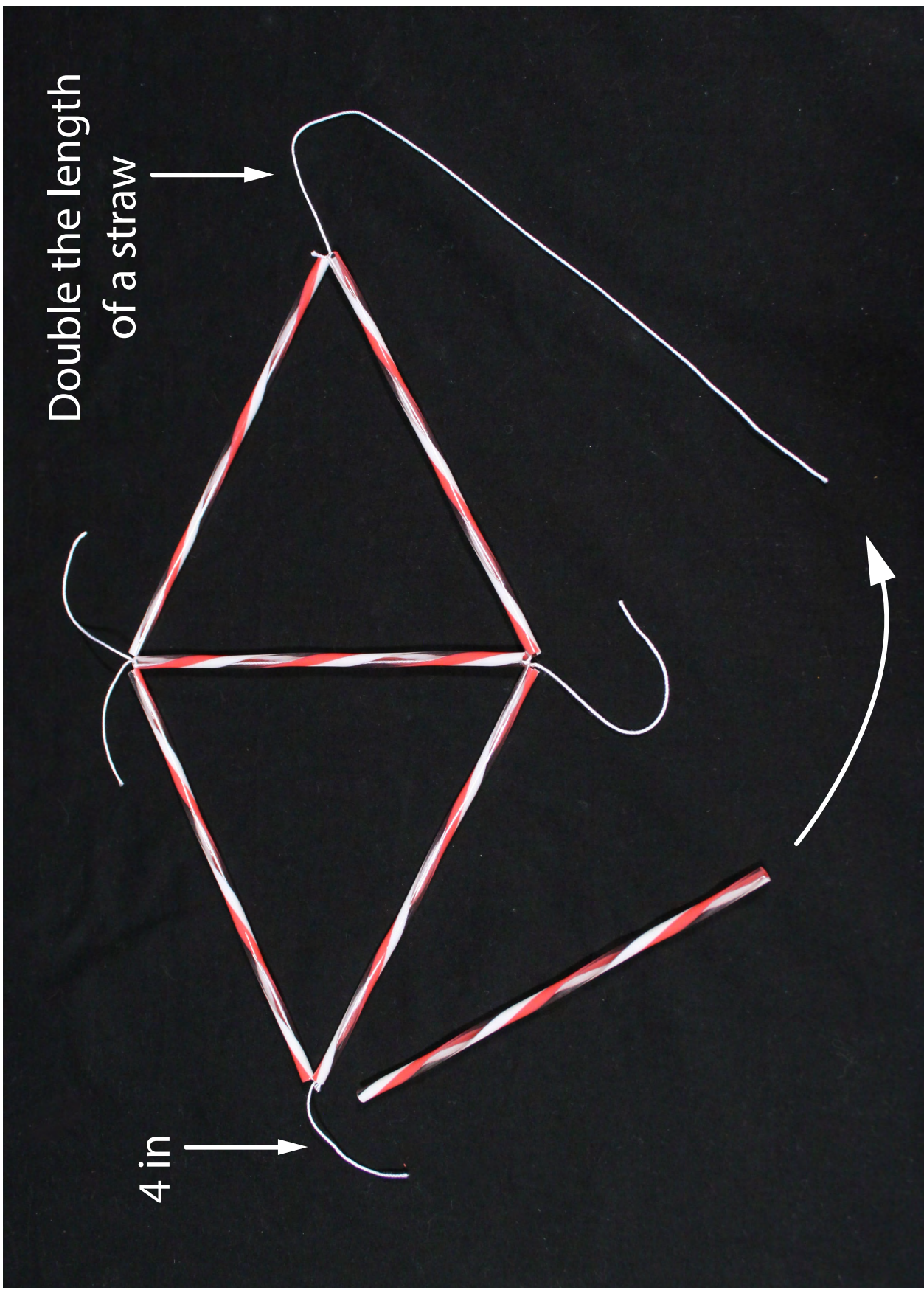


Fig. 6 Completed three dimensional tetrahedron

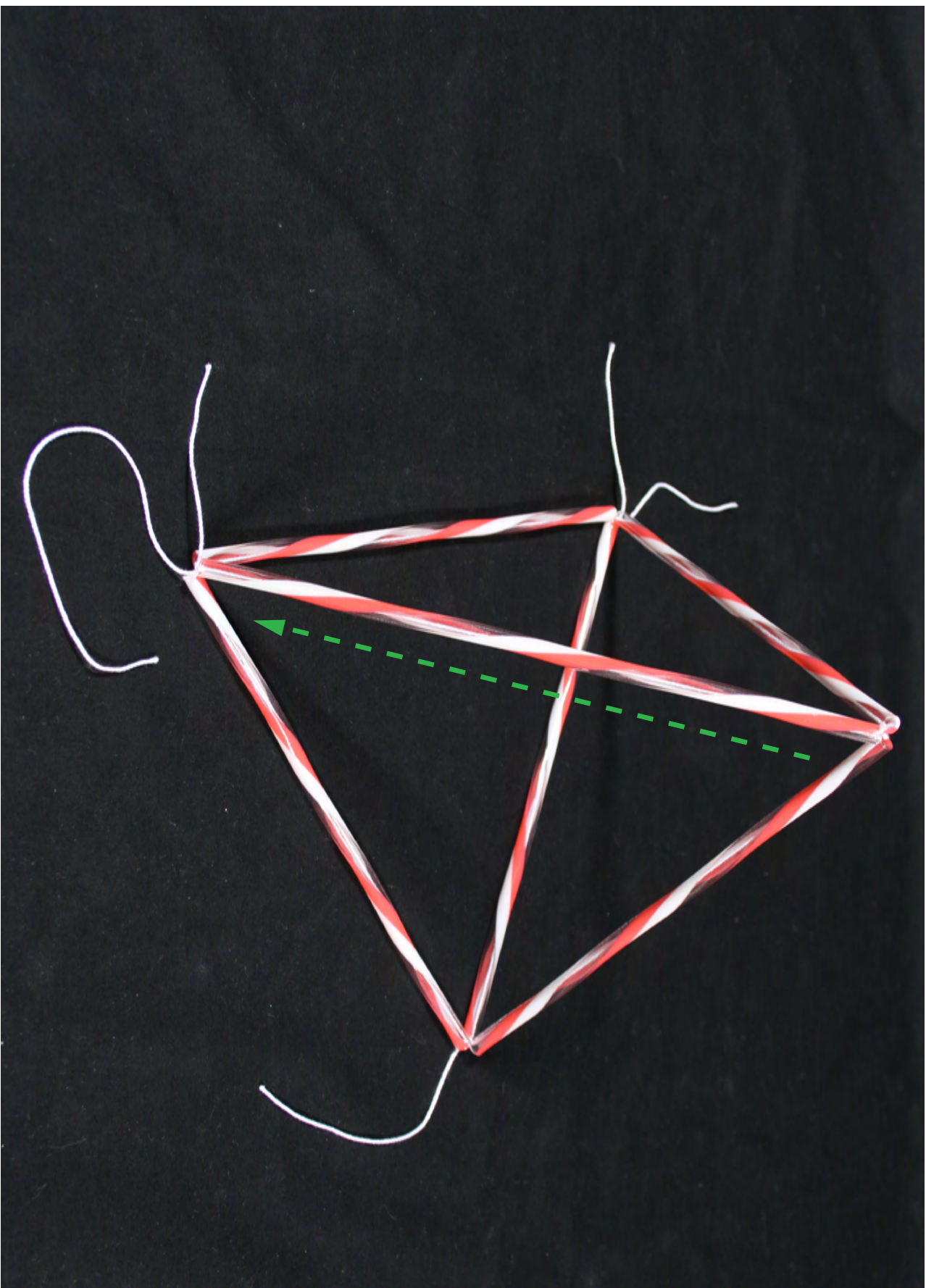
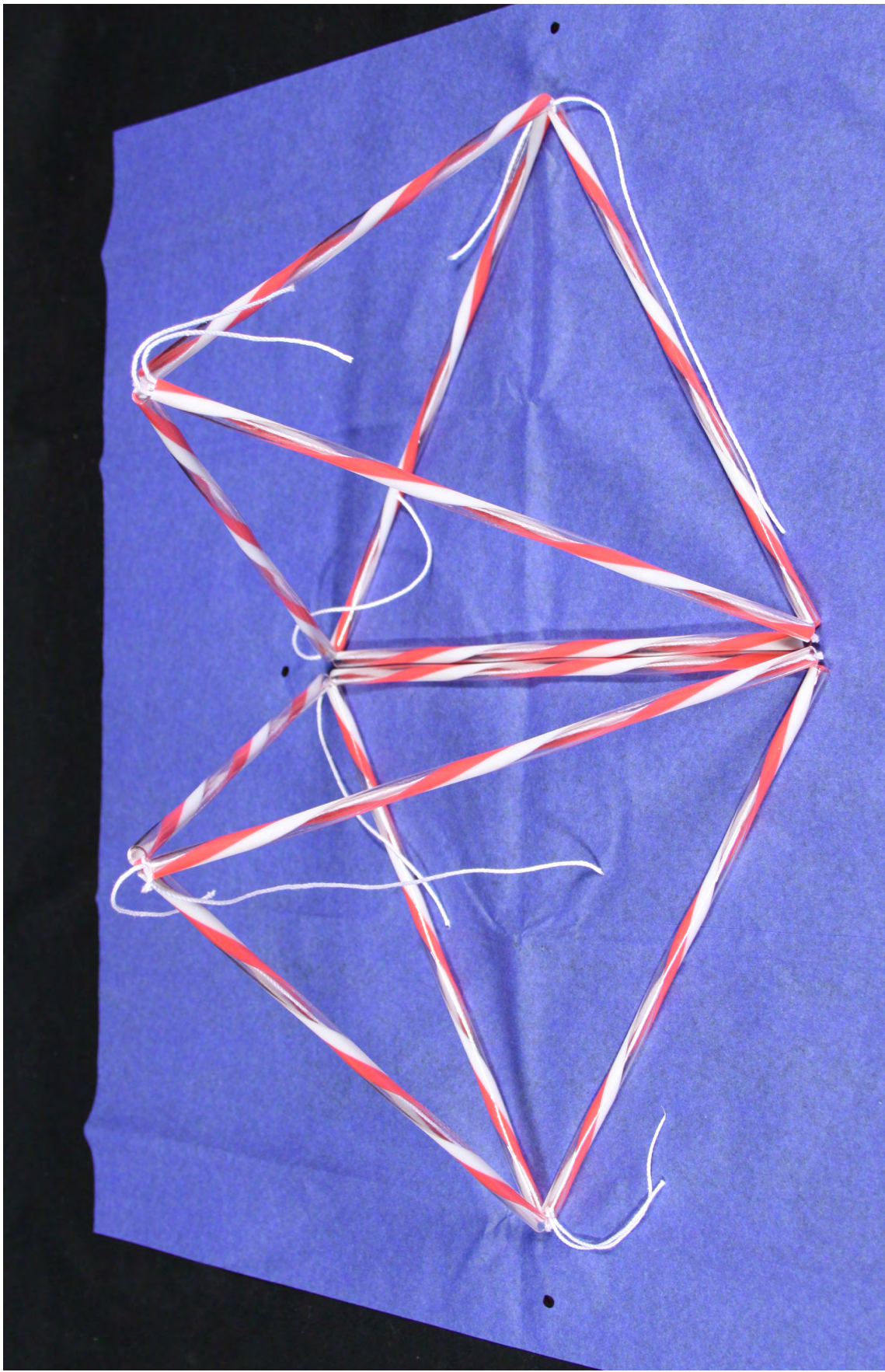


Fig. 7 One-inch marks to create template



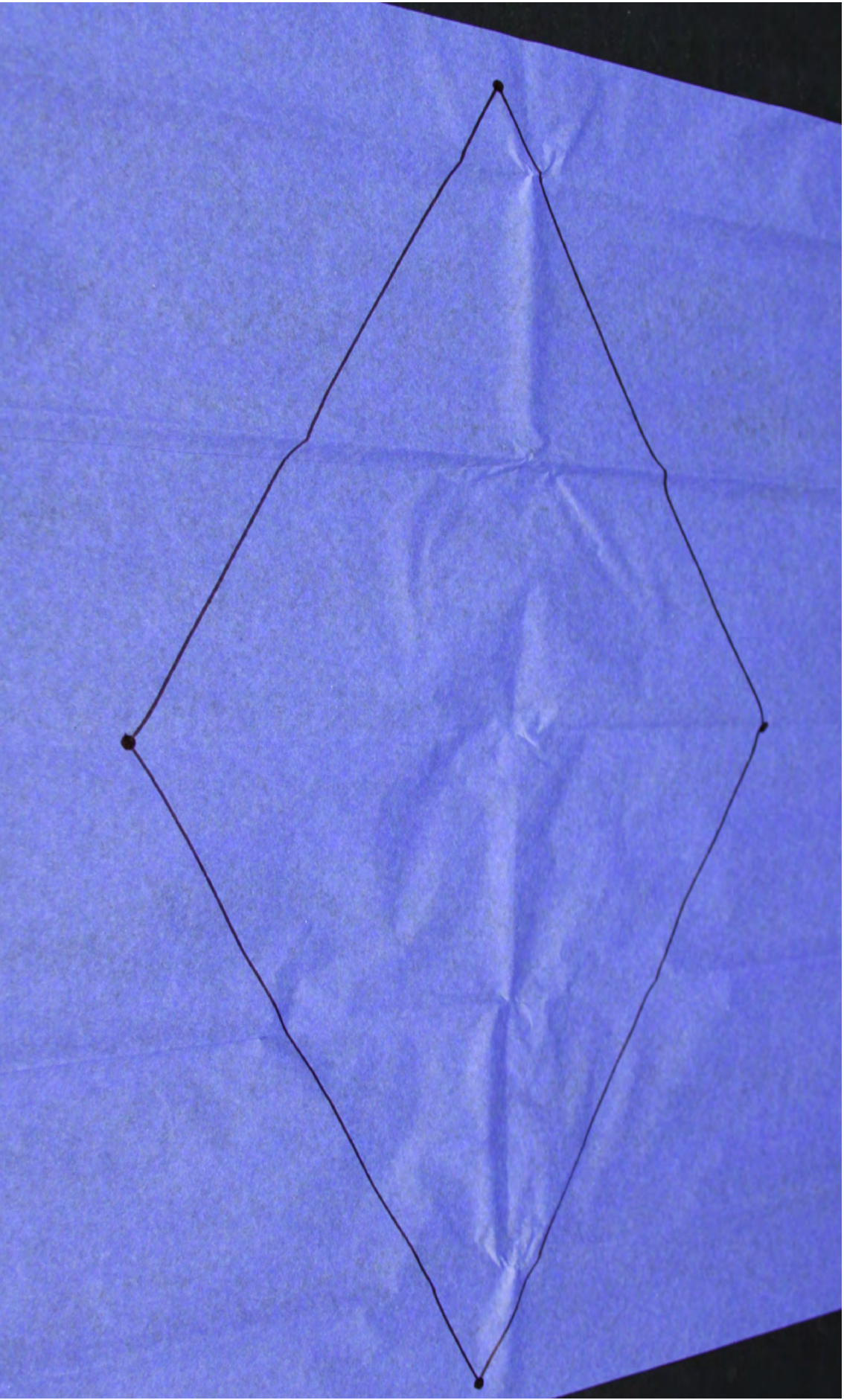
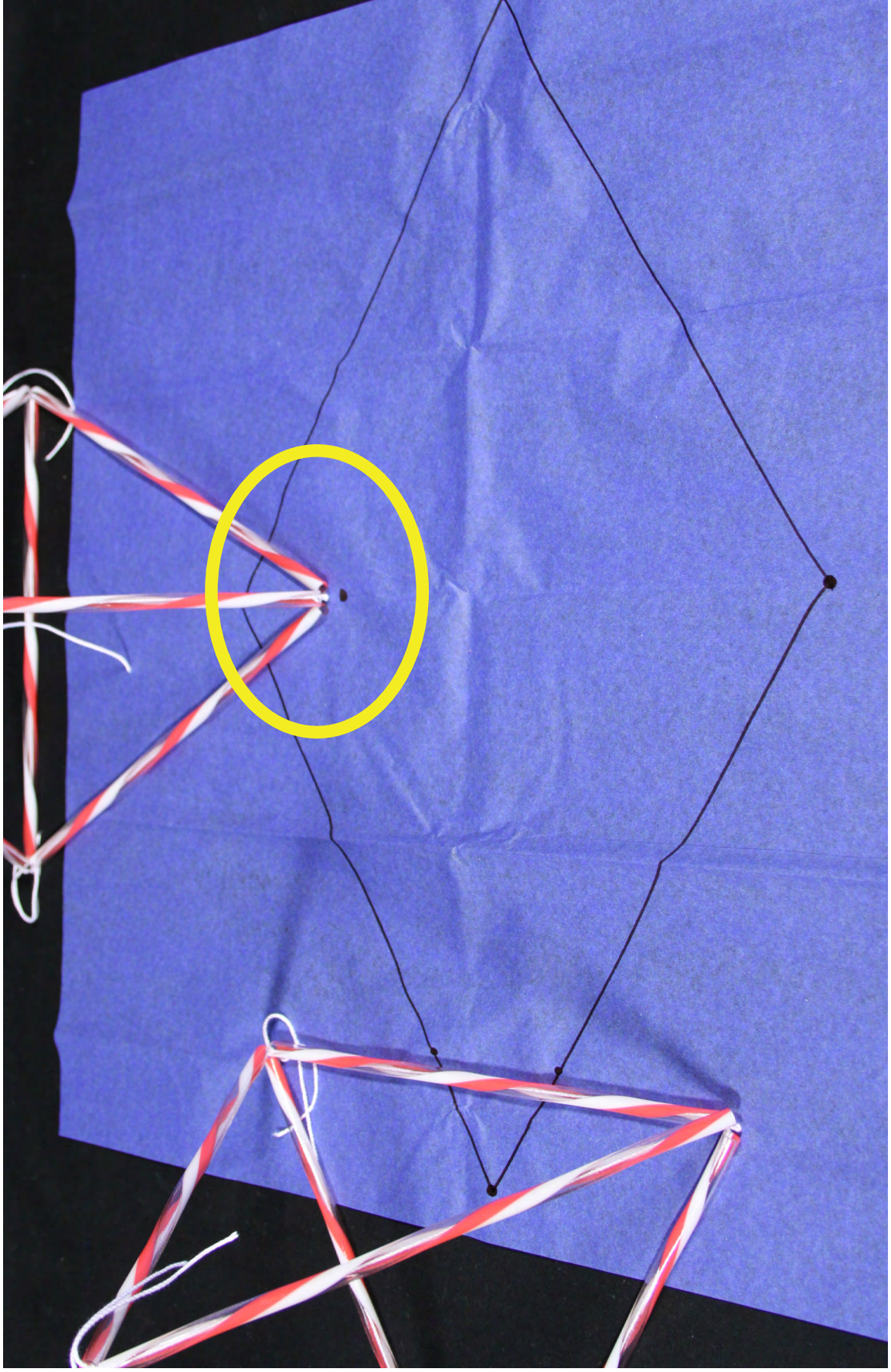


Fig. 8 Template construction

Fig. 9 Obtuse angle marking for template construction



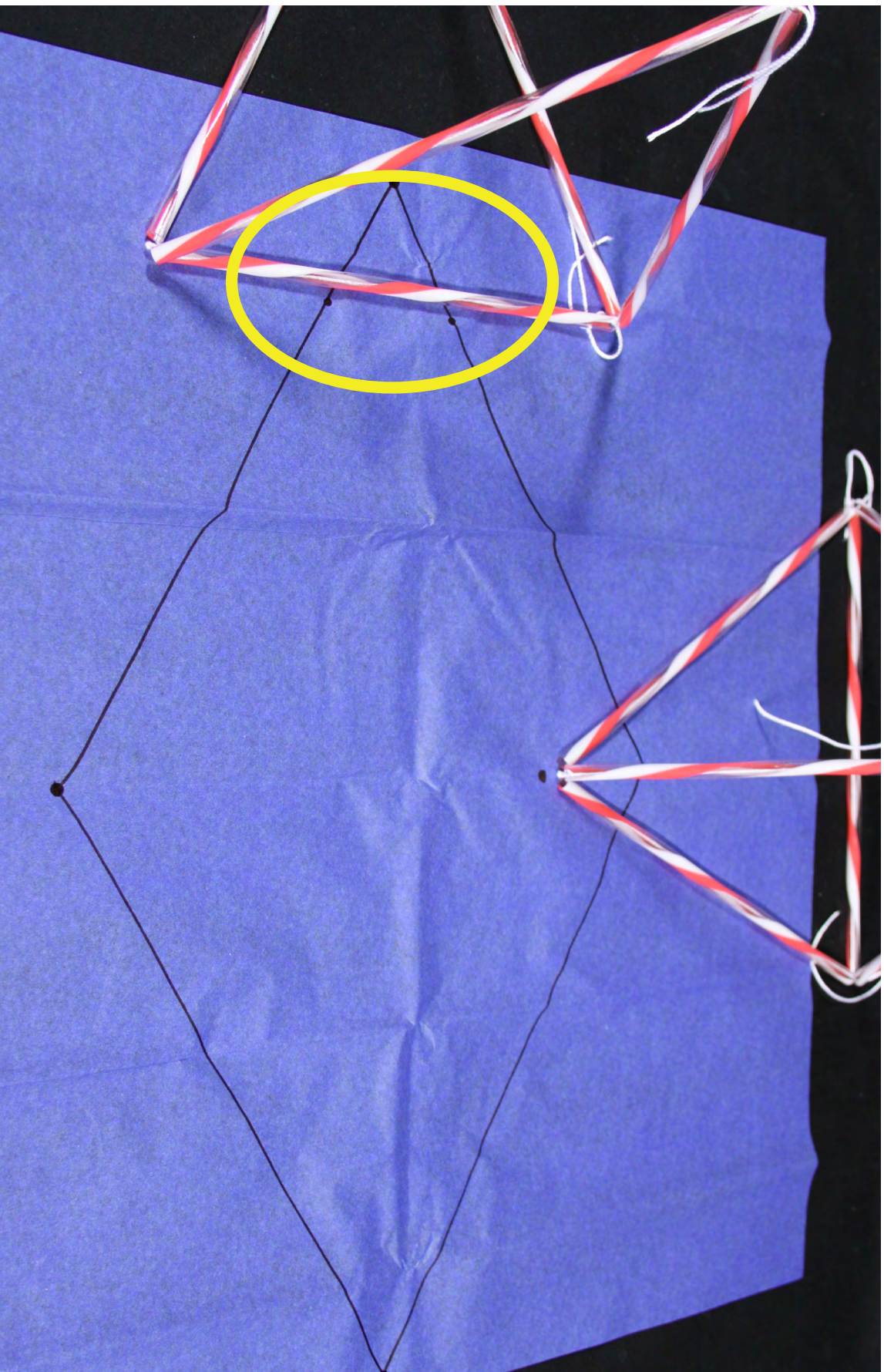


Fig. 10 Acute angle marking for template construction

Fig. 11 Tissue paper template

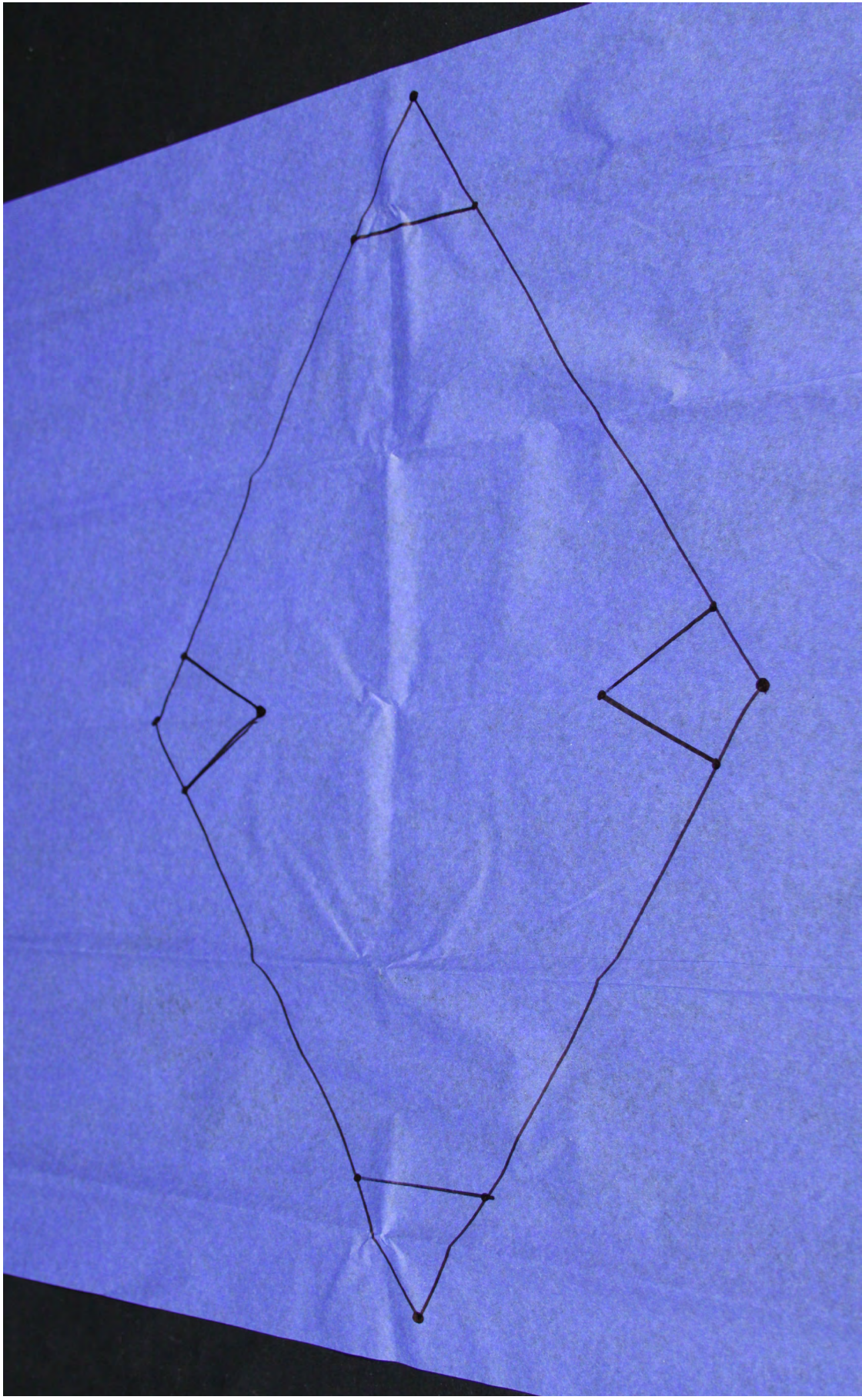


Fig. 12 Completed tissue paper template

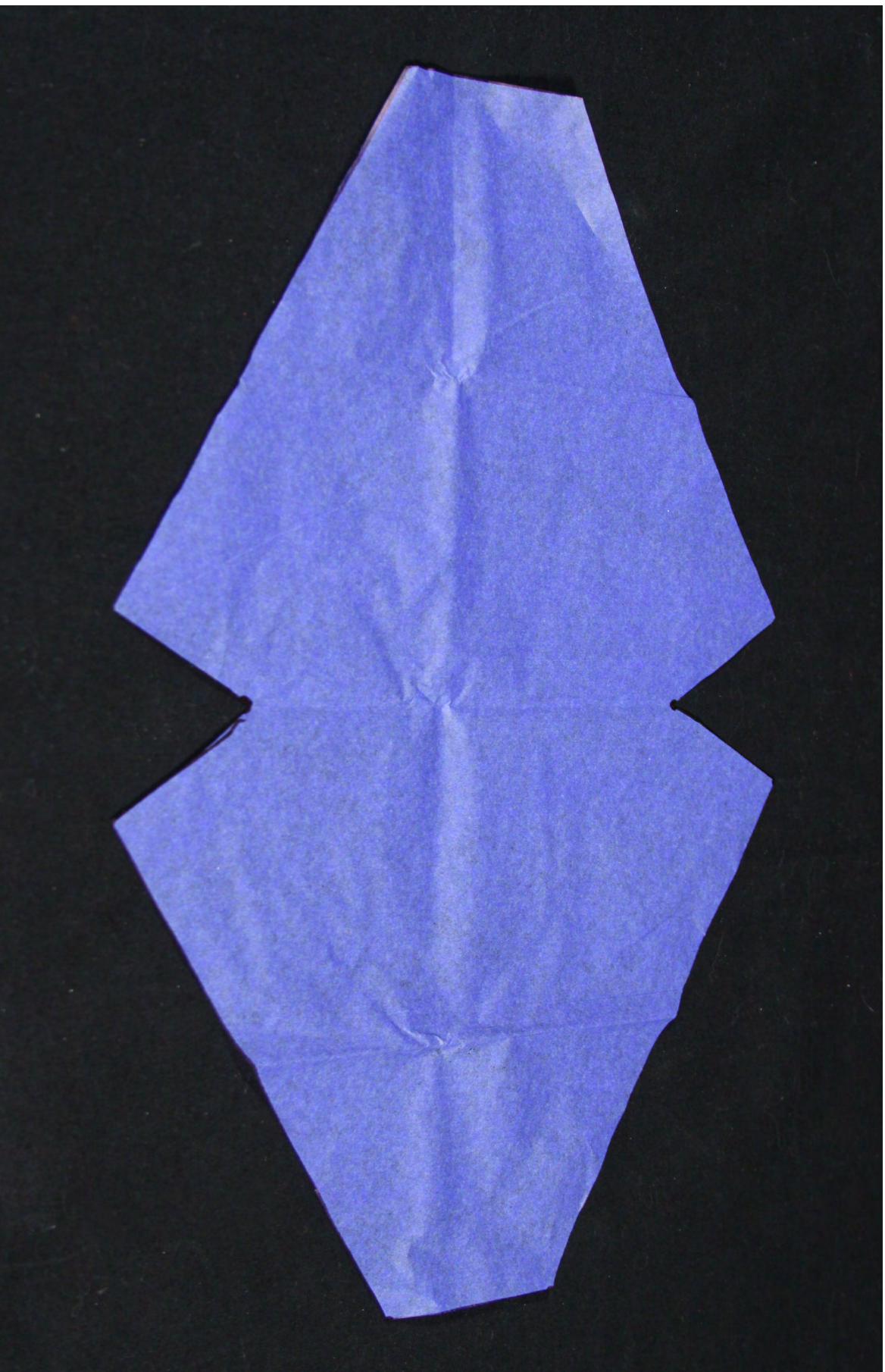


Fig. 13 Placement of tetrahedron on tissue paper template

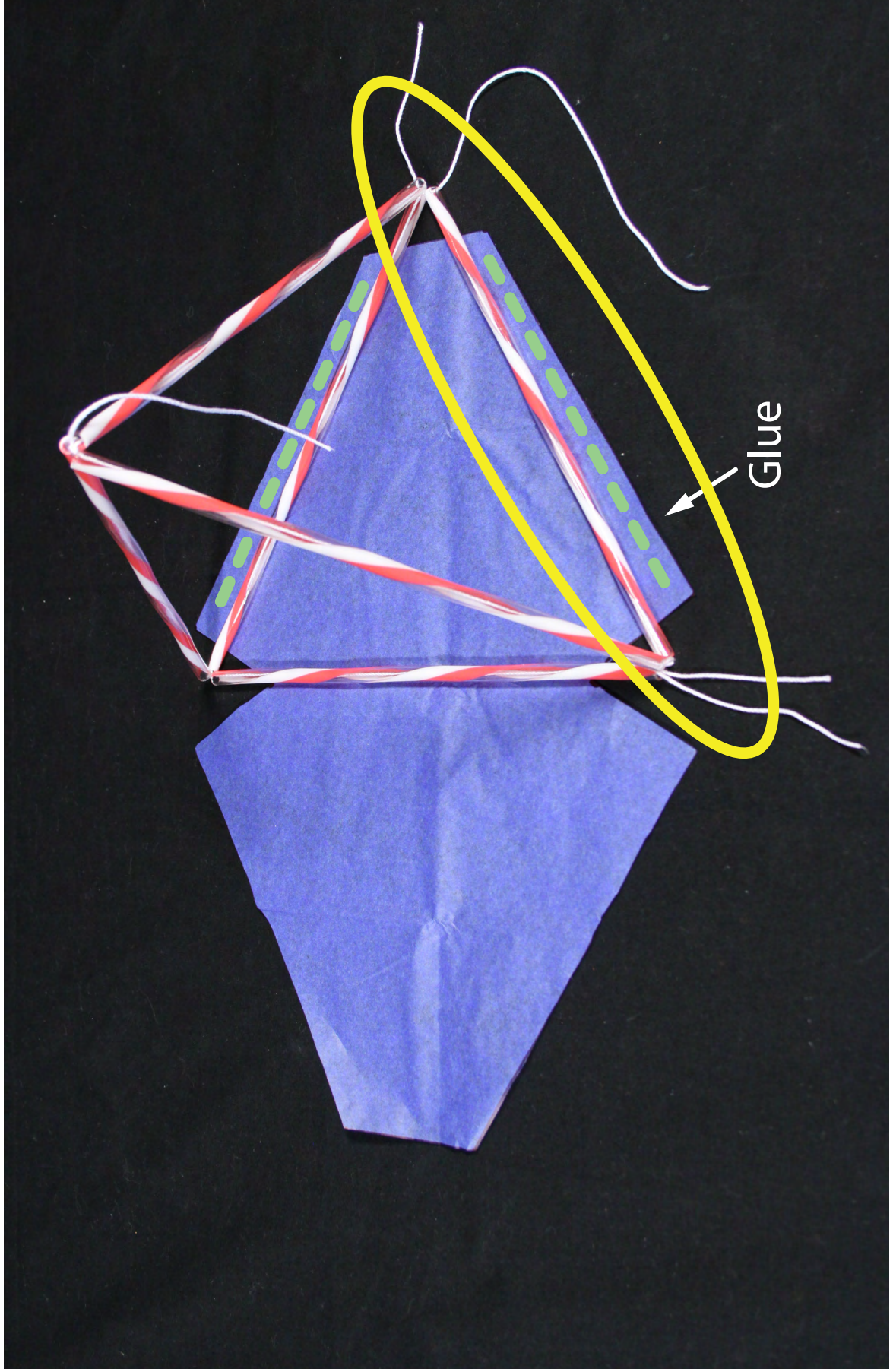


Fig. 14 Covered tetrahedron

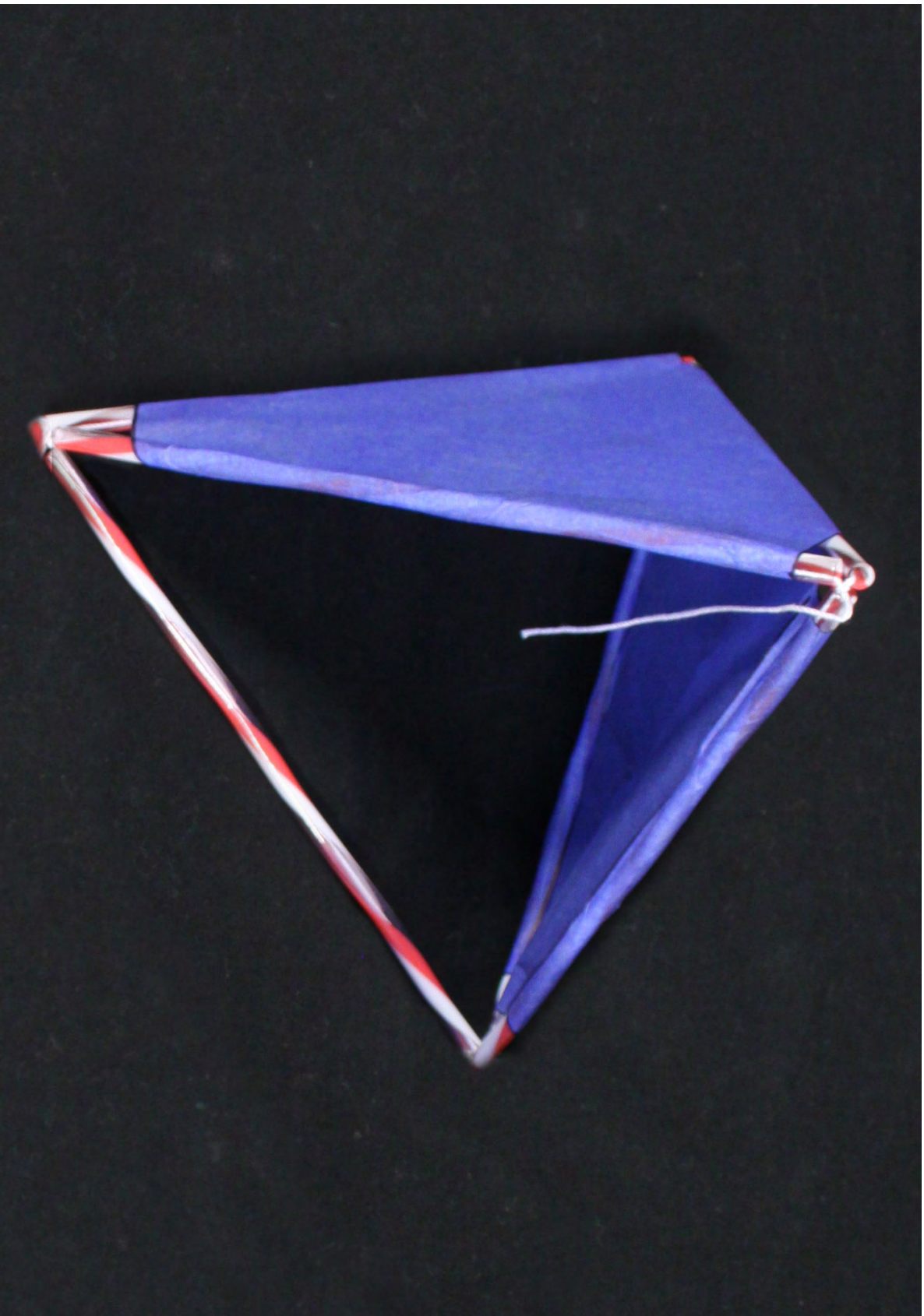


Fig. 15 Three tetrahedrons in the form of one large triangle

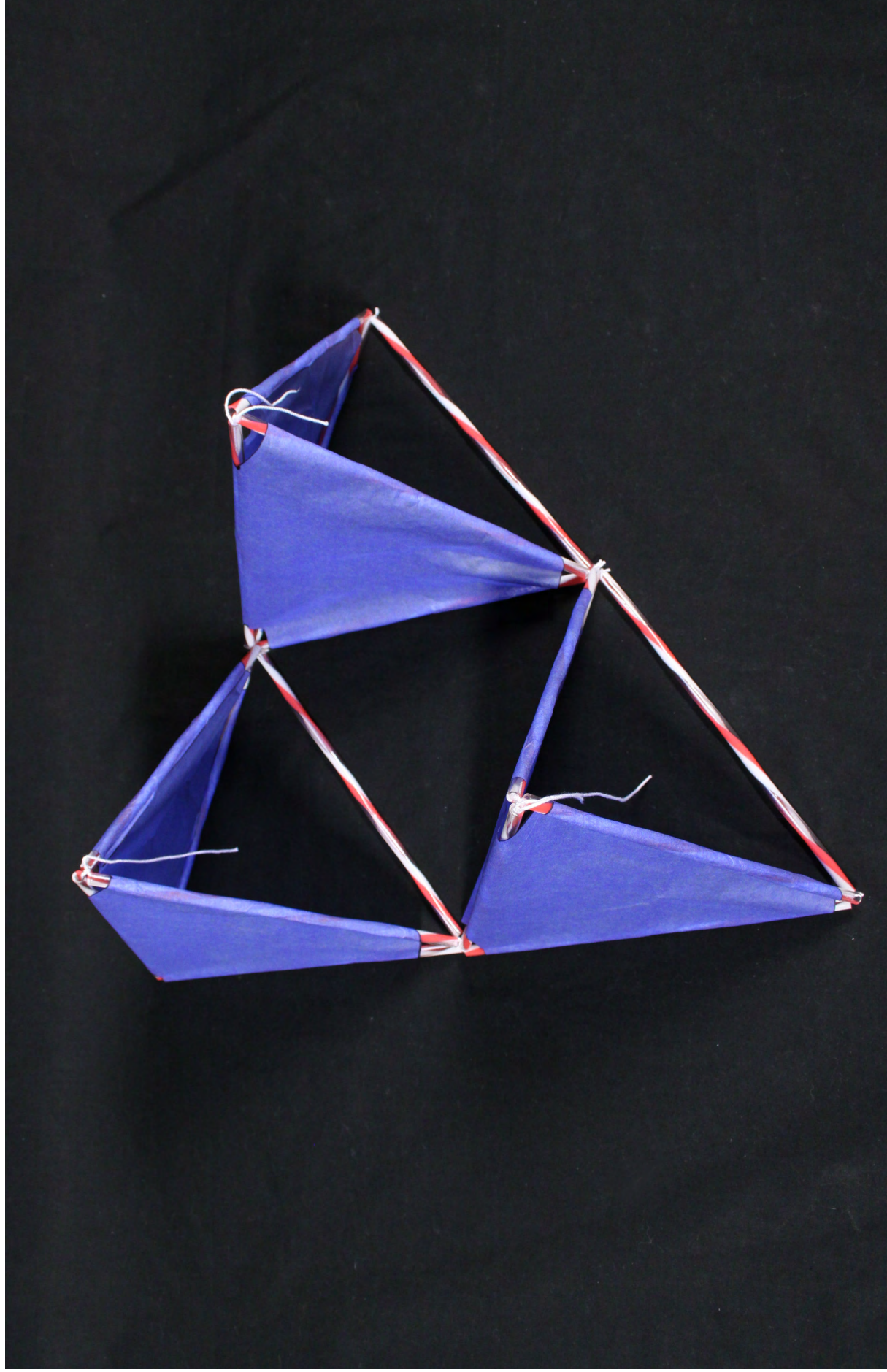


Fig. 16 4 Tetrahedrons

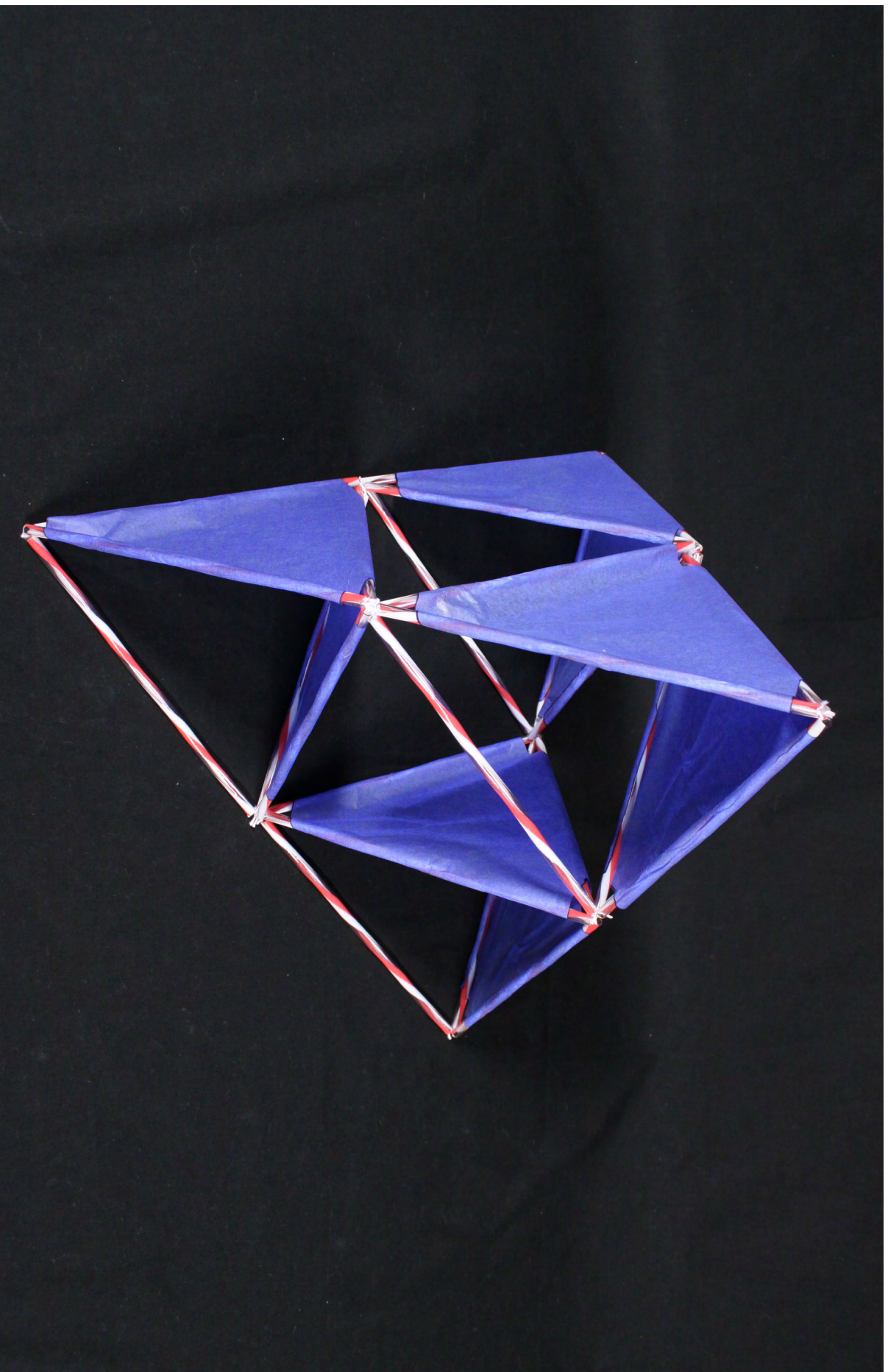
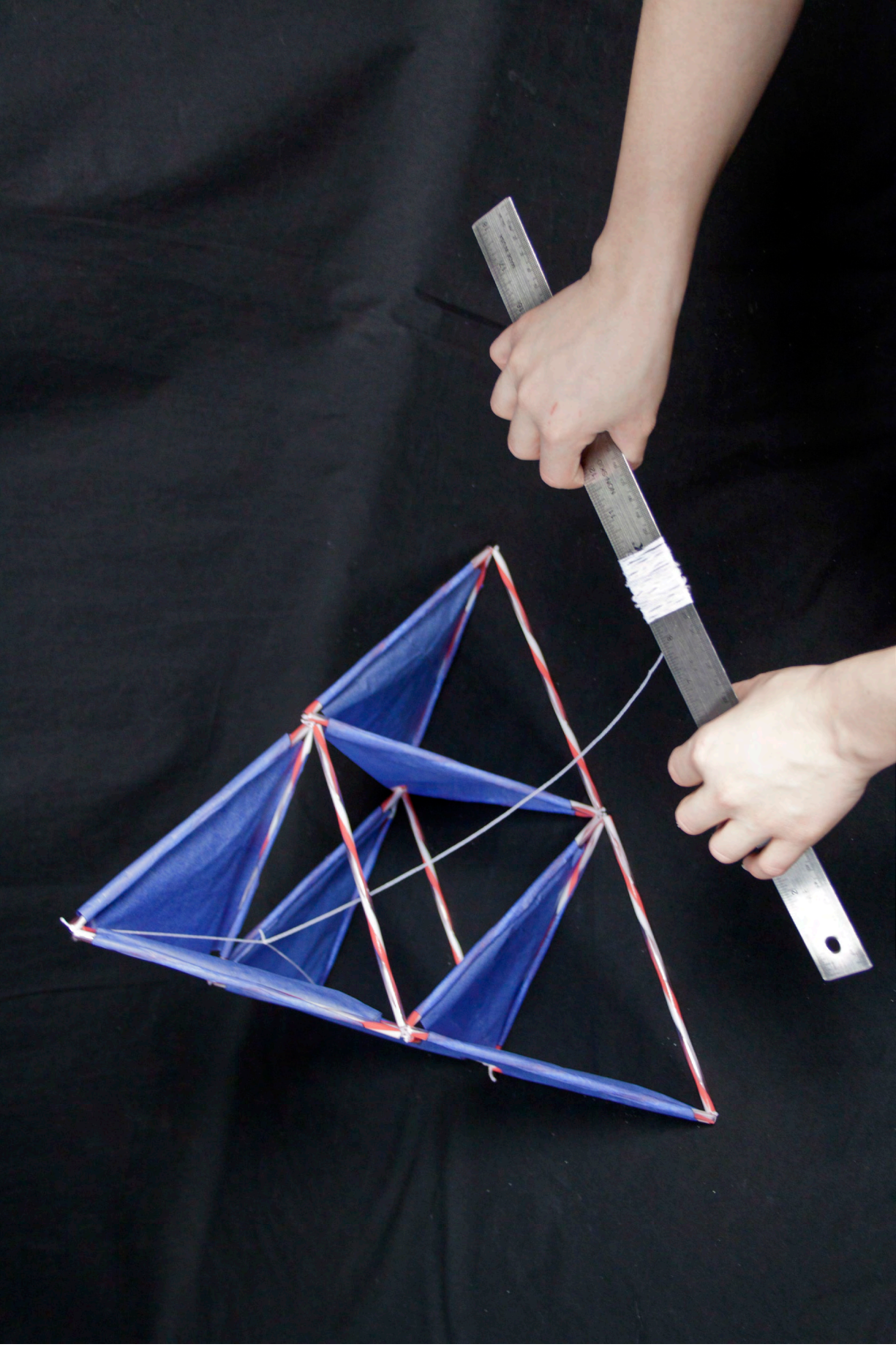


Fig. 17 Completed kite with bridle



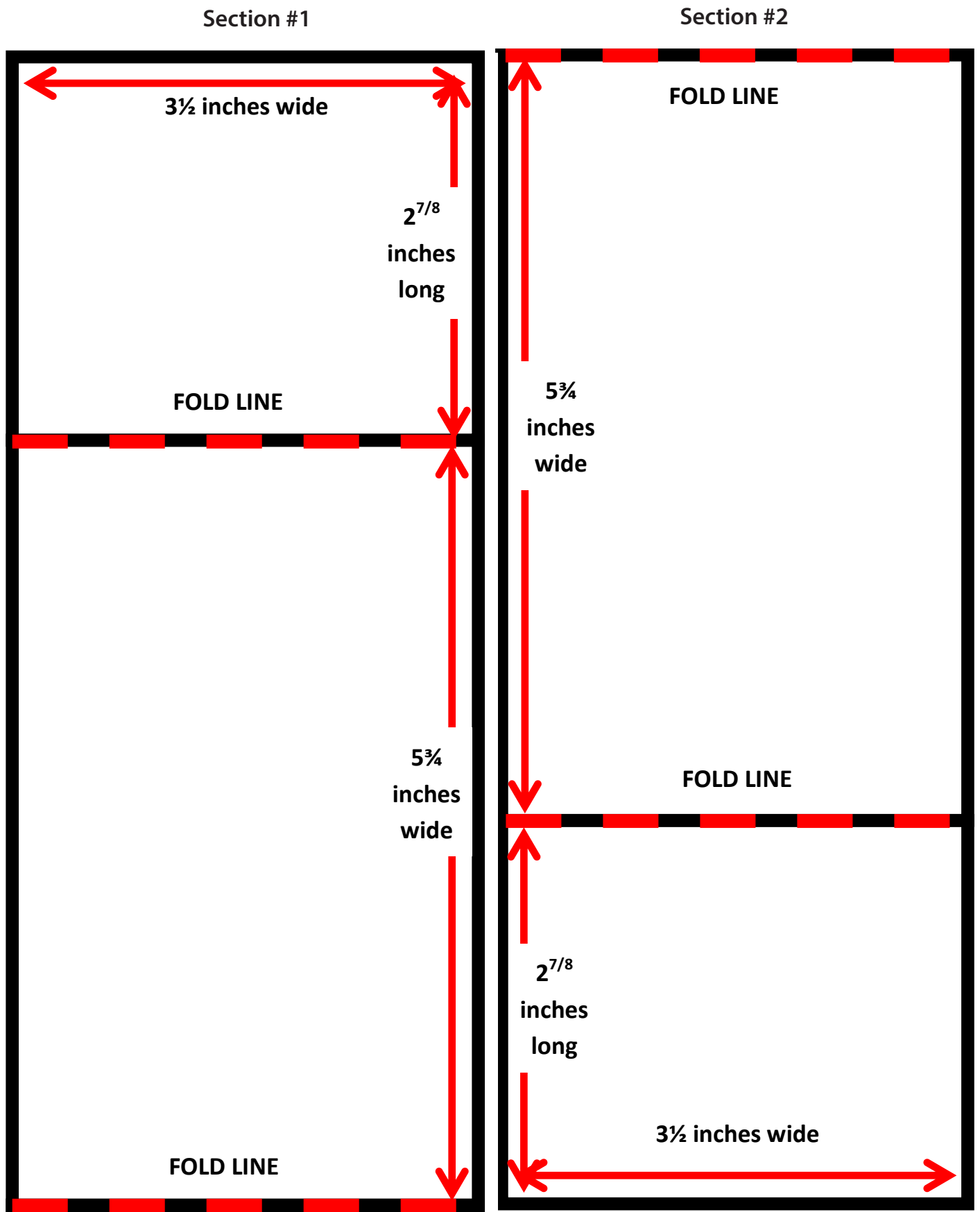


Fig. 18 Box Kite Template

Section #3

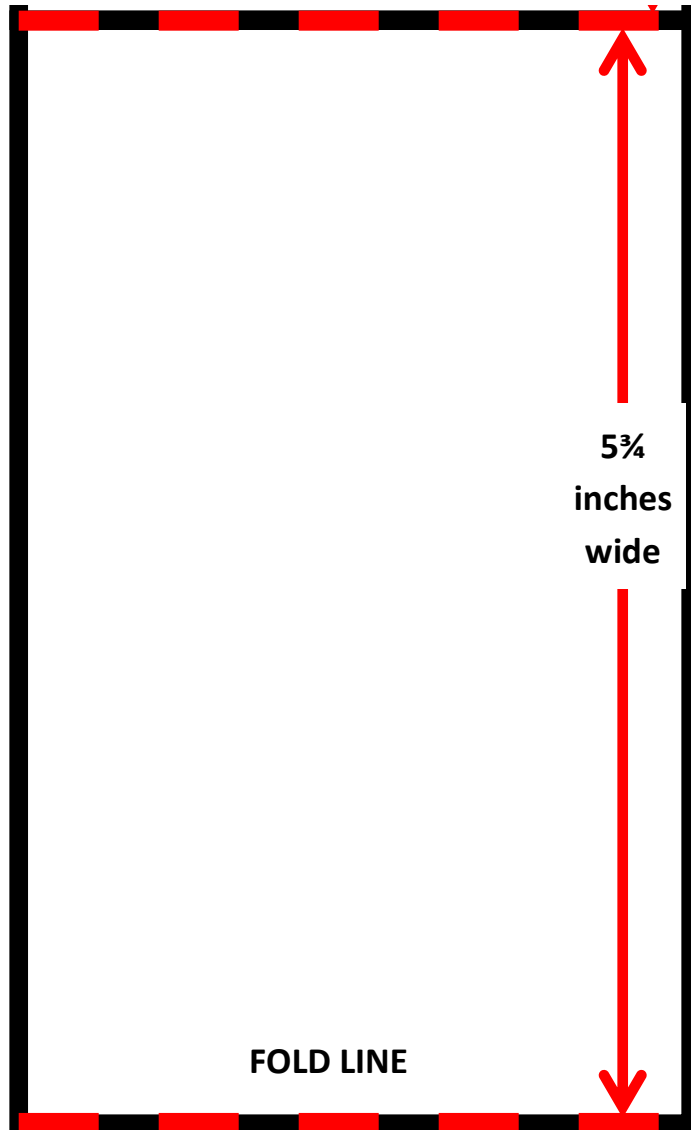


Fig. 18 Box Kite Template



Student Worksheets

Worksheet 1

Shape, Define and Design

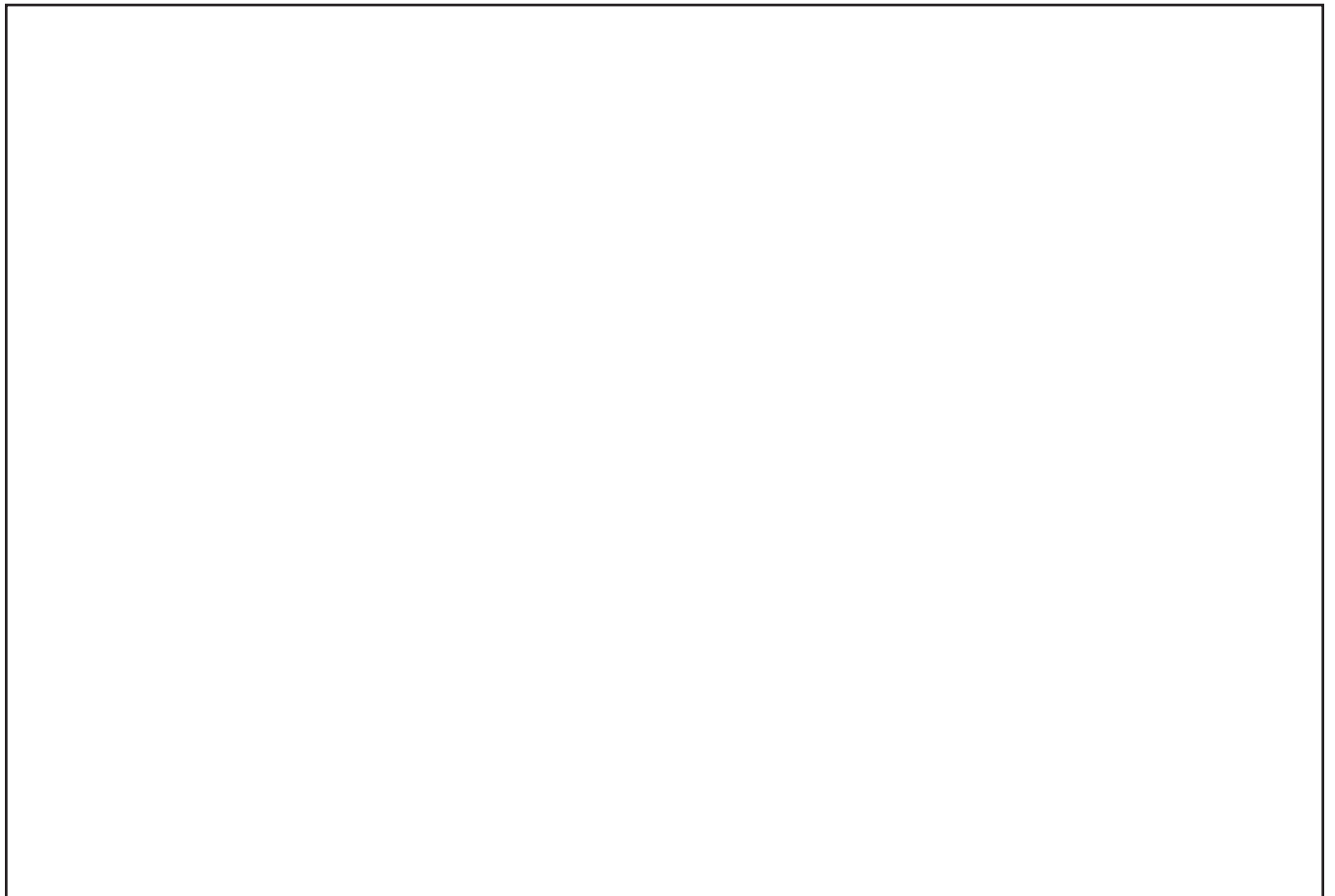
Directions: Read the vocabulary word and definition. Next, rewrite the definition in your own words in the space provided below. A space is provided for you to draw your representation of this geometric term.

Apex:

The tip or point of an object.

Rewrite this definition in your own words.

Draw a representation of this shape or geometric term in the space provided below.



Directions: Read the vocabulary word and definition. Next, rewrite the definition in your own words in the space provided below. A space is provided for you to draw your representation of this geometric term.

Equilateral:

All sides of an object are equal.

Rewrite this definition in your own words.

Draw a representation of this shape or geometric term in the space provided below.



Worksheet 1 (cont.)

Shape, Define and Design

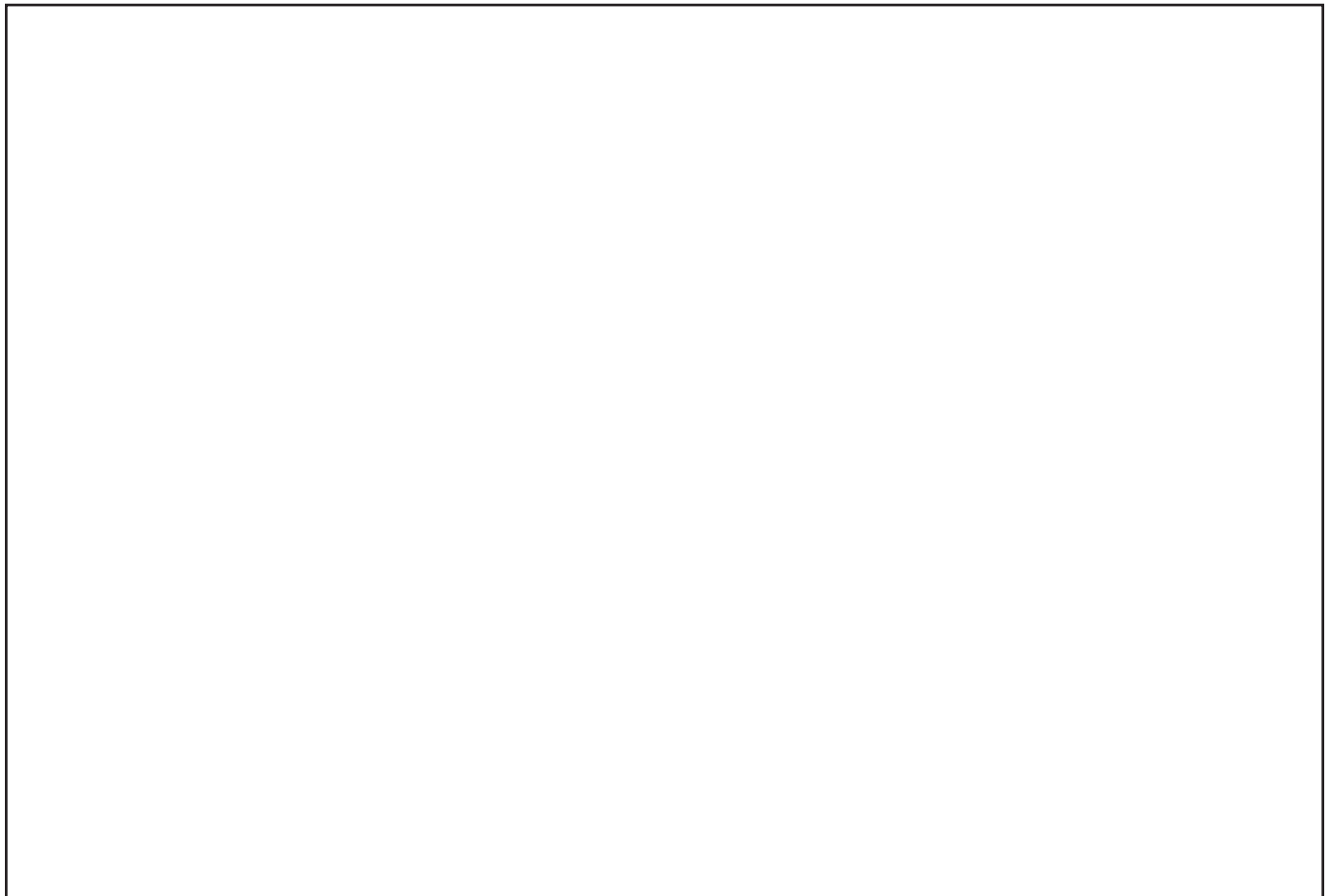
Directions: Read the vocabulary word and definition. Next, rewrite the definition in your own words in the space provided below. A space is provided for you to draw your representation of this geometric term.

Equilateral Triangle:

A triangle that has three equal angles.

Rewrite this definition in your own words.

Draw a representation of this shape or geometric term in the space provided below.



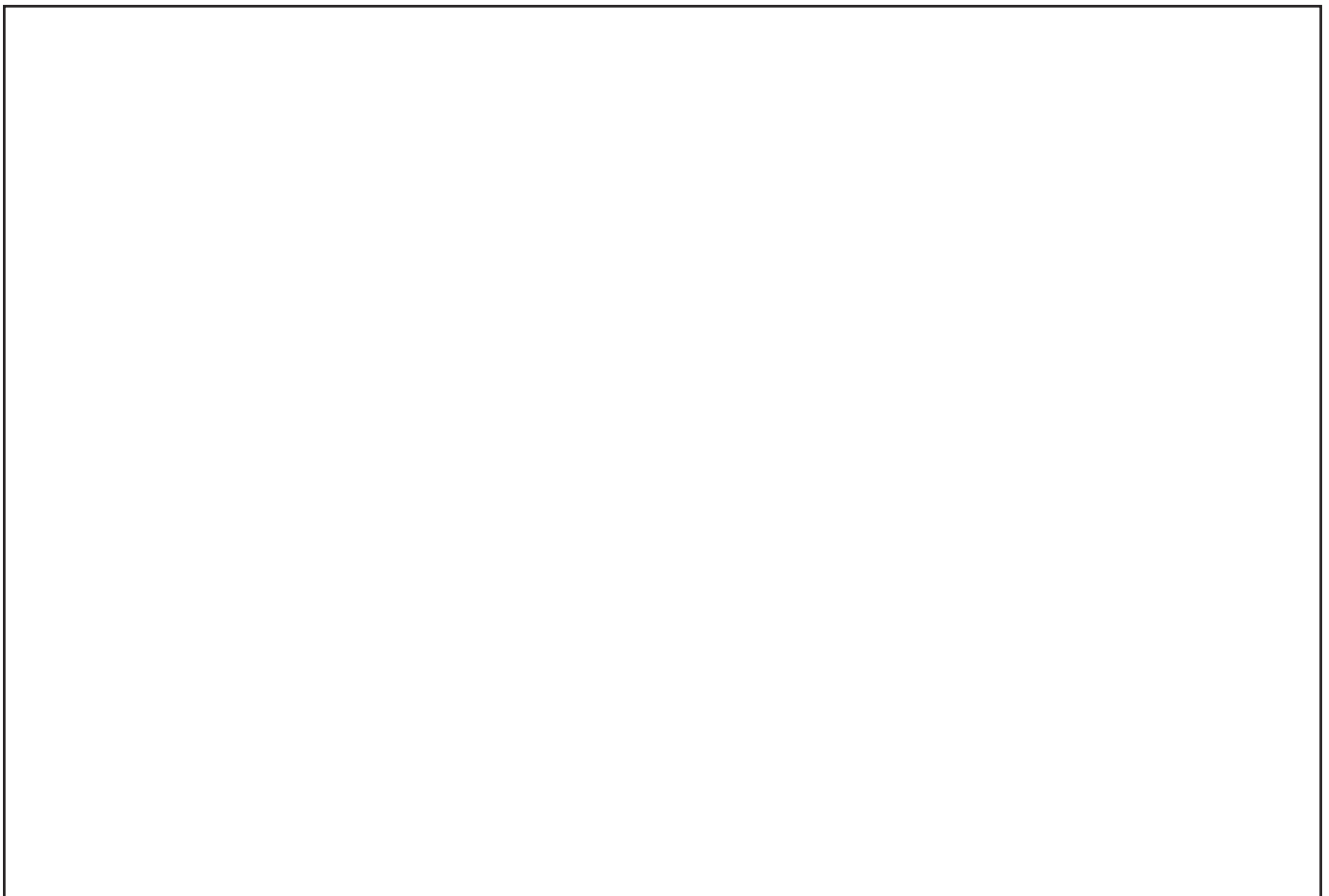
Directions: Read the vocabulary word and definition. Next, rewrite the definition in your own words in the space provided below. A space is provided for you to draw your representation of this geometric term.

Pyramid:

A solid geometric shape that has a polygonal base and triangular sides that meet in a singular point.

Rewrite this definition in your own words.

Draw a representation of this shape or geometric term in the space provided below.



Worksheet 1 (cont.)

Shape, Define and Design

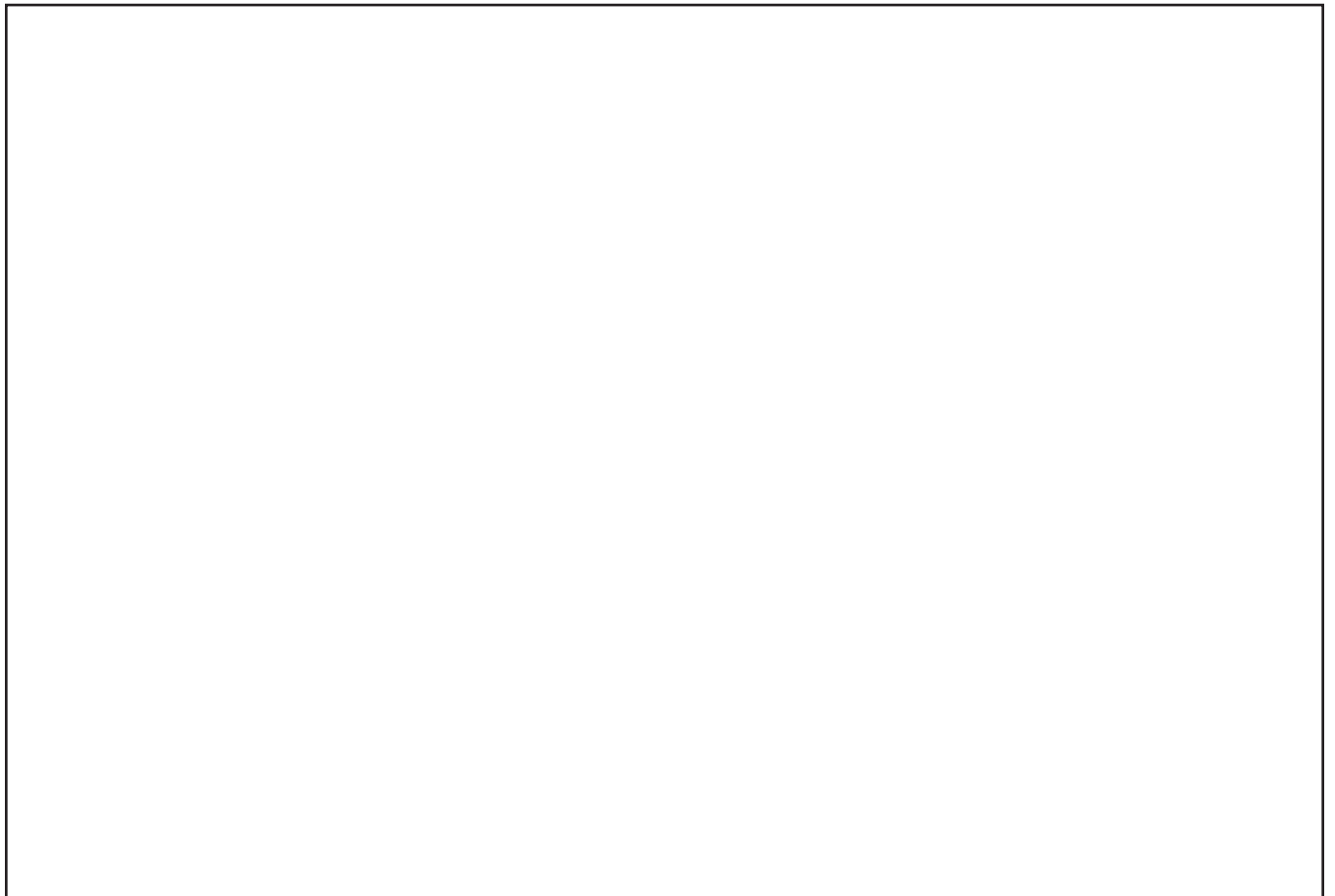
Directions: Read the vocabulary word and definition. Next, rewrite the definition in your own words in the space provided below. A space is provided for you to draw your representation of this geometric term.

Triangle:

A closed plane figure or geometric shape that has three sides and three angles.

Rewrite this definition in your own words.

Draw a representation of this shape or geometric term in the space provided below.



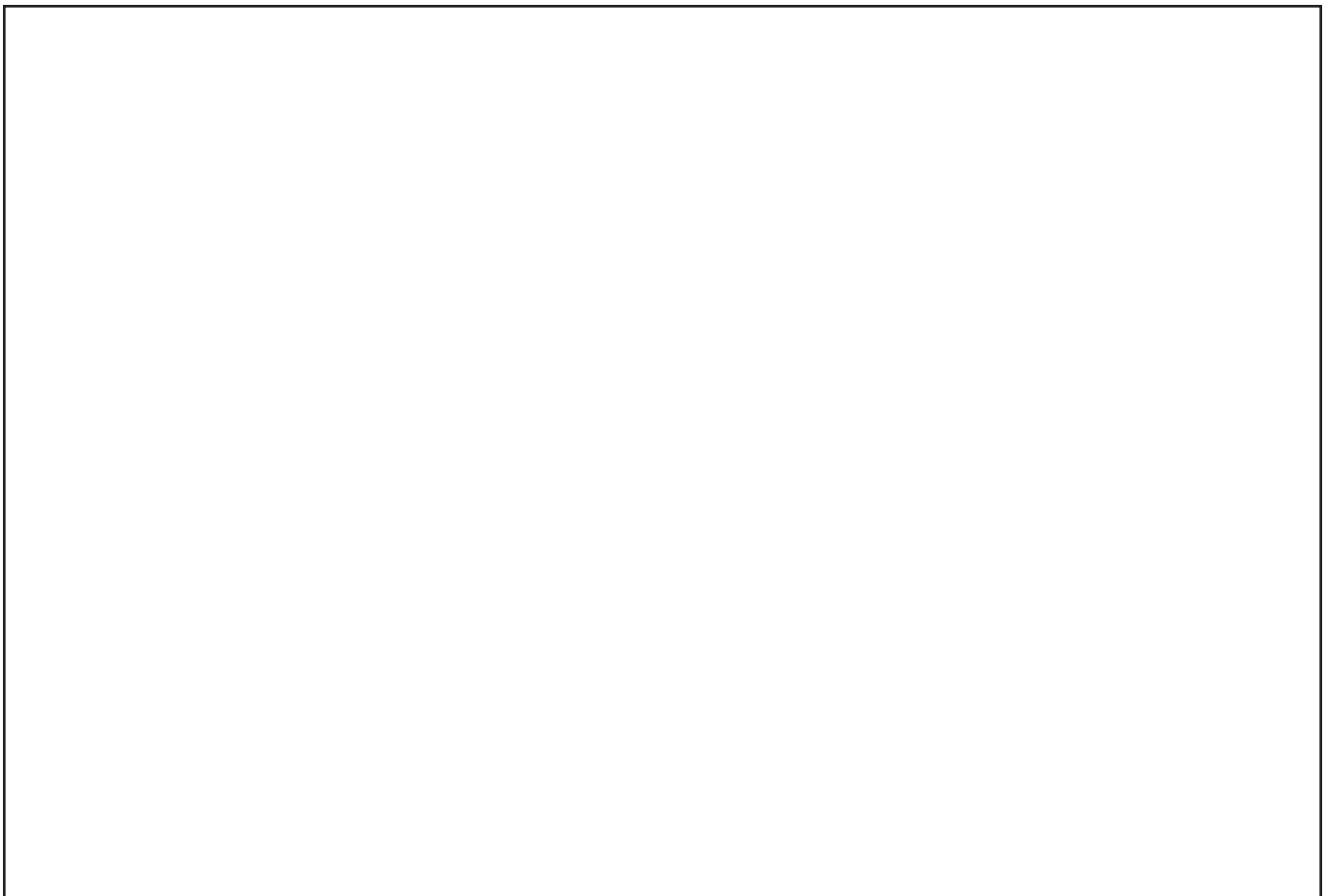
Directions: Read the vocabulary word and definition. Next, rewrite the definition in your own words in the space provided below. A space is provided for you to draw your representation of this geometric term.

Tetrahedron:

A solid triangular pyramid or a geometric shape comprised of four plane faces.

Rewrite this definition in your own words.

Draw a representation of this shape or geometric term in the space provided below.



Worksheet 1 (cont.)

Shape, Define and Design

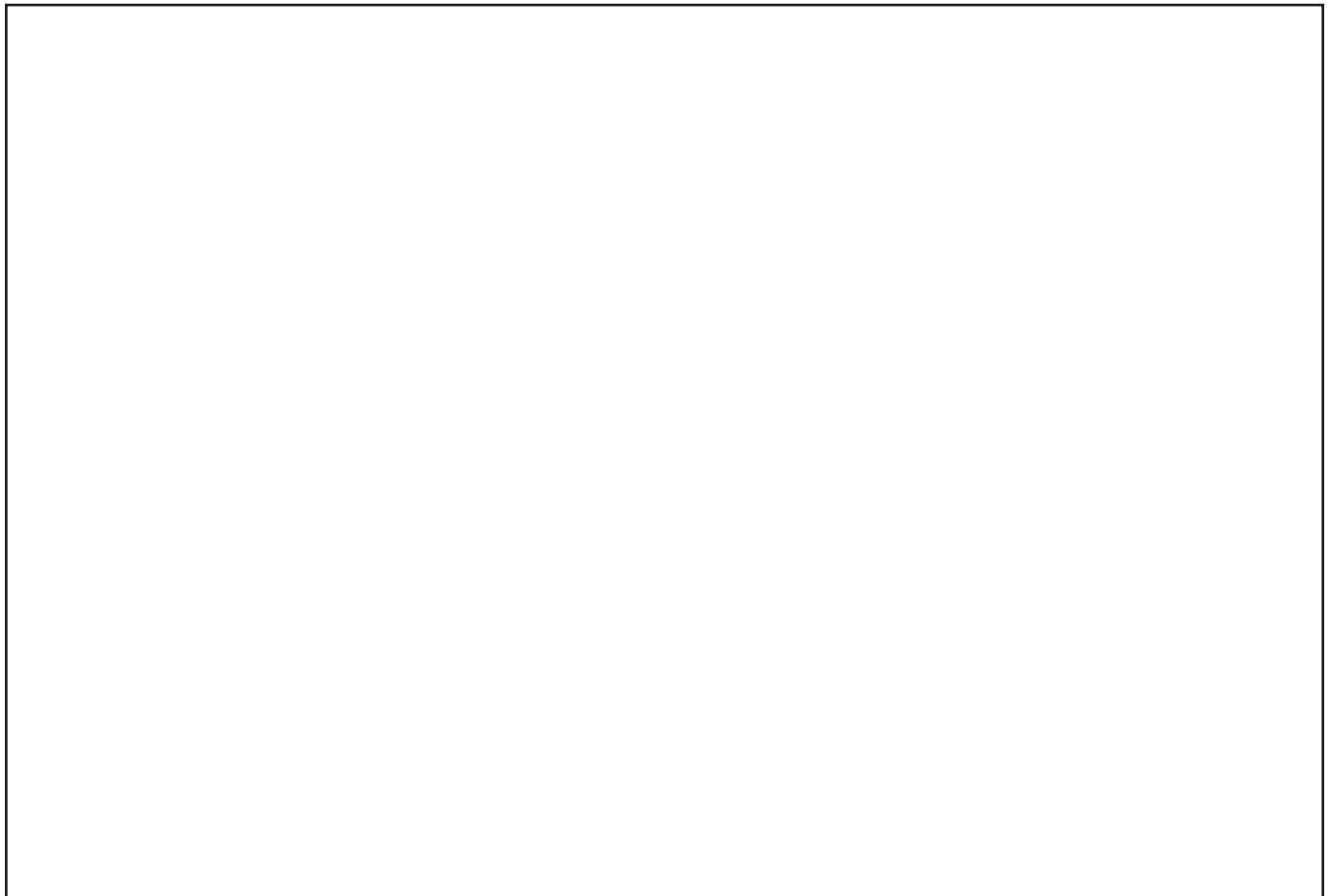
Directions: Read the vocabulary word and definition. Next, rewrite the definition in your own words in the space provided below. A space is provided for you to draw your representation of this geometric term.

Vertex:

A point in a geometrical solid that is common to three or more sides.

Rewrite this definition in your own words.

Draw a representation of this shape or geometric term in the space provided below.



Use the space below to sketch a design for your straw pyramid.

Worksheet 2

Beaufort Wind Scale

Use the information below to fill in the Beaufort Wind Scale. Within your group, deduce the order and description of the wind scale. Once you have completed the scale, cross off your selections and then check your team's answers using the answer sheet.

Wind / Knots (Wind speed that is equal to one nautical mile per hour)	World Meteorological Organization Classification (WMOC)
7 - 10	Strong Gale
11 - 16	Storm
Less Than 1	Violent Storm
1 - 3	Light Breeze
4 - 6	Gentle Breeze
17 - 21	Fresh Breeze
22 - 27	Strong Breeze
48 - 55	Calm
56 - 63	Light Air
64+	Near Gale
28 - 33	Gale

Appearance of Wind Effects on Land	Appearance of Wind Effects on Water
<p>Small trees in leaf begin to sway</p> <p>Larger tree branches moving, whistling in wires</p> <p>Wind felt on face, leaves rustle, vanes begin to move</p> <p>Leaves and small twigs constantly moving, light flags extended</p> <p>Calm, smoke rises vertically</p> <p>Smoke drift indicates wind direction, still wind vanes</p> <p>Dust, leaves, and loose paper lifted, small tree branches move</p> <p>Slight structural damage occurs, slate blows off roofs</p> <p>Seldom experienced on land, trees broken or uprooted, "considerable structural damage"</p> <p>Whole trees moving, resistance felt walking against wind</p> <p>Twigs breaking off trees, generally impedes progress</p>	<p>Exceptionally high (30-45 ft) waves, foam patches cover sea, visibility more reduced</p> <p>Sea surface smooth and mirror-like</p> <p>Large wavelets, crests begin to break, scattered whitecaps</p> <p>Small waves 1-4 ft. becoming longer, numerous whitecaps</p> <p>Scaly ripples, no foam crests</p> <p>Small wavelets, crests glassy, no breaking</p> <p>Moderate waves 4-8 ft taking longer form, many whitecaps, some spray</p> <p>Larger waves 8-13 ft, whitecaps common, more spray</p> <p>Sea heaps up, waves 13-20 ft, white foam streaks off breakers</p> <p>Air filled with foam, waves over 45 ft, sea completely white with driving spray, visibility greatly reduced</p> <p>Moderately high (13-20 ft) waves of greater length, edges of crests begin to break into spindrift, foam blown in streaks</p> <p>High waves (20 ft), sea begins to roll, dense streaks of foam, spray may reduce visibility</p> <p>Very high waves (20-30 ft) with overhanging crests, sea white with densely blown foam, heavy rolling, lowered visibility</p> <p>Moderately high (18-25 ft) waves of greater length, edges of crests begin to break into spindrift, foam blown in streaks</p>

Worksheet 2 (cont.)

Beaufort Wind Scale

Please complete the Beaufort Wind Scale. To provide you with examples, several forces are completed for you:

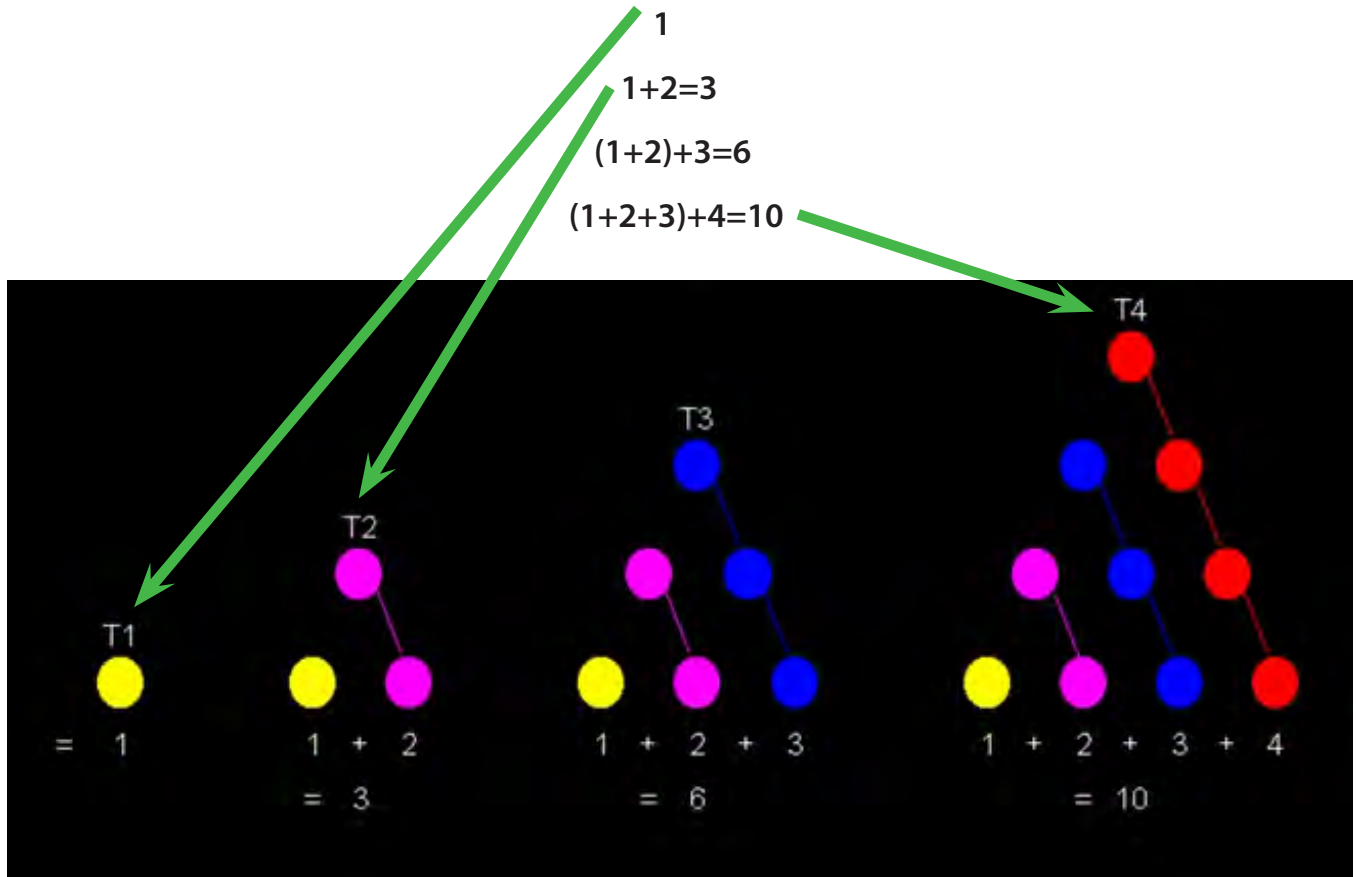
Force	Wind (Knots)	WMO Classification	Appearance of Wind Effects on Land	Appearance of Wind Effects on Water
0				
1	1-3	Light Air	Smoke drift indicates wind direction, still wind vanes	Scaly ripples, no foam crests
2				
3				
4	11-16	Moderate Breeze	Dust, leaves, and loose paper lifted, small tree branches move	Small waves 1-4 feet, becoming longer, numerous whitecaps
5				
6				
7				
8				
9	41-47	Strong Gale	Slight structural damage occurs, slate blows off roofs	High waves (23 feet to 32 feet), sea begins to roll, dense streaks of foam, spray may reduce visibility
10				
11			NO RANKING FOR LAND - PLEASE SKIP	
12	64+	Hurricane	NO RANKING FOR LAND - PLEASE SKIP	Air filled with foam, waves over 45 feet, sea completely white with driving spray, visibility greatly reduced

Force	Wind (Knots)	WMO Classification	Appearance of Wind Effects on Land	Appearance of Wind Effects on Water
0	<i>Less than 1</i>	<i>Calm</i>	<i>Calm, smoke rises vertically</i>	<i>Sea surface smooth and mirror-like</i>
1	1-3	Light Air	Smoke drift indicates wind direction, still wind vanes	Scaly ripples, no foam crests
2	4-6	<i>Light Breeze</i>	<i>Wind felt on face, leaves rustle, vanes begin to move</i>	<i>Small wavelets, crests glassy, no breaking</i>
3	7-10	<i>Gentle Breeze</i>	<i>Leaves and small twigs constantly moving, light flags extended</i>	<i>Large wavelets, crests begin to break, scattered whitecaps</i>
4	11-16	Moderate Breeze	Dust, leaves, and loose paper lifted, small tree branches move	Small waves 1-4 ft. becoming longer, numerous whitecaps
5	17-21	<i>Fresh Breeze</i>	<i>Small trees in leaf begin to sway</i>	<i>Moderate waves 4-8 ft taking longer form, many whitecaps, some spray</i>
6	22-27	<i>Strong Breeze</i>	<i>Larger tree branches moving, whistling in wires</i>	<i>Larger waves 8-13 ft, whitecaps common, more spray</i>
7	28-33	<i>Near Gale</i>	<i>Whole trees moving, resistance felt walking against wind</i>	<i>Sea heaps up, waves 13-20 ft, white foam streaks off breakers</i>
8	34-40	<i>Gale</i>	<i>Whole trees in motion, resistance felt walking against wind</i>	<i>Moderately high (13-20 ft) waves of greater length, edges of crests begin to break into spindrift, foam blown in streaks</i>
9	41-47	Strong Gale	Slight structural damage occurs, slate blows off roofs	High waves (20 ft), sea begins to roll, dense streaks of foam, spray may reduce visibility
10	48-55	<i>Storm</i>	<i>Seldom experienced on land, trees broken or uprooted, "considerable structural damage"</i>	<i>Very high waves (20-30 ft) with overhanging crests, sea white with densely blown foam, heavy rolling, lowered visibility</i>
11	56-63	<i>Violent Storm</i>	NO RANKING FOR LAND - PLEASE SKIP	<i>Exceptionally high (30-45 ft) waves, foam patches cover sea, visibility more reduced</i>
12	64+	Hurricane	NO RANKING FOR LAND - PLEASE SKIP	Air filled with foam, waves over 45 ft, sea completely white with driving spray, visibility greatly reduced

Worksheet 3

Triangles in Numbers

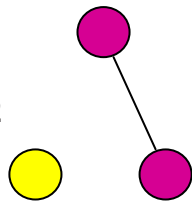
Below is a sample math problem of a triangular number. Note there are four different layers. One is represented with numbers and the other is represented through dots that form triangles. Please complete similar mathematical problems below to understand the different levels.



We are going to do the fifth level together. Then you will be asked to do the next five levels yourself.

If $(1) = \text{Level 1 or T1}$ 

Then $(1+2)=3$ is Level 2 or T2



It follows that by looking at the first four levels, the fifth level would look like this:

$$1$$

$$1+2=3$$

$$(1+2)+3=6$$

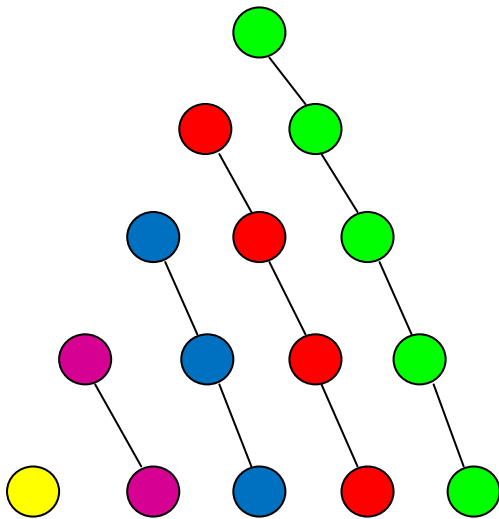
$$(1+2+3)+4=10$$

$$(1+2+3+4)+5=15$$

$$(1+2+3+4)+5=15$$

This would be considered the fifth level or layer.

If you were to represent this in a figure with dots in triangles, this is how it would look:



$$1 + 2 + 3 + 4 + 5 = 15$$

You will be asked to show both of these representations in your mathematical problems. Colored pencils or markers may help in representing the different layers. If you have any questions do not hesitate to ask your instructor.

Worksheet 3 (cont.)

Triangles in Numbers

Problem #1

Please write the mathematical representation using numbers to show six levels or layers.

Level 1 _____
 Level 2 _____
 Level 3 _____
 Level 4 _____
 Level 5 _____
 Level 6 _____

Problem #2

Represent your answer in problem #1 in dots and triangles as we did together above. It is recommended that you use colored pencils or markers.

Problem #3

Please write the mathematical representation using numbers to show seven levels or layers.

Level 1 _____
 Level 2 _____
 Level 3 _____
 Level 4 _____
 Level 5 _____
 Level 6 _____
 Level 7 _____

Problem #4

Represent your answer in problem #3 in dots and triangles as we did together above. It is recommended that you use colored pencils or markers.

Problem #5

Please write the mathematical representation using numbers to show six levels or layers.

Level 1 _____

Level 2 _____

Level 3 _____

Level 4 _____

Level 5 _____

Level 6 _____

Level 7 _____

Level 8 _____

Problem #6

Represent your answer in problem #5 in dots and triangles as we did together above. It is recommended that you use colored pencils or markers.

Problem #7

Please write the mathematical representation using numbers to show seven levels or layers.

Level 1 _____

Level 2 _____

Level 3 _____

Level 4 _____

Level 5 _____

Level 6 _____

Level 7 _____

Level 8 _____

Level 9 _____

Problem #8

Represent your answer in problem #7 in dots and triangles as we did together above. It is recommended that you use colored pencils or markers.

Worksheet 3 (cont.)

Triangles in Numbers

Problem #9

Please write the mathematical representation using numbers to show seven levels or layers.

Level 1 _____

Level 2 _____

Level 3 _____

Level 4 _____

Level 5 _____

Level 6 _____

Level 7 _____

Level 8 _____

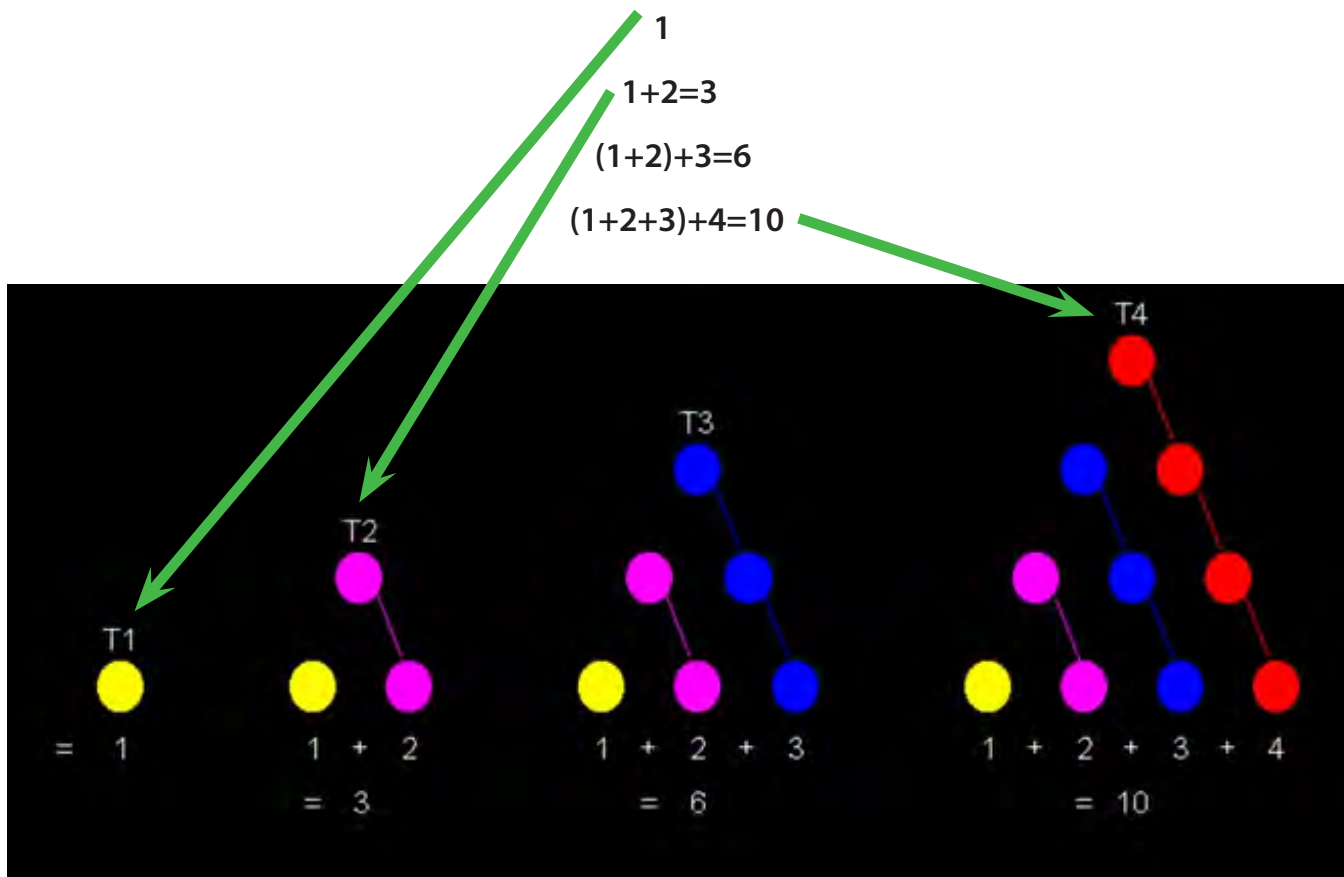
Level 9 _____

Level 10 _____

Problem #10

Represent your answer in problem #9 in dots and triangles as we did together above. It is recommended that you use colored pencils or markers.

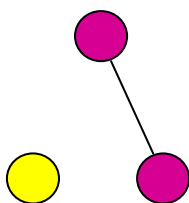
Below is a sample math problem of a triangular number. Note there are four different layers. One is represented with numbers and the other is represented through dots that form triangles. Please complete similar mathematical problems below to understand the different levels.



We are going to do the fifth level together. Then you will be asked to do the next five levels yourself.

If $(1) = \text{Level 1 or T1}$ 

Then $(1+2)=3$ is Level 2 or T2



It follows that by looking at the first four levels, the fifth level would look like this:

$$1$$

$$1+2=3$$

$$(1+2)+3=6$$

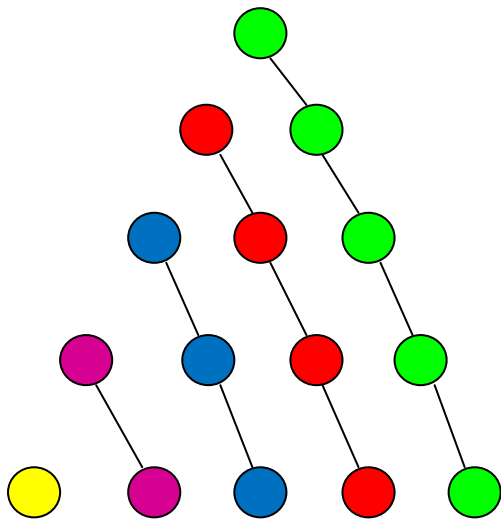
$$(1+2+3)+4=10$$

$$(1+2+3+4)+5=15$$

$$(1+2+3+4)+5=15$$

This would be considered the fifth level or layer.

If you were to represent this in a figure with dots in triangles, this is how it would look:



$$1 + 2 + 3 + 4 + 5 = 15$$

You will be asked to show both of these representations in your mathematical problems. Colored pencils or markers may help in representing the different layers. If you have any questions do not hesitate to ask your instructor.

Problem #1

Please write the mathematical representation using numbers to show six levels or layers.

Level 1 1

Level 2 1+2=3

Level 3 (1+2)+3=6

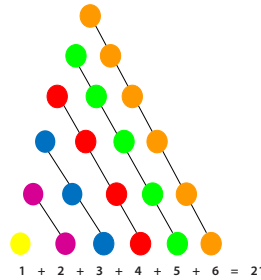
Level 4 (1+2+3)+4=10

Level 5 (1+2+3+4)+5=15

Level 6 (1+2+3+4+5)+6=21

Problem #2

Represent your answer in problem #1 in dots and triangles as we did together above. It is recommended that you use colored pencils or markers.



Problem #3

Please write the mathematical representation using numbers to show seven levels or layers.

Level 1 1

Level 2 1+2=3

Level 3 (1+2)+3=6

Level 4 (1+2+3)+4=10

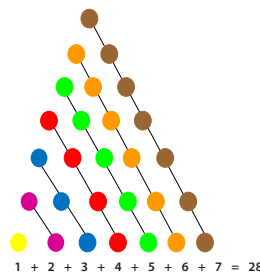
Level 5 (1+2+3+4)+5=15

Level 6 (1+2+3+4+5)+6=21

Level 7 (1+2+3+4+5+6)+7=28

Problem #4

Represent your answer in problem #3 in dots and triangles as we did together above. It is recommended that you use colored pencils or markers.



Worksheet 3 (cont.)

Triangles in Numbers (Teacher Version)

Problem #5

Please write the mathematical representation using numbers to show six levels or layers.

Level 1 1

Level 2 1+2=3

Level 3 (1+2)+3=6

Level 4 (1+2+3)+4=10

Level 5 (1+2+3+4)+5=15

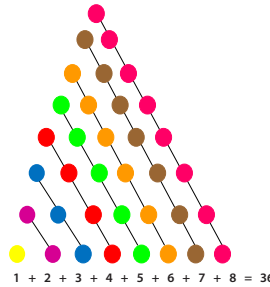
Level 6 (1+2+3+4+5)+6=21

Level 7 (1+2+3+4+5+6)+7=28

Level 8 (1+2+3+4+5+6+7)+8=36

Problem #6

Represent your answer in problem #5 in dots and triangles as we did together above. It is recommended that you use colored pencils or markers.



Problem #7

Please write the mathematical representation using numbers to show seven levels or layers.

Level 1 1

Level 2 1+2=3

Level 3 (1+2)+3=6

Level 4 (1+2+3)+4=10

Level 5 (1+2+3+4)+5=15

Level 6 (1+2+3+4+5)+6=21

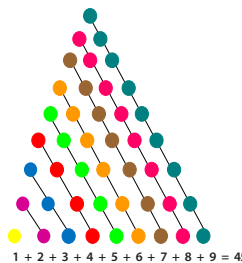
Level 7 (1+2+3+4+5+6)+7=28

Level 8 (1+2+3+4+5+6+7)+8=36

Level 9 (1+2+3+4+5+6+7+8)+9=45

Problem #8

Represent your answer in problem #7 in dots and triangles as we did together above. It is recommended that you use colored pencils or markers.



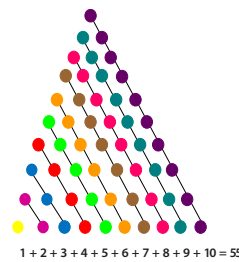
Problem #9

Please write the mathematical representation using numbers to show seven levels or layers.

$$\begin{array}{l}
 \text{Level 1} \quad \underline{1} \\
 \text{Level 2} \quad \underline{1+2=3} \\
 \text{Level 3} \quad \underline{(1+2)+3=6} \\
 \text{Level 4} \quad \underline{(1+2+3)+4=10} \\
 \text{Level 5} \quad \underline{(1+2+3+4)+5=15} \\
 \text{Level 6} \quad \underline{(1+2+3+4+5)+6=21} \\
 \text{Level 7} \quad \underline{(1+2+3+4+5+6)+7=28} \\
 \text{Level 8} \quad \underline{(1+2+3+4+5+6+7)+8=36} \\
 \text{Level 9} \quad \underline{(1+2+3+4+5+6+7+8)+9=45} \\
 \text{Level 10} \quad \underline{(1+2+3+4+5+6+7+8+9)+10=55}
 \end{array}$$

Problem #10

Represent your answer in problem #9 in dots and triangles as we did together above. It is recommended that you use colored pencils or markers.



Worksheet 4

Tetrahedral Kite

Section One - Create a Tetrahedron Cell

1. You will need the following supplies for this step: string, 6 straws (no longer than 8 inches long), scissors, and a flat surface.
2. First, cut a length of yarn/string four (4) feet long. (If the cut string has not already been provided.)
3. Second, take 6 straws and place them flat on the surface.
4. Use your piece of string to string 3 straws together. One end of the conjoined 3 straws should have two strings extended, 1) approximately 20 inches long, and 2) approximately 4 inches long.
5. Tie these two ends of the string tightly together to make sure that there is no room for the triangle to "wobble."
6. The three straws should form a tight triangle.
7. There should be one a short and long piece of string now hanging off of the ends of two conjoined straws.
8. See figure 2 as an example of a tight, three-straw triangle.

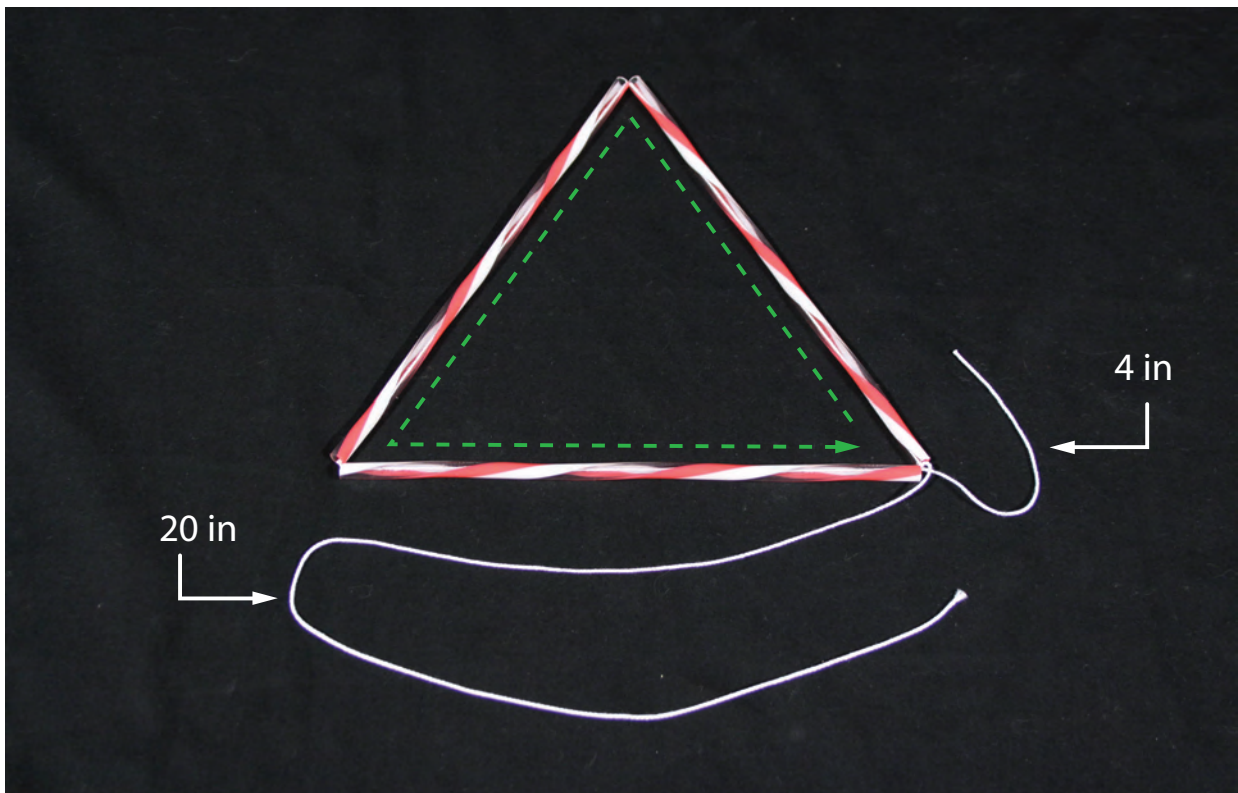


Fig. 2 Triangle

Section One Questions

You have now completed the first part of constructing a tetrahedron. You have made a triangle connecting three straws. Record the following facts about the triangle:

1. Length of a side in inches = _____

2. The measurement of each angle on the triangle = _____

Hint: 3 angles added together = 180°

3. Height of the triangle = _____

4. Area of the triangle = _____

5. All sides are equal or are not equal. (Circle one.)

6. All angles are equal or are not equal. (Circle one.)

7. This type of triangle is called an _____ triangle.

Section Two - Create a Rhombus

1. The three straws should form a tight triangle.
2. Cut another 4 inch piece of string and tie one end to any empty corner of the triangle.
3. Take one end of the 4-inch string, and tie that end to any empty corner of the triangle.
4. Now, add 2 more straws onto the longest piece of string.

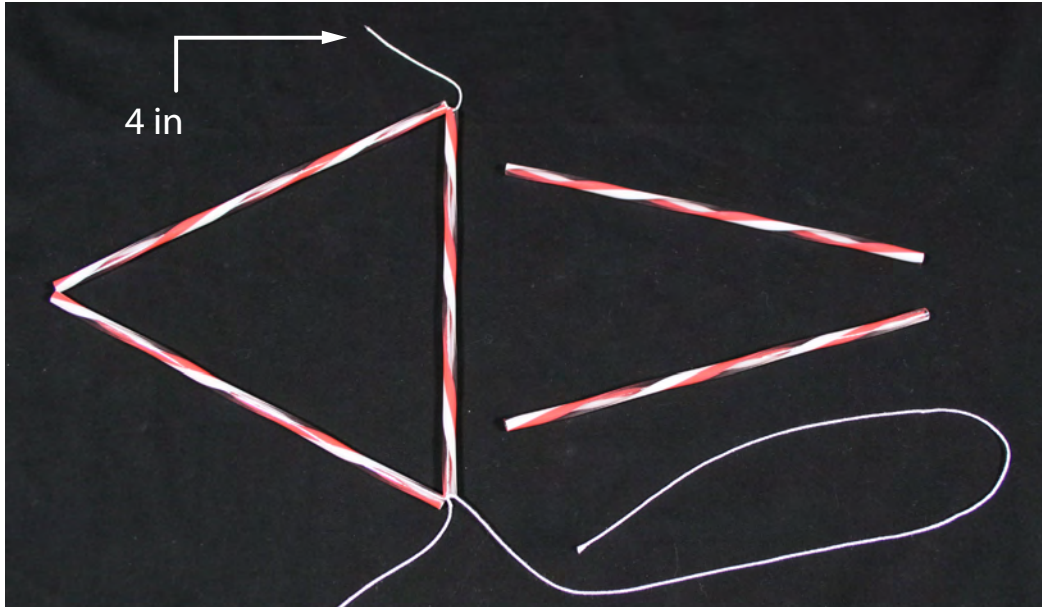


Fig. 3 Rhombus construction

5. Next, take the string that holds the two additional straws and tie it to the end of the 4-inch string closest to the straw to make a another tight triangle. See picture below:

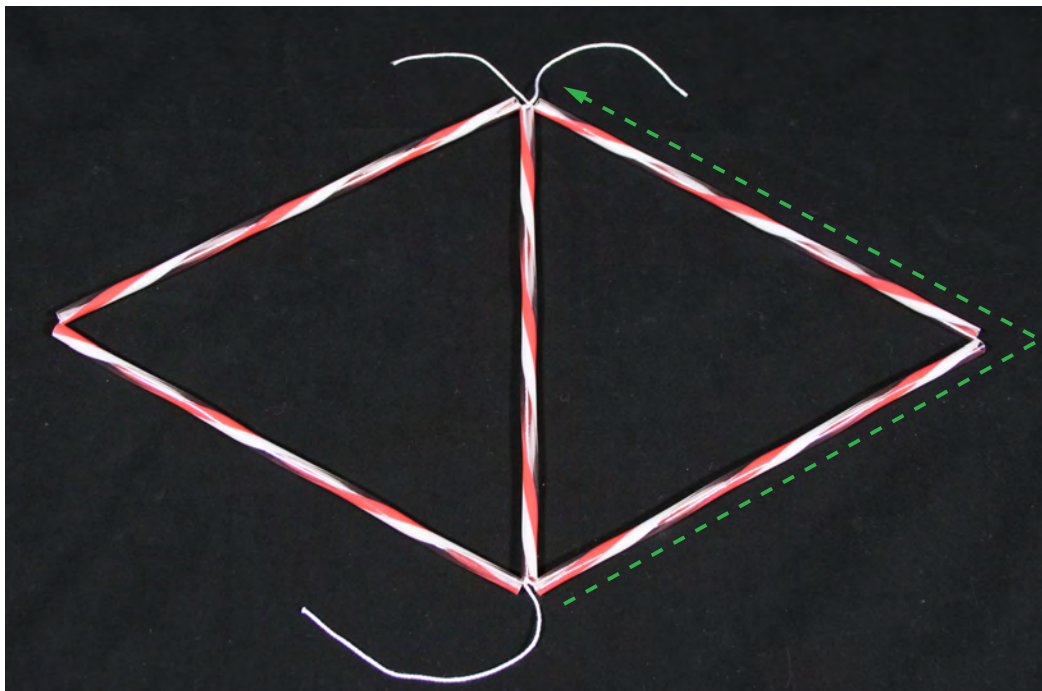


Fig. 4 Completed Rhombus

Section Two Questions

You have now completed the second part of constructing a tetrahedron and have made a rhombus. Record the following facts about the rhombus:

1. Length of a side in inches = _____

2. The measurement of each angle in the rhombus = _____

Hint: 4 angles added together = 360°

3. Height of the rhombus = _____

4. Area of the rhombus = _____

5. All sides are equal or are not equal. (Circle one.)

6. All angles are equal or are not equal. (Circle one).

Worksheet 4 (cont.)

Tetrahedral Kite

Section Three - Create a Three Dimensional Tetrahedron

1. Cut another 4-inch piece of string.
2. Take that 4-inch piece of string and tie one of its ends to one of the empty corners.
3. Next, cut a piece of string that is double the length of one straw (or side of a tetrahedron).
4. Tie one end of that double-length string to the remaining empty corner. See picture below:

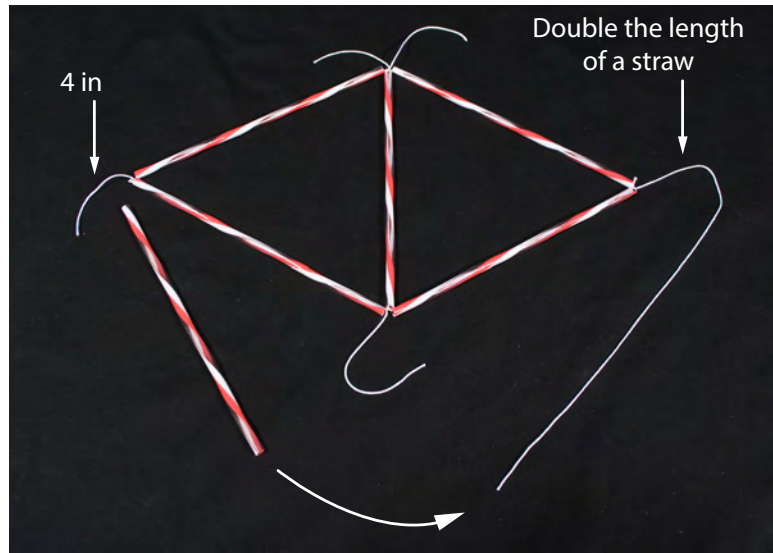


Fig. 5 Three dimensional tetrahedron construction

5. Now, add the last straw onto the double-length string.
6. Tie together the two opposite ends (the end of the 4-inch string and the end of the double-length string closest to the straws) to form a tight 3-dimensional tetrahedron.
7. Follow all instructions in Steps 1, 2 and 3 to create a second tetrahedron.

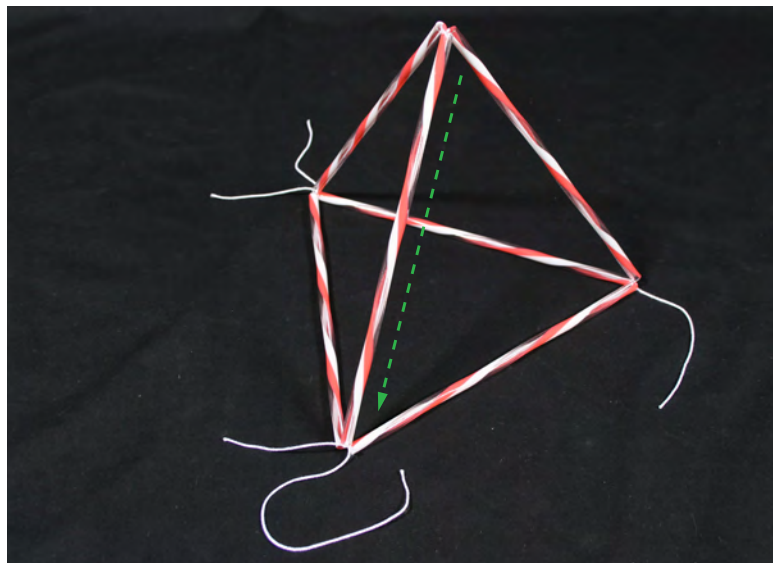


Fig. 6 Completed three dimensional tetrahedron

Section Three Questions

You have now completed the third set of steps and have constructed a tetrahedron. Record the following facts about the tetrahedron:

1. How many triangular faces or surfaces does it have? _____

2. What is the volume? _____

Hint: First you must find the area of the base.

That formula is $\text{Area} = \frac{1}{2} \times \text{Base} \times \text{Height}$

Hint: The formula for finding the volume is

$\text{Volume} = \frac{1}{3} \times (\text{area of the base}) \times \text{Height}$

Section Four - Create a Tetrahedron Tissue Paper Cover

1. Remember to pay attention to the length of the straws as the template may be different and may need to be adjusted in size since straws come in a variety of lengths.
2. Choose a piece of colored tissue paper.
3. Fold the paper so that it will fill the template shown below in figure 10.
4. Place your tetrahedron on the tissue paper so that you are able to trace around the edges.
5. Now trace around the edges lightly with a pen or pencil.
6. Cut out the pattern that you just traced and open it.
7. See the picture below (figures 7, 8, 9 & 10). Your tissue paper should look like this:

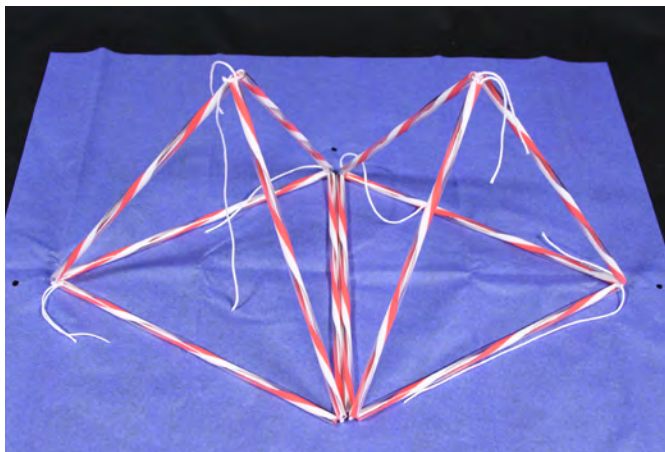


Fig. 7 One-inch marks to create template

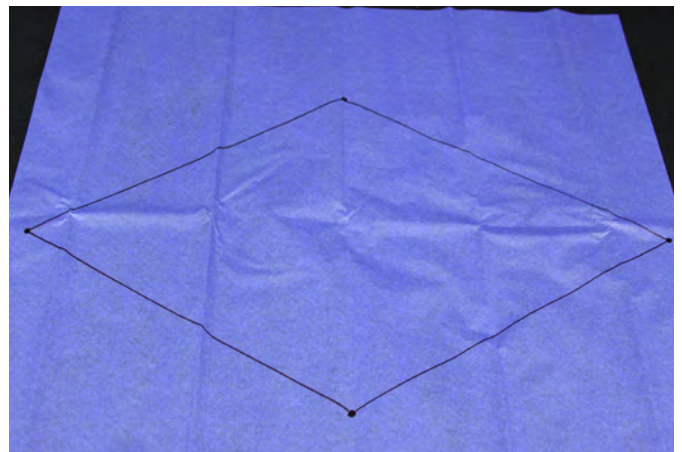


Fig. 8 Template construction

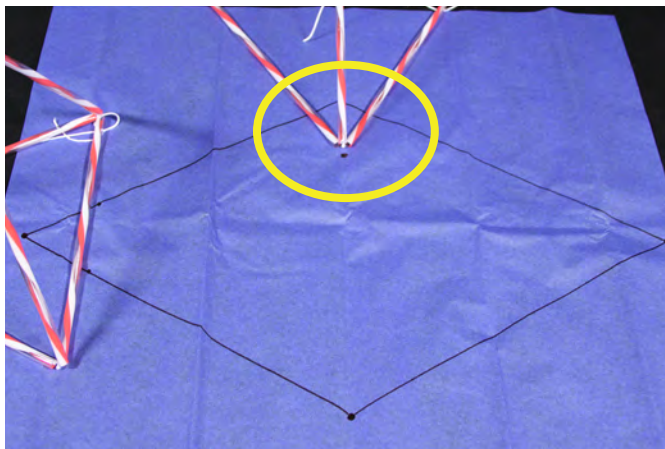


Fig. 9 Obtuse angle marking for template construction

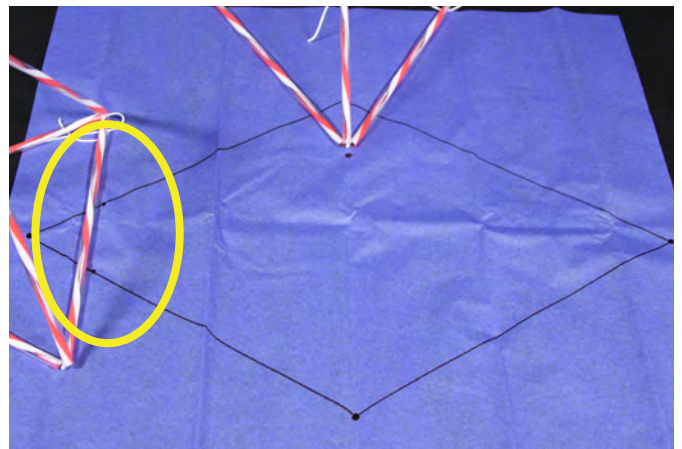


Fig. 10 Acute angle marking for template construction

Section Five - Cover the Tetrahedron

1. Lay the tissue paper on your table.
2. Wrap the tissue paper around the two sides of the tetrahedron.
3. Now glue the tabs using a glue stick and fold them around the straws. (Spread the glue along the flaps and fold the flaps over the straws.) Make sure that it is a tight fit.
4. Rotate the tetrahedron so you can do the same steps to the other side.
5. Now, add glue to the other flap.
6. Fold these flaps over the straws.
7. See Figures 11, 12 and 13 shown below. This is how your tetrahedron should now look:

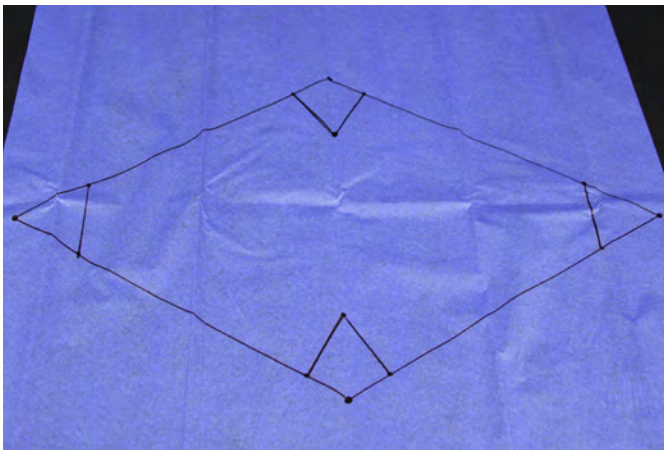


Fig. 11 Tissue paper template

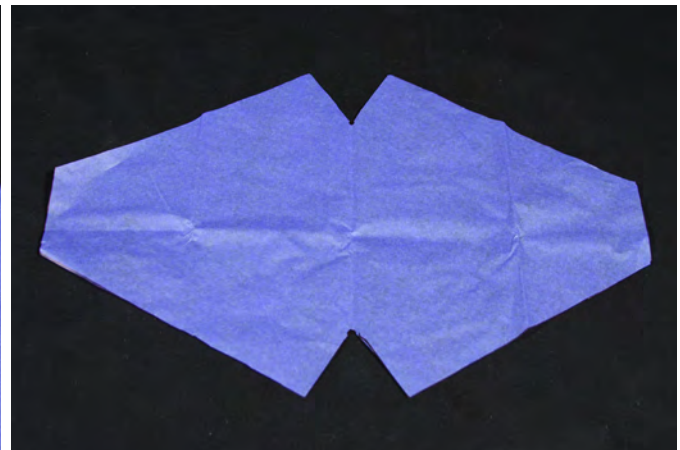


Fig. 12 Completed tissue paper template

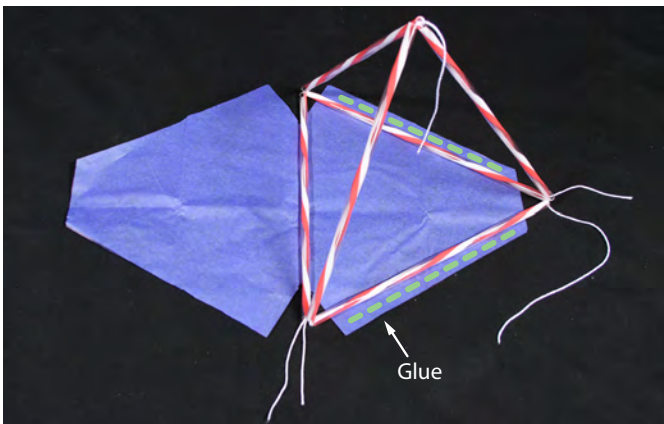


Fig. 13 Placement of tetrahedron on tissue paper template

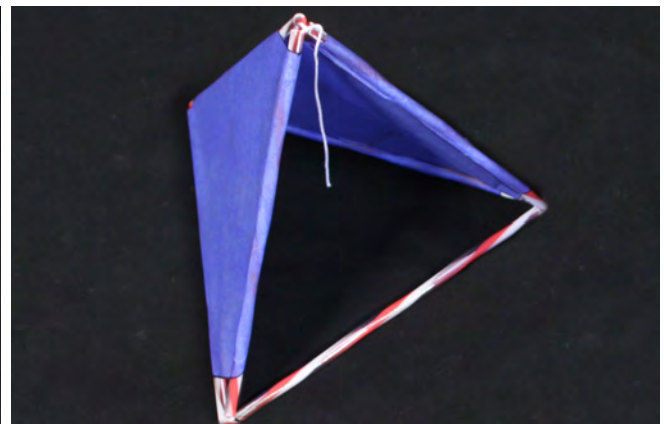


Fig. 14 Covered Tetrahedron

Section Six - Add Levels to the Tetrahedron

1. Now that you have successfully created one tetrahedron, you will need to repeat Step One through Step Five to make an additional three tetrahedrons (four in total).
2. Once you have created the other three remaining tetrahedrons, choose three of them and place the tetrahedrons on a flat surface or table.
3. Each tetrahedron will have strings that are free. Use those free strings to tie one tetrahedron to another. This will tie the adjacent base vertices together. See picture below (figure 14).
4. Now, take the fourth tetrahedron and place it on top of the other three that you have tied together. Tie the fourth tetrahedron to the adjacent vertices.
5. Note that all of your connections need to be tight so that there is not any slack in the string.
6. Now your tetrahedron should look like this: (See picture below, figure 15).
7. As a team, decide how many more tetrahedrons you want to add to your kite before you decide to fly it. Repeat Step One through Step Five as necessary for your additions. Also, remember that when you add your additional tetrahedrons make sure the connections are tight.

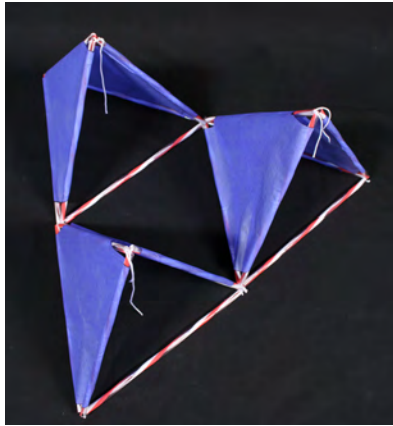


Fig. 15 Three tetrahedrons in the form of one large triangle

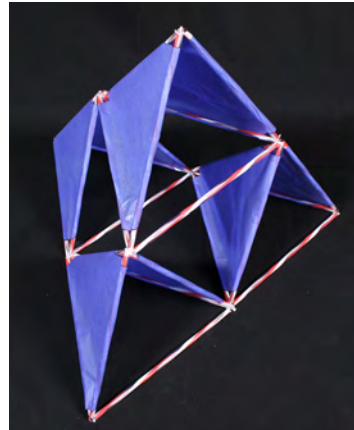


Fig. 16 Four Tetrahedrons

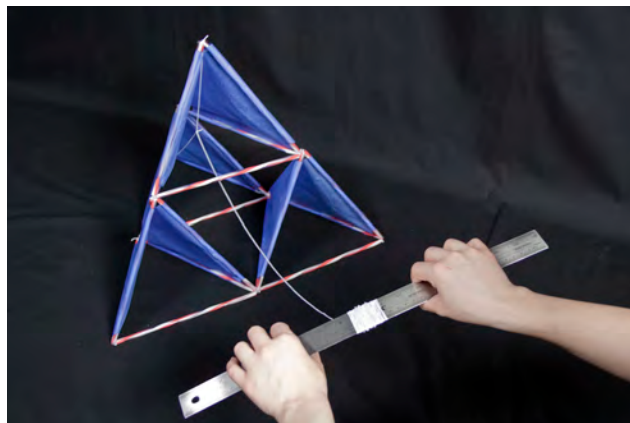


Fig. 17 Completed kite with bridle

Section Seven - Build Your Bridle

1. Now that you have made your kite, you will need to create and attach your bridle in order to fly it.
2. Tie your string (approximately 15 feet long) to the ruler so it can serve as your bridle.
3. Take your ruler to your teacher and he or she will use the hot glue gun to make sure your string stays on the ruler.
4. **TEACHER:** Take the hot glue gun and insert a glue stick. Plug the glue gun into the wall giving it time to heat up. Once the glue gun is ready, apply glue (approximately the size of the quarter) to the ruler in order to fasten the string to the bridle. Only when glue has cooled, return the glued ruler and string to the students.
5. Place your kite on the table with the base touching the table.
6. Next, tie a 24-inch string firmly to the very top of the kite.
7. Tie the same piece of string again to the middle joint. This will be between the top section of the kite and the bottom toward the front. There should not be any slack in the string.
8. Next, tie a loop in the middle of your string. The loop should be about the size of a quarter.
9. Now, attach the string of your kite to the loop.
10. Your kite is finished and ready to fly.
11. Complete the questions on your Kite Engineering Worksheet before attempting to fly your kite.

Section Eight Questions

You have completed the final stages of constructing a tetrahedral kite. Now your team must decide how many layers to make your kite. Discuss and build your kite. When completed, please answer the following questions:

1. What is the ratio between covered sides and uncovered sides?

2. When you have assembled your kite, discuss what shapes are evident and list them below.

3. What is similar about the entire kite compared to the single tetrahedron you created earlier?

4. What is the ratio between covered cells and uncovered cells in the entire kite?

5. What is the surface area of the entire kite?

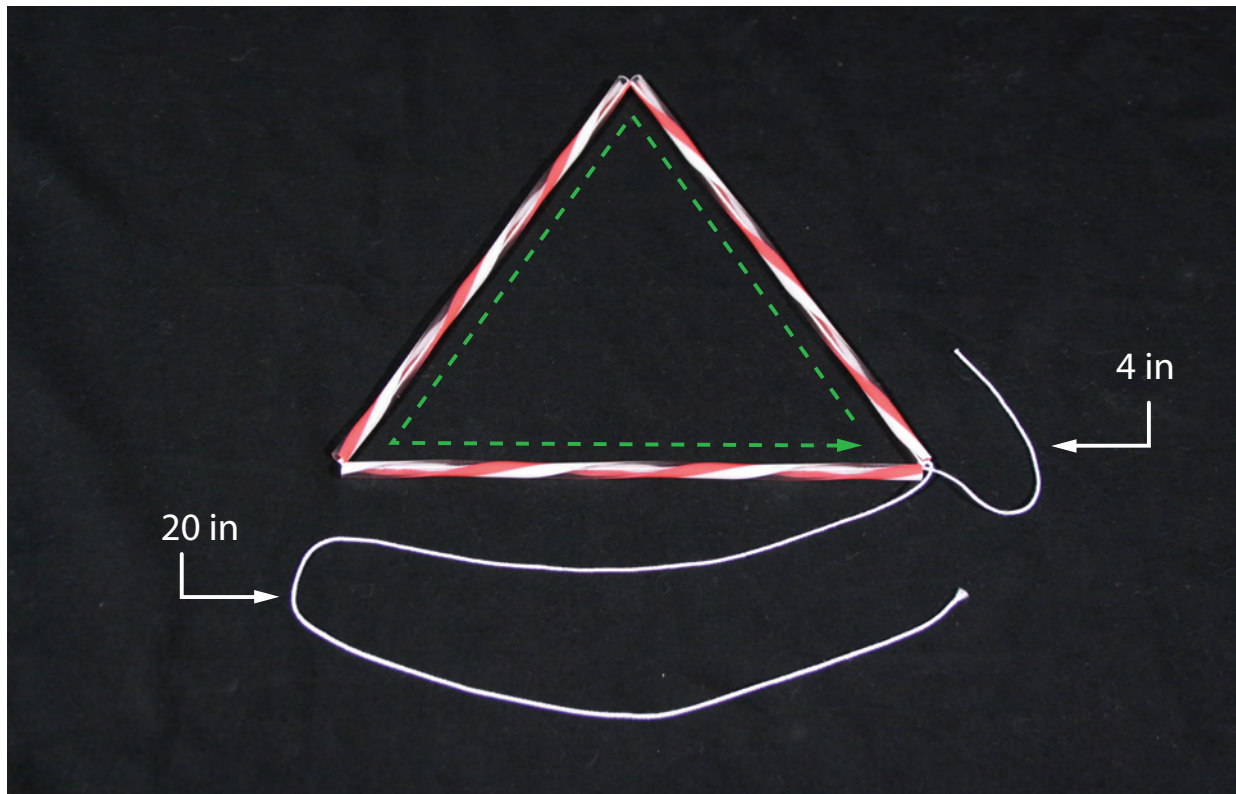
6. What is the volume of the entire kite?

7. What is the ratio between the surface area of a single cell compared to the entire kite?

8. What is the ratio between the volume of a single cell compared to the entire kite?

Section One - Create a Tetrahedron Cell

1. You will need the following supplies for this step: string, 6 straws (no longer than 8 inches long), scissors, and a flat surface.
2. First, cut a length of yarn/string four (4) feet long. (If the cut string has not already been provided.)
3. Second, take 6 straws and place them flat on the surface.
4. Use your piece of string to string 3 straws together. One end of the conjoined 3 straws should have two strings extended, 1) approximately 20 inches long, and 2) approx. 4 inches long.
5. Tie these two ends of the string tightly together to make sure that there is no room for the triangle to "wiggle."
6. The three straws should form a tight triangle.
7. There should be one a short and long piece of string now hanging off of the ends of two conjoined straws.
8. See figure 2 as an example of a tight, three-straw triangle.

**Fig. 2** Triangle

Section One Questions & Answers

You have now completed the first part of constructing a tetrahedron. You have made a triangle connecting three straws. Record the following facts about the triangle:

1) Length of a side in inches = _____
(answers will vary based on the measurement of the length of the individual straw)

2) The measurement of each angle on the triangle = _____

*Hint: 3 angles added together = 180°
 (60°)*

3) Height of the triangle = _____
(8 inches)

4) Area of the triangle = _____
(27.7)

$$\text{Area} = \frac{s^2\sqrt{3}}{4}$$

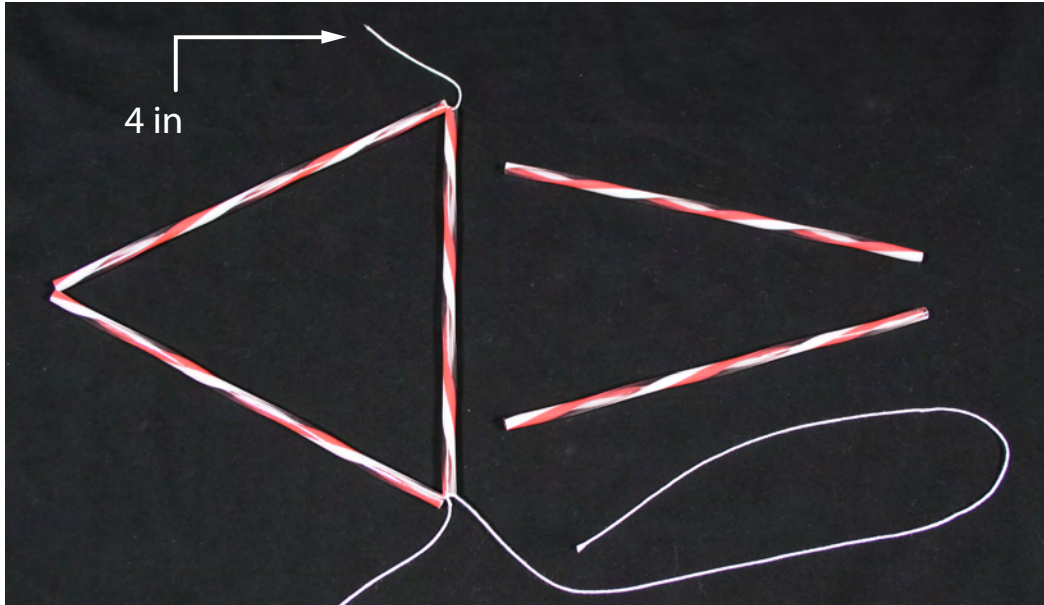
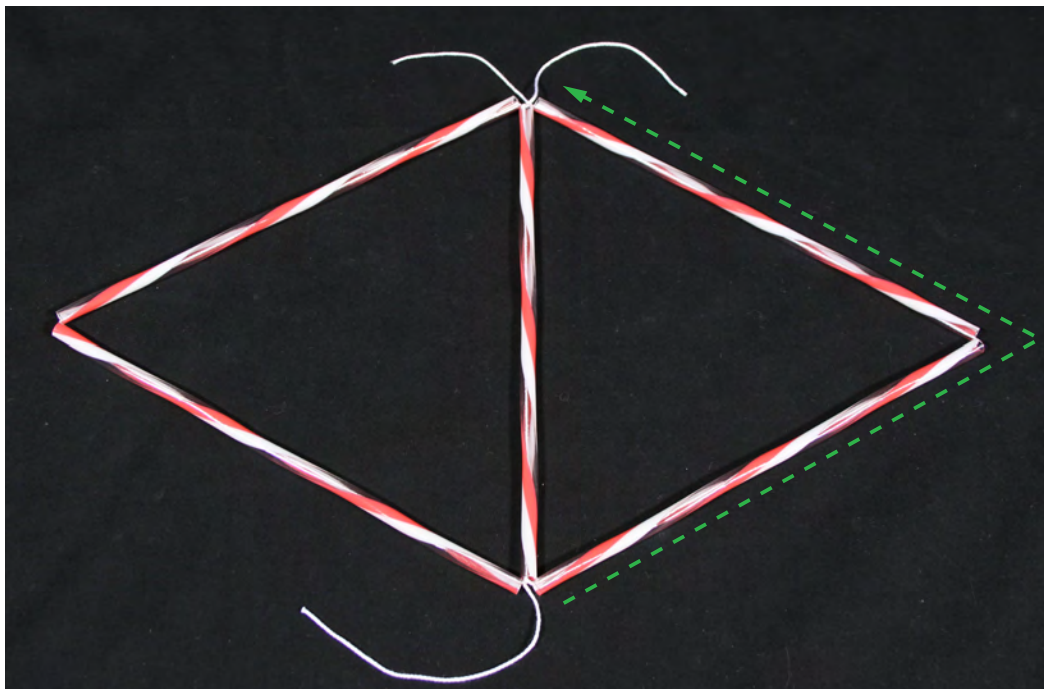
5) All sides are equal or are not equal. (Circle one.)
(Equal)

6) All angles are equal or are not equal. (Circle one.)
(Equal)

7) This type of triangle is called an _____ triangle.
(Equilateral)

Section Two - Create a Rhombus

1. The three straws should form a tight triangle.
2. Cut a 10 cm piece of string and tie one end to any empty corner of the triangle.
3. Now, add 2 more straws onto the remaining longer end of the string.
4. Next, tie the long string to one end of the 10 centimeter string to form a rhombus.
5. See the picture below (fi . 3 & 4). Your rhombus should look like this.

**Fig. 3** Rhombus construction**Fig. 4** Completed rhombus

Worksheet 4 (cont.)

Tetrahedral Kite (Teacher Version)

Section Two Questions & Answers

You have now completed the second part of constructing a tetrahedron and have made a rhombus. Record the following facts about the rhombus:

- 1) Length of a side in inches = _____
(answers will vary based on the measurement of the length of the individual straw)
- 2) The measurement of each angle in the rhombus = (60°) (60°) (120°) (120°)

Hint: 4 angles added together = 360°

(60°) (60°) (120°) (120°)

- 3) Height of the rhombus = _____
(answers will vary based on the measurement of the length of the individual straw)
- 4) Area of the rhombus = _____
(answers will vary based on the measurement of the length of the individual straw)

5) All sides are *equal* or are not equal. (Circle one.)

6) All angles are *equal* or are not equal. (Circle one).

Section Three - Create a Three Dimensional Tetrahedron

1. Cut a piece of string that is double the length of one straw (or side of a tetrahedron).
2. Tie one end of that string to one of the remaining empty corners.
3. Cut another piece of string 10 centimeters long.
4. Take that shorter piece of string and tie one end to the other empty corner.
5. Now, string the last straw onto the longer piece of string.
6. Tie the two opposite sides together.
7. See the picture below (fig . 5 & 6). Your tetrahedron should look like this:

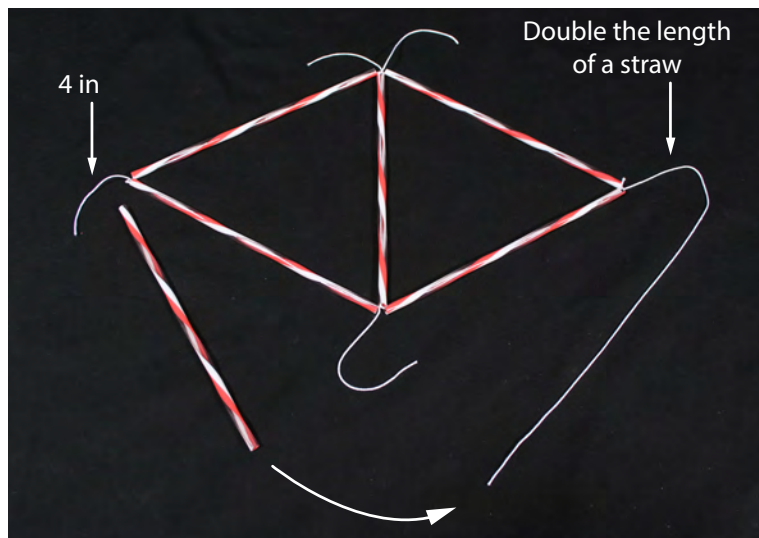


Fig. 5 Three dimensional tetrahedron construction

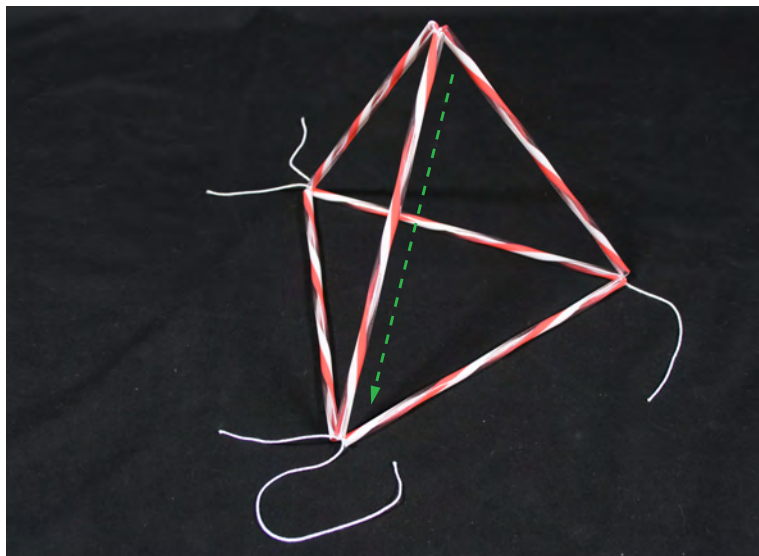


Fig. 6 Completed three dimensional tetrahedron

Section Three Questions & Answers

You have now completed the third set of steps and have constructed a tetrahedron! Record the following facts about the tetrahedron:

- 1) How many triangular faces does it have? (4)

- 2) What is the volume? _____

Hint: First you must find the area of the base.

That formula is $A = \frac{1}{2} \times \text{base} \times \text{height}$

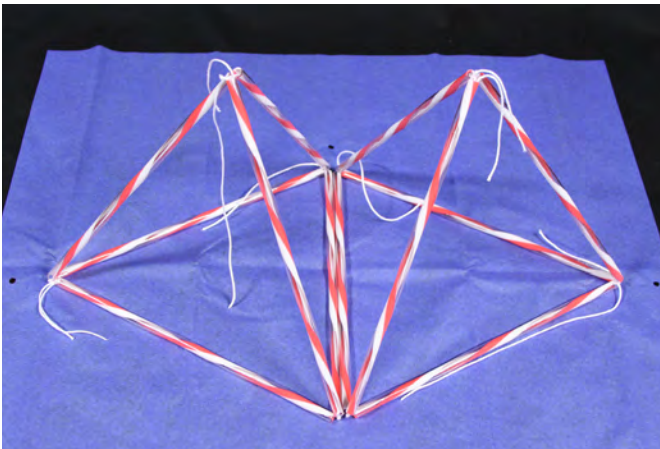
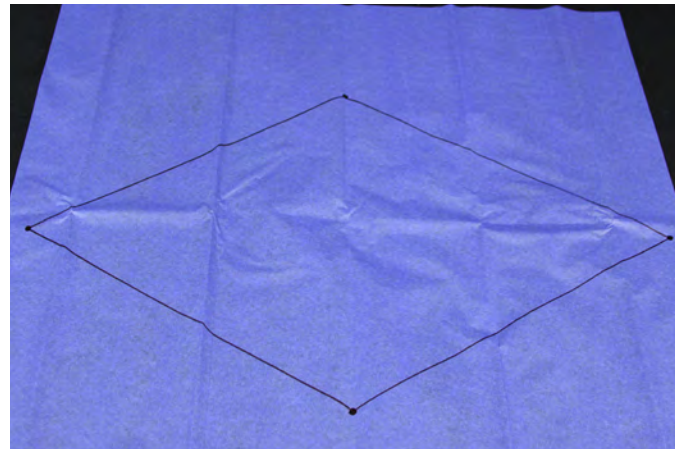
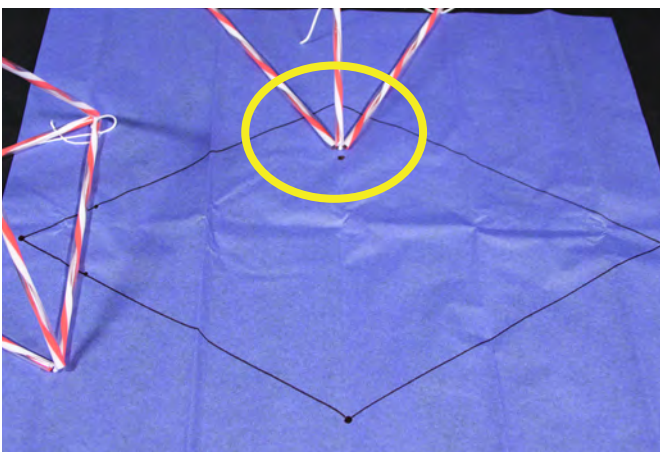
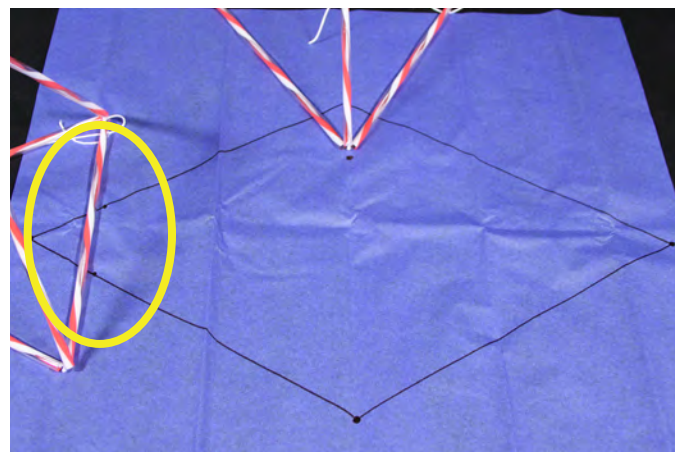
Hint: The formula for finding the volume is

$V = \frac{1}{3} \times (\text{area of the base}) \times \text{height}$

(answers will vary based on the measurement of the lengths of the individual straws)

Section Four - Create a Tetrahedron Tissue Paper Cover

1. Remember to pay attention to the length of the straws as the template may be different and may need to be adjusted in size since straws come in a variety of lengths.
2. Choose a piece of colored tissue paper.
3. Fold the paper so that it will fill the template shown on your worksheet.
4. Be sure to place the widest edge on the fold.
5. Now trace around the edges lightly with a pen or pencil.
6. Cut out the pattern that you just traced and open it.
7. See the picture below (fig 7, 8, 9 & 10). Your tissue paper should look like this:

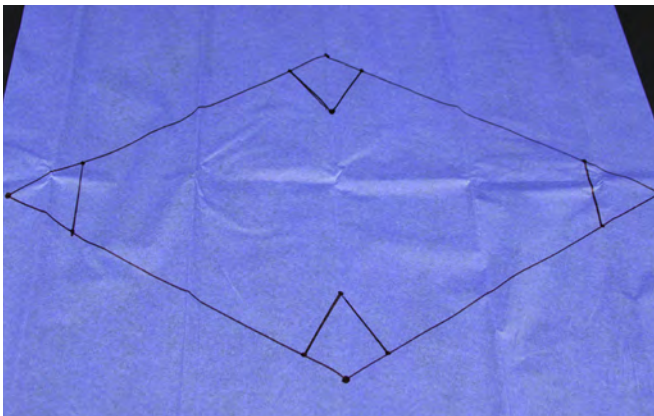
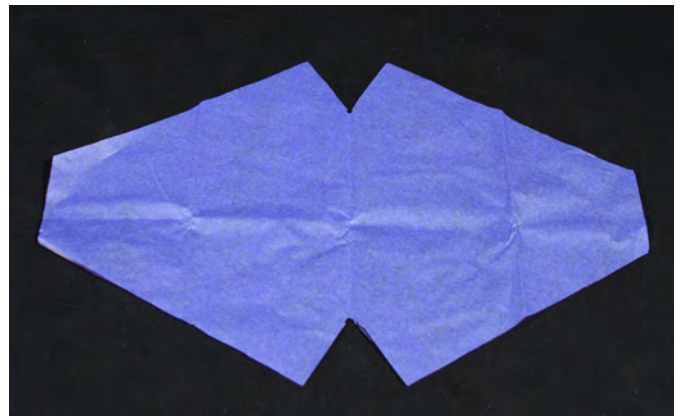
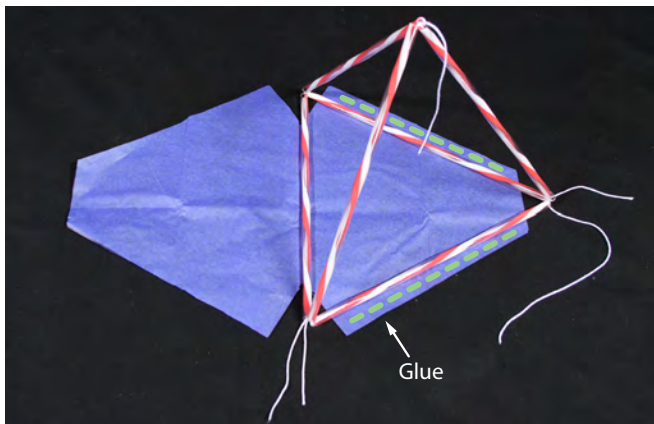
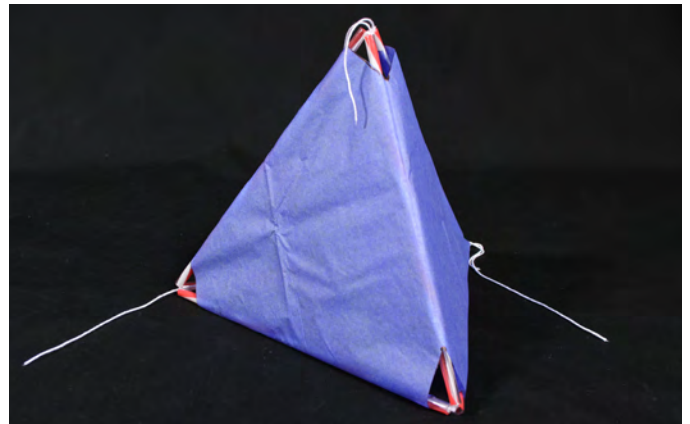
**Fig. 7** One-inch marks to create template**Fig. 8** Template construction**Fig. 9** Obtuse angle marking for template construction**Fig. 10** Acute angle marking for template construction

Worksheet 4 (cont.)

Tetrahedral Kite (Teacher Version)

Section Five - Cover the Tetrahedron

1. Lay the tissue paper on your table.
2. Wrap the tissue paper around the two sides of the tetrahedron.
3. Now glue the tabs using a glue stick and fold them around the straws. (Spread the glue along the flaps and fold the flaps over the straws.) Make sure that it is a tight fit.
4. Rotate the tetrahedron so you can do the same steps to the other side.
5. Now, add glue to the other flap.
6. Fold these flaps over the straws.
7. See Figures 11, 12, and 13 shown below. This is how your tetrahedron should now look:

**Fig. 11** Tissue paper template**Fig. 12** Completed tissue paper cover**Fig. 13** Placement of tetrahedron on tissue paper template**Fig. 14** Covered Tetrahedron

Section Six - Add Levels to the Tetrahedron

1. Now that you have successfully created one tetrahedron, you will need to repeat Step One through Step Five to make an additional three tetrahedrons (four in total).
2. Once you have created the other three remaining tetrahedrons, choose three of them and place the tetrahedrons on a flat surface or table.
3. Each tetrahedron will have strings that are free. Use those free strings to tie one tetrahedron to another. This will tie the adjacent base vertices together. See picture below (fig. 14).
4. Now, take the fourth tetrahedron and place it on top of the other three that you have tied together. Tie the fourth tetrahedron to the adjacent vertices.
5. Note that all of your connections need to be tight so that there is not any slack in the string.
6. Now your tetrahedron should look like this: (See picture below, fig. 15).
7. As a team, decide how many more tetrahedrons you want to add to your kite before you decide to fly it. Repeat Step One through Step Five as necessary for your additions. Also, remember that when you add your additional tetrahedrons make sure the connections are tight.

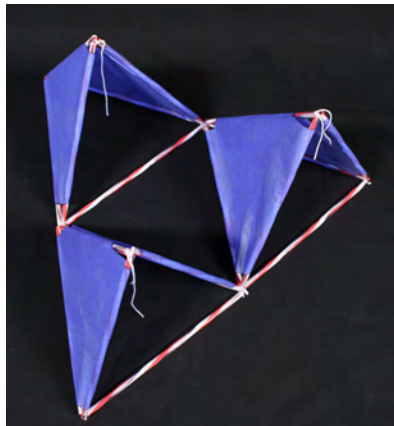


Fig. 15 Three tetrahedrons in the form of one large triangle

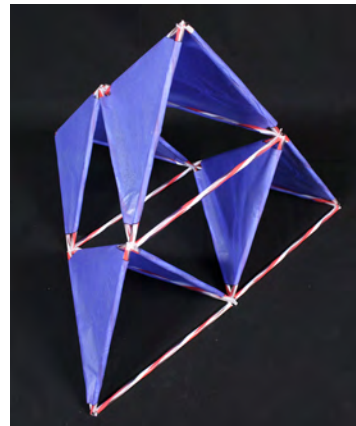


Fig. 16 Four tetrahedrons

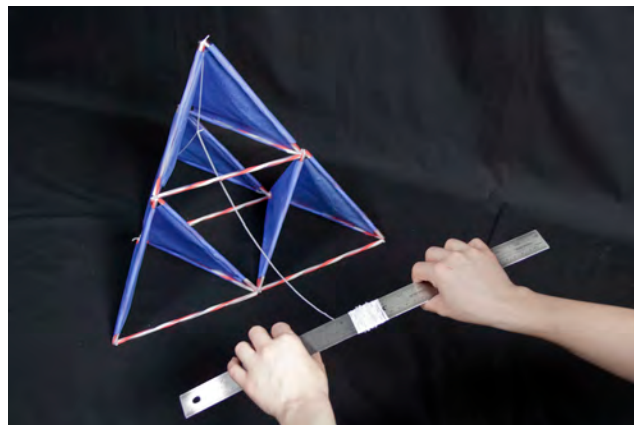


Fig. 17 Completed kite with bridle

Section Seven - Build Your Bridle

1. Now that you have made your kite, you will need to create and attach your bridle in order to fly it.
2. Tie your string (approximately 15 feet long) to the ruler so it can serve as your bridle.
3. Take your ruler to your teacher and he or she will use the hot glue gun to make sure your string stays on the ruler.
4. **TEACHER:** Take the hot glue gun and insert a glue stick. Plug the glue gun into the wall giving it time to heat up. Once the glue gun is ready, apply glue (approximately the size of the quarter) to the ruler in order to fasten the string to the bridle. Only when glue has cooled, return the glued ruler and string to the students.
5. Place your kite on the table with the base touching the table.
6. Next, tie a 24-inch string firmly to the very top of the kite.
7. Tie the same piece of string again to the middle joint. This will be between the top section of the kite and the bottom toward the front. There should not be any slack in the string.
8. Next, tie a loop in the middle of your string. The loop should be about the size of a quarter.
9. Now, attach the string of your kite to the loop.
10. Your kite is finished and ready to fly.
11. Complete the questions on your Kite Engineering Worksheet before attempting to fly your kite.

Section Eight Questions & Answers

You have completed the final stages of constructing a tetrahedral kite. Now your team must decide how many layers to make your kite. Discuss and build your kite. When completed, please answer the following questions:

- 1) What is the ratio between covered sides and uncovered sides?

(1:1)

- 2) When you have assembled your kite, discuss what shapes are evident and list them below.

(Answers should include triangles, equilateral triangles, rhombus, tetrahedron)

- 3) What is similar about the entire kite compared to the single tetrahedron you created earlier?

(Answer should include one cell builds on another cell to create a tetrahedron)

- 4) What is the ratio between covered cells and uncovered cells in the entire kite?

(The ratio needs to be equal like 1:1 but the student answers will vary based on the layers they decided to build on the kite. They will need to count the covered cells to uncovered cells to get the answer.)

- 5) What is the surface area of the entire kite?

(Answers will vary based on how big their kite is.)

- 6) What is the volume of the entire kite?

(Answers will vary based on how big their kite is.)

- 7) What is the ratio between the surface area of a single cell compared to the entire kite?

(Answers will vary based on how big their kite is.)

- 8) What is the ratio between the volume of a single cell compared to the entire kite?

(Answers will vary based on how big their kite is.)



Images

Img. 1 Children flying kites



(Public Domain)

Img. 2 Cody manlifter



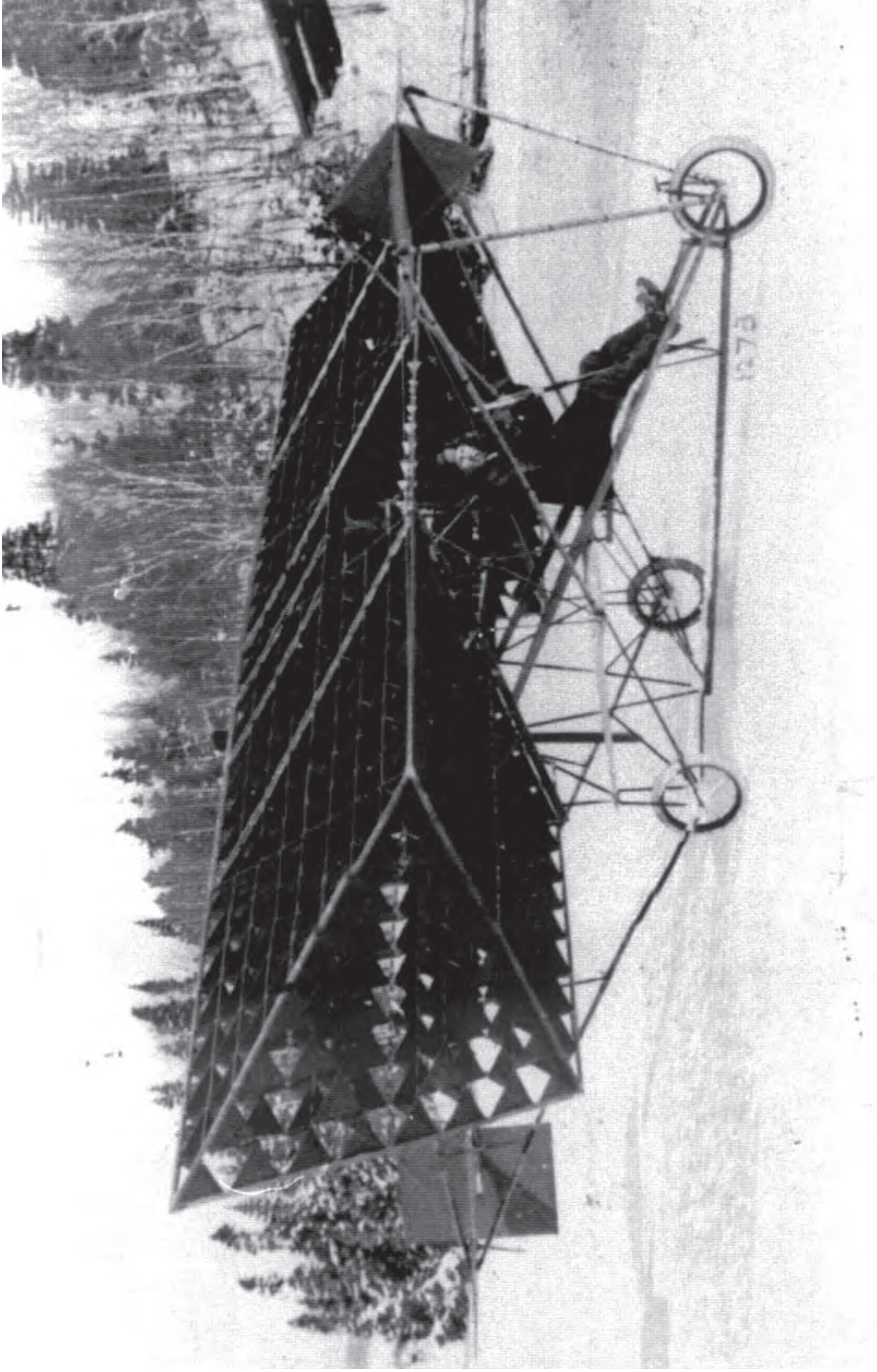
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Img. 3 Samuel Cody



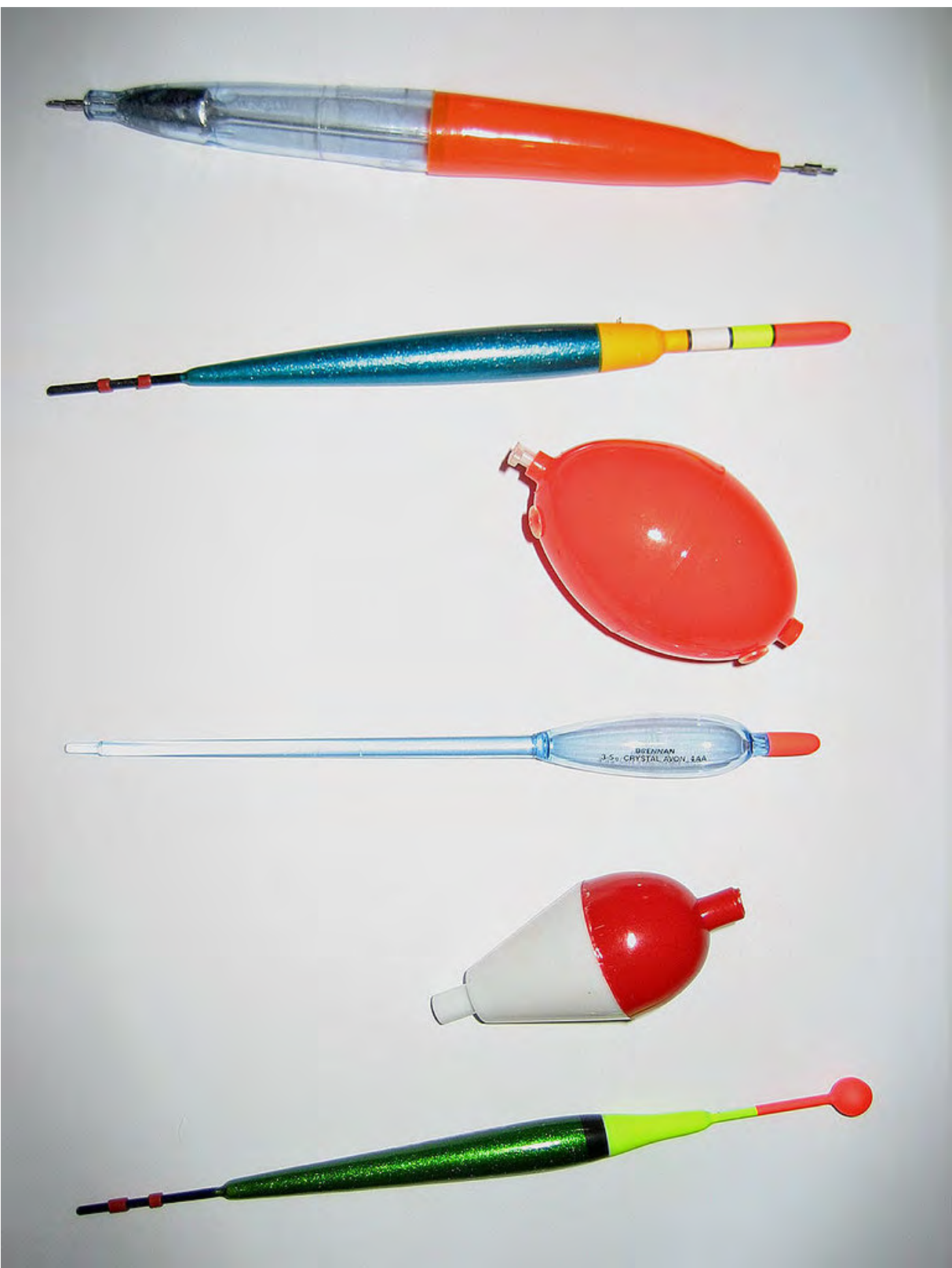
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Img. 4 Bell's tetrahedron kite



(Photo courtesy of NASA)

Img. 5 Fishing bobbers



(Public Domain)

Img. 6 Kite fishin



(Public Domain)

Img. 7 Scarecrow



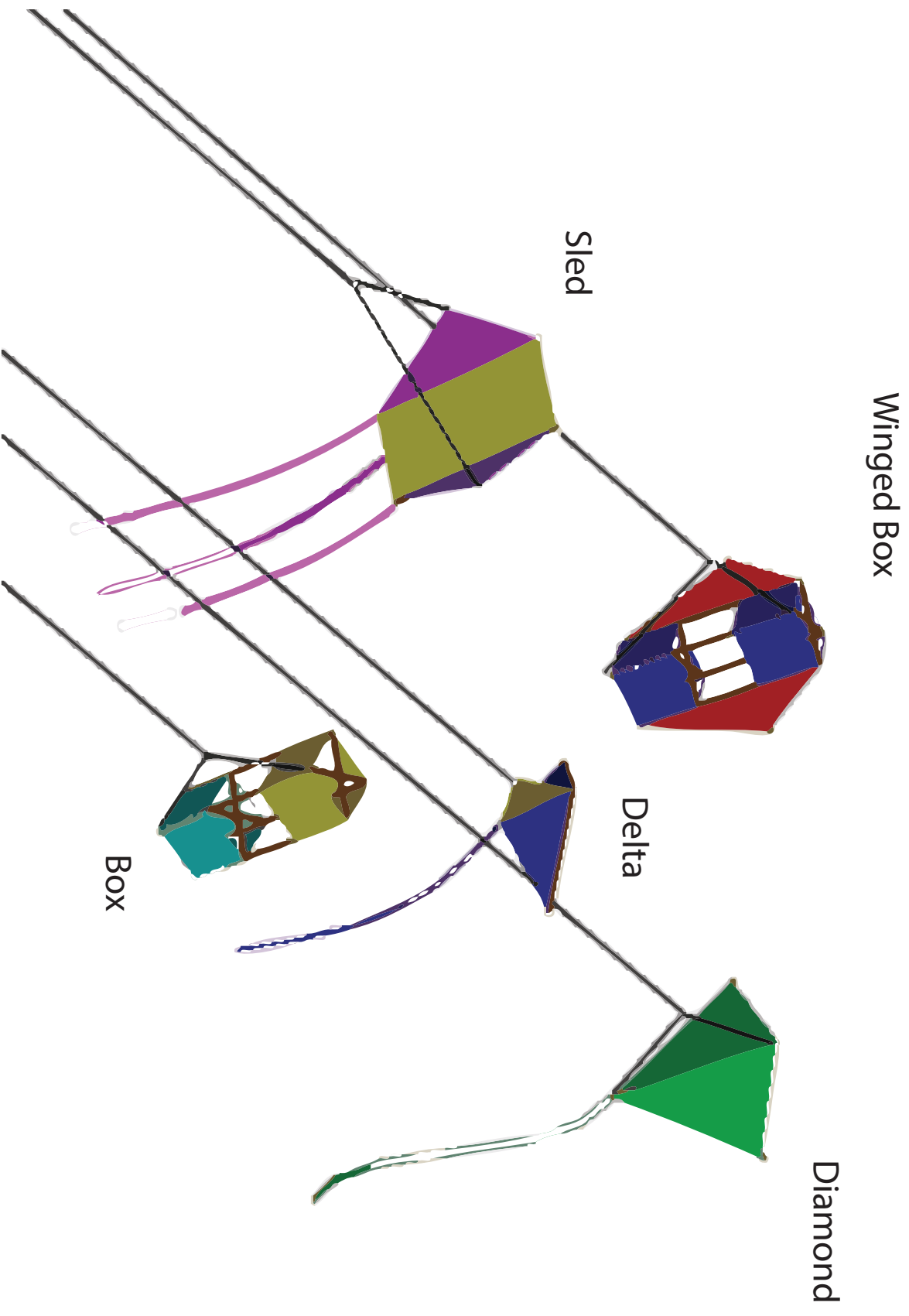
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Img. 8 A modern kite



(Photo courtesy of Shari Weinsheimer via PublicDomainPictures.net)

Img. 9 Types of kites



(Photo courtesy of NASA)

Img. 10 Benjamin Franklin flying his kite



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Img. 11 Leonardo da Vinci's Ornithopter



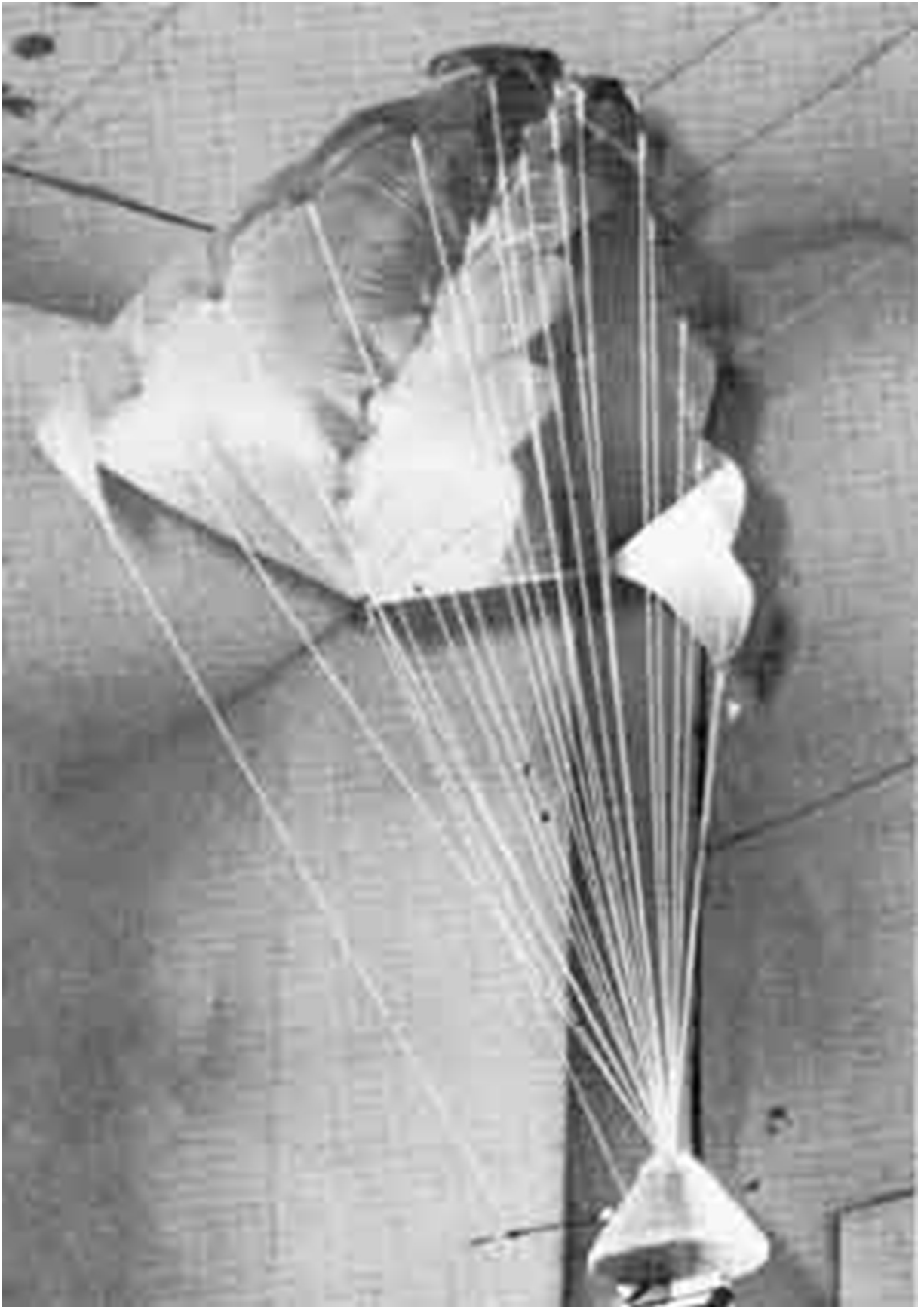
(Public Domain)

Img. 12 Wright fl er



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Img. 13 Rogallo's wing



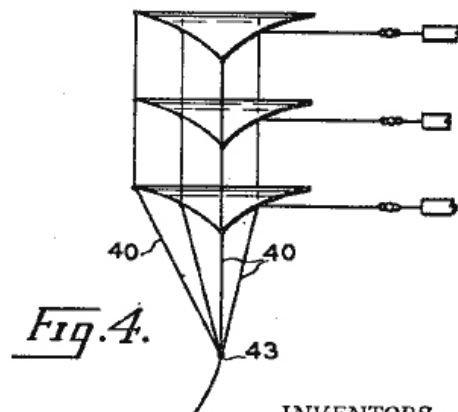
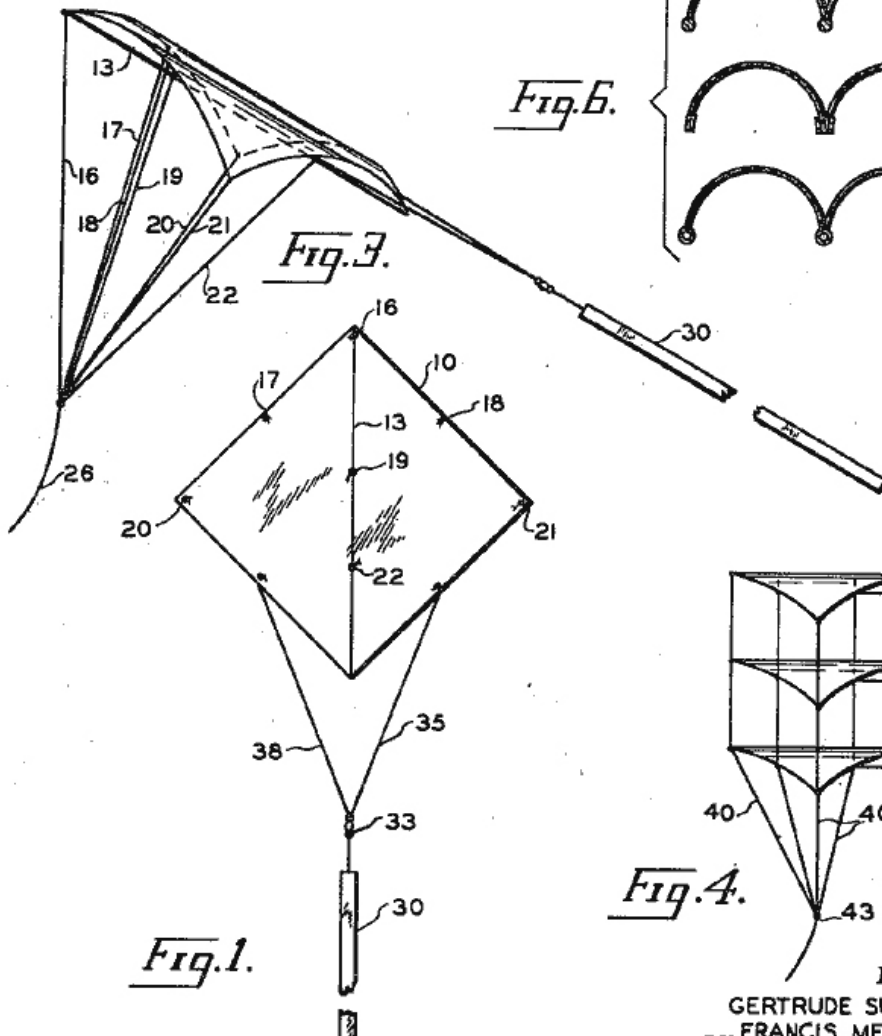
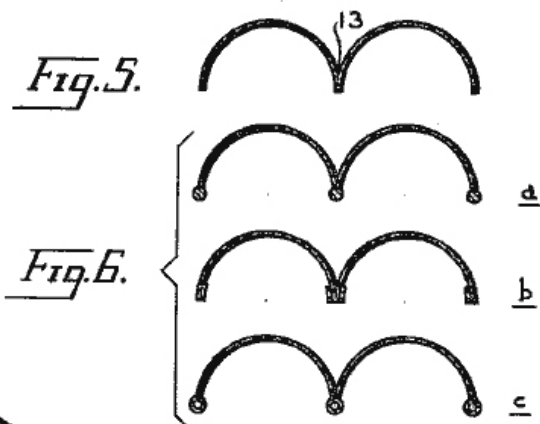
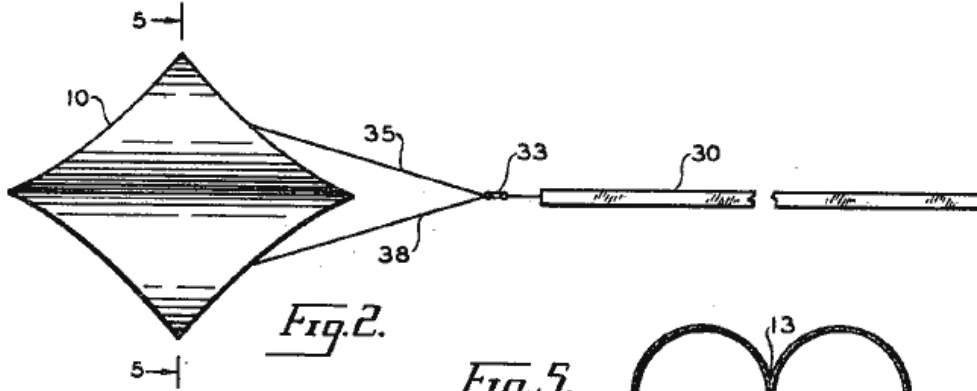
(Public Domain)

March 20, 1951

G. S. ROGALLO ET AL
FLEXIBLE KITE

2,546,078

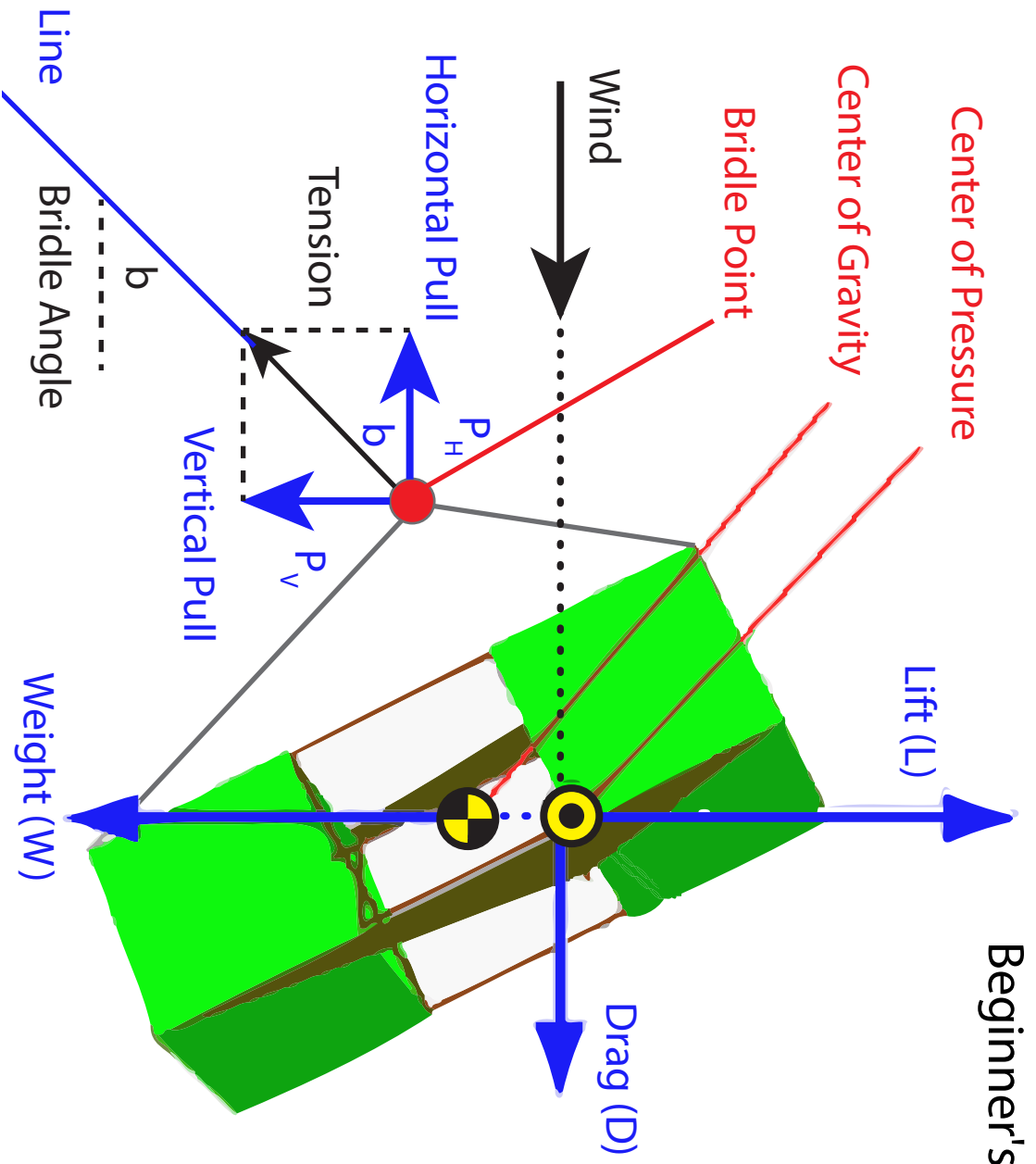
Filed Nov. 23, 1948



INVENTORS.
GERTRUDE SUGDEN ROGALLO
FRANCIS MELVIN ROGALLO

(Public Domain)

Img. 15 Forces on a kite



Beginner's Guide to Aeronautics

In Stable Flight:

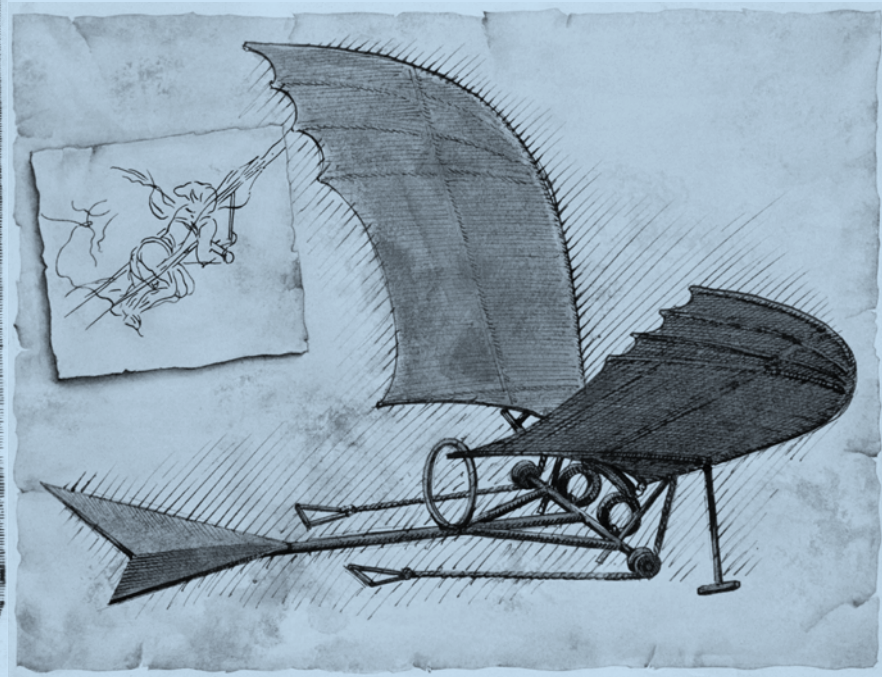
$$P_V + W - L = 0$$

$$P_H - D = 0$$

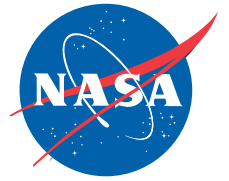
$$\tan b = \frac{P_V}{P_H}$$

(Photo courtesy of NASA)

Aeronautics
Research
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principles of flight



GRADES

K-4

Axes / Control Surfaces



principles of flight

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Axes / Control Surfaces

Lesson Overview

Through hands-on experiments and physical demonstrations, students will learn about position and motion of forces as they are introduced to some of the basic concepts of flight, including the three axes of flight and the control surfaces that guide the aircraft.

Objectives

Students will:

1. Learn how to identify the various parts of an airplane and gain a basic understanding of their functions.
2. Gain an understanding of how the three axes of flight relate to the movement of an aircraft.
3. Study the three axes of flight.

Materials:

In the Box

- Pencils (3 per student)
- Tape
- Scissors

Provided by User

- Colored pencils or crayons
- Chair (1 per student)

GRADES

K-4

Time Requirements: 1 hour 50 minutes

Background

The mechanics of flight are highly complex, encompassing principles such as the four forces and axes, as well as technical terms such as control surfaces, adverse yaw and coordinated flight. While this lesson covers all of these topics, its purpose is to provide just a very basic insight into the true mechanics of flight and body-axis systems. Wind-axis systems, which refer to aircraft forces in relation to the direction of the aircraft's velocity, are not discussed here to avoid confusion. Also, some of the explanations given are highly simplified in order to allow educators to help students visualize the principle being discussed. For educators with an aviation background and capable students, modification of these activities and background information is encouraged.

The Forces of Flight

Every aircraft, whether an airplane, helicopter or rocket, is affected by four opposing forces: Thrust, Lift, Drag and Weight (Fig. 1). Control surfaces, such as the rudder or ailerons, adjust the direction of these forces, allowing the pilot to use them in the most advantageous way possible.

A force can be thought of as a push or pull in a specific direction. It is a vector quantity, which means a force has both a magnitude (amount) and a direction.

For this lesson we will deal specifically with fixed-wing airplanes. Other aircraft, such as hot-air balloons and helicopters, use the same basic principles but the physics are very different.

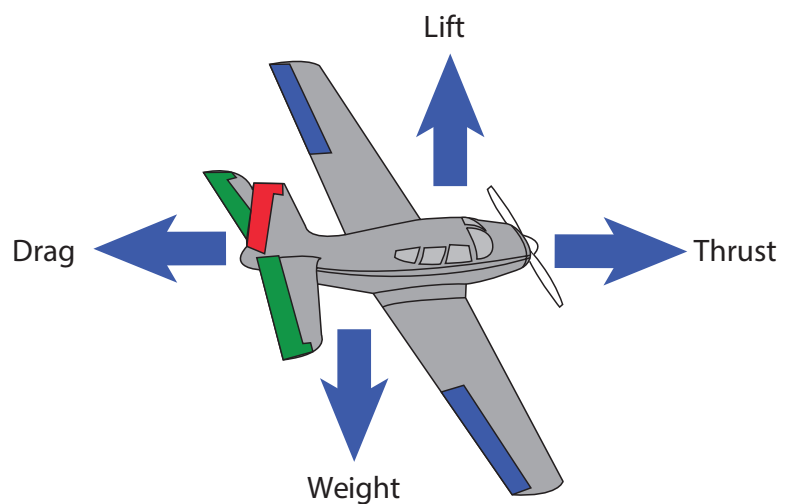


Fig. 1 Four forces of flight

Thrust

Thrust is produced by an aircraft's propulsion system or engine. The direction of the thrust dictates the direction in which the aircraft will move. For example, the engines on an airliner point backwards, which means that generally speaking, the airplane's thrust vector will point forwards.

Lift

Lift is generated by the motion of air passing over the aircraft's wings. The direction of lift is always perpendicular to the flight direction (Fig. 2) and its magnitude depends on several factors, including the shape, size and velocity of the aircraft.

Drag

Drag is simply resistance of the aircraft against the air. There are many types of drag, but each is a force opposing thrust.

Weight

Weight is a force that is always directed toward the center of the earth due to gravity. The magnitude of the weight is the sum of all the airplane parts, plus the fuel, people and cargo. While the weight is distributed throughout the entire airplane, its effect is on a single point called the center of gravity.

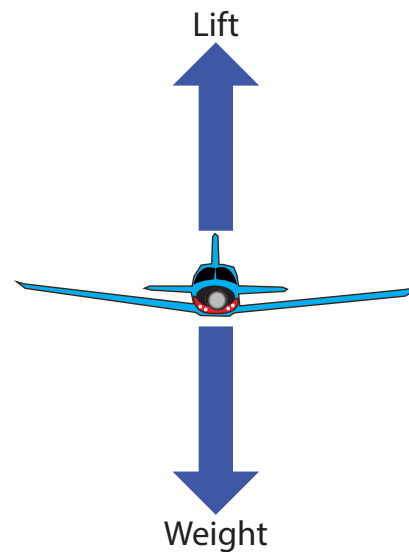


Fig. 2 The lift and weight forces of flight

Controlling the Motion of Flight

In order for an aircraft to reach its destination, the forces of flight have to be precisely manipulated. To do this, the aircraft has control surfaces (Fig. 3) which can direct airflow in very specific ways.

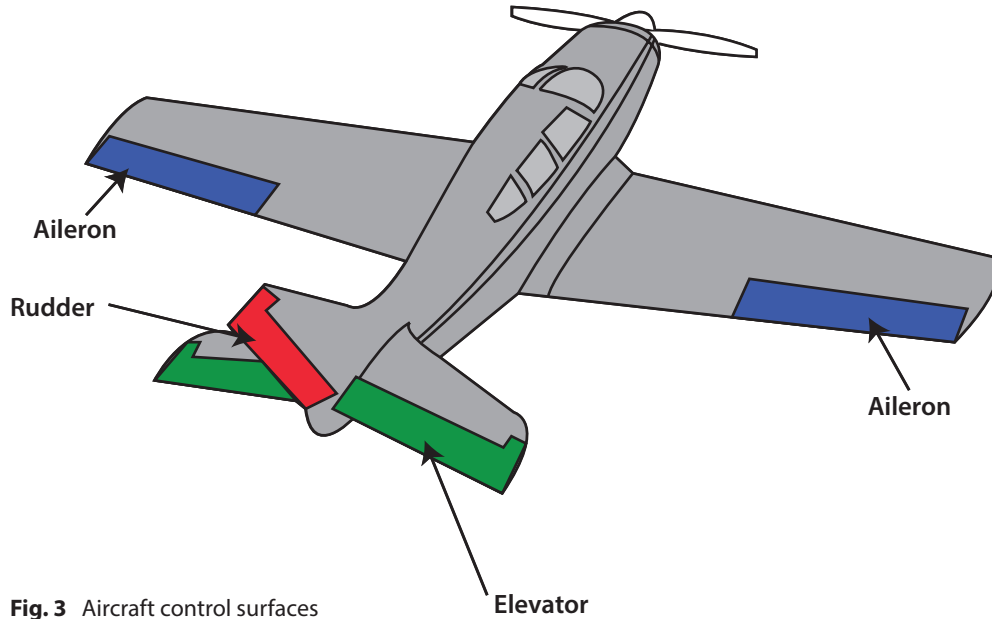


Fig. 3 Aircraft control surfaces

Elevator | Pitch

As the name implies, the elevator helps “elevate” the aircraft. It is usually located on the tail of the aircraft and serves two purposes. The first is to provide stability by producing a downward force on the tail. Airplanes are traditionally nose-heavy and this downward force is required to compensate for that. The second is to direct the nose of the aircraft either upwards or downwards, known as pitch, in order to make the airplane climb and descend. (Fig. 4).

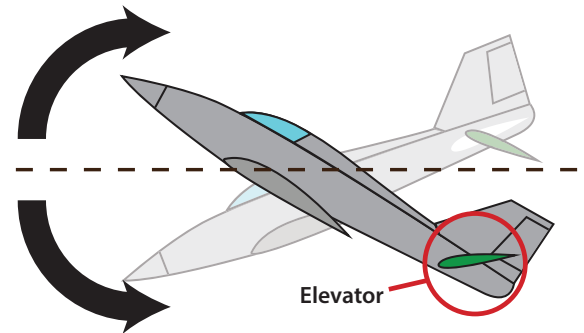


Fig. 4 Elevator and pitch movement

Ailerons | Roll

The ailerons are located at the rear of the wing, one on each side. They work opposite to each other, so when one is raised, the other is lowered. Their job is to increase the lift on one wing, while reducing the lift on the other. By doing this, they roll the aircraft sideways, which allows the aircraft to turn. This is the primary method of steering a fixed-wing aircraft (Fig. 5).

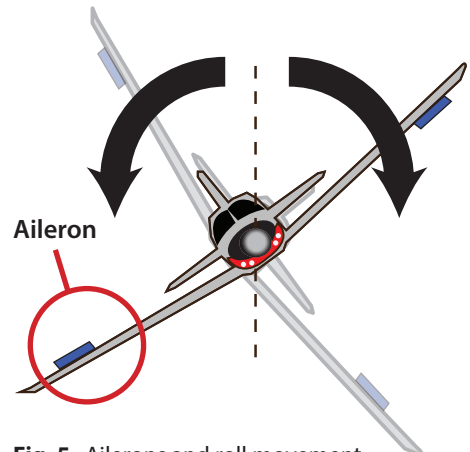


Fig. 5 Ailerons and roll movement

Rudder | Yaw

The rudder is located on the tail of the aircraft. It works identically to a rudder on a boat, steering the nose of the aircraft left and right. Unlike the boat however, it is not the primary method of steering. Its main purpose is to counteract the drag caused by the lowered aileron during a turn. This adverse yaw, as it is known, causes the nose of the airplane to point away, or outwards, from the direction of the turn. The rudder helps to correct this by pushing the nose in the correct direction, maintaining what is known as coordinated flight (Fig. 6).

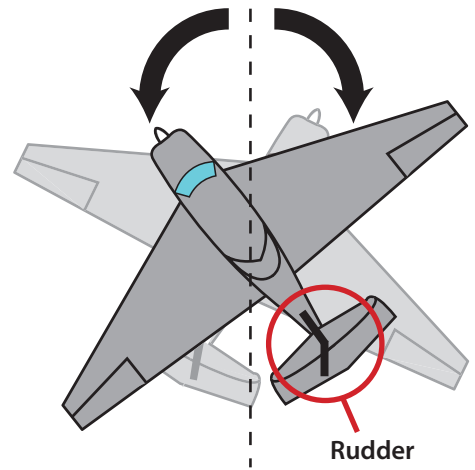


Fig. 6 Rudder and yaw movement

The Axes of Flight

Each axis of flight is an imaginary line around which an airplane can turn. Think of an airplane rotating around an axis like a wheel rotates around an axle.

Regardless of the type of aircraft, there are three axes upon which it can move: Left and Right, Forwards and Backwards, Up and Down. In aviation though, their technical names are the lateral axis, longitudinal axis and vertical axis.

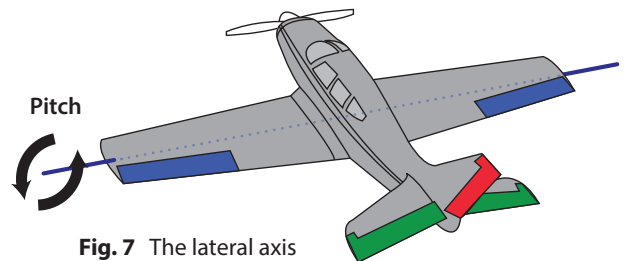


Fig. 7 The lateral axis

The Lateral Axis (Pitch)

The lateral axis runs from wing tip to wing tip. The aircraft pitches around this axis (Fig. 7).

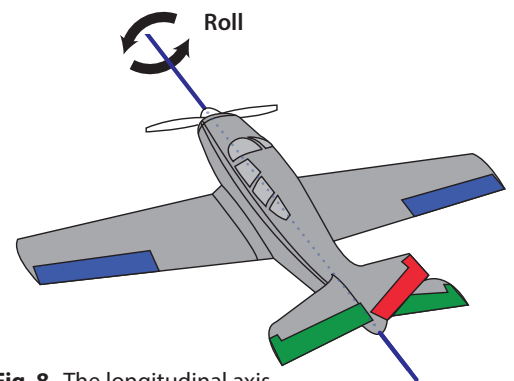


Fig. 8 The longitudinal axis

The Longitudinal Axis (Roll)

The longitudinal axis runs from the nose of the aircraft to the tail. This is the axis around which the aircraft rolls (Fig. 8).

The Vertical Axis (Yaw)

The vertical axis is slightly different to the others, running vertically through the center of the aircraft. The aircraft yaws around this axis (Fig. 9).

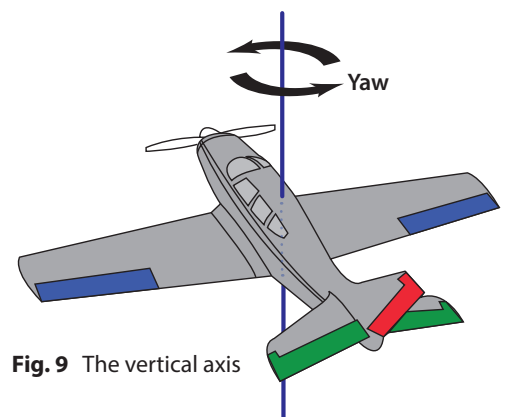


Fig. 9 The vertical axis

The Center of Gravity

The center of gravity, also known as CG, is the effective point whereby all weight is considered to be. The CG is also the same point where the axes of flight meet (Fig. 10). This point isn't fixed on any aircraft, but moves forwards or backwards along the longitudinal axis, depending on how the aircraft is loaded. It is vital that its center of gravity remain within certain limits however, as an aircraft that is too nose- or tail-heavy will either not fly, or be so difficult to control that it becomes too dangerous to try. These limits are referred to as its operational envelope.

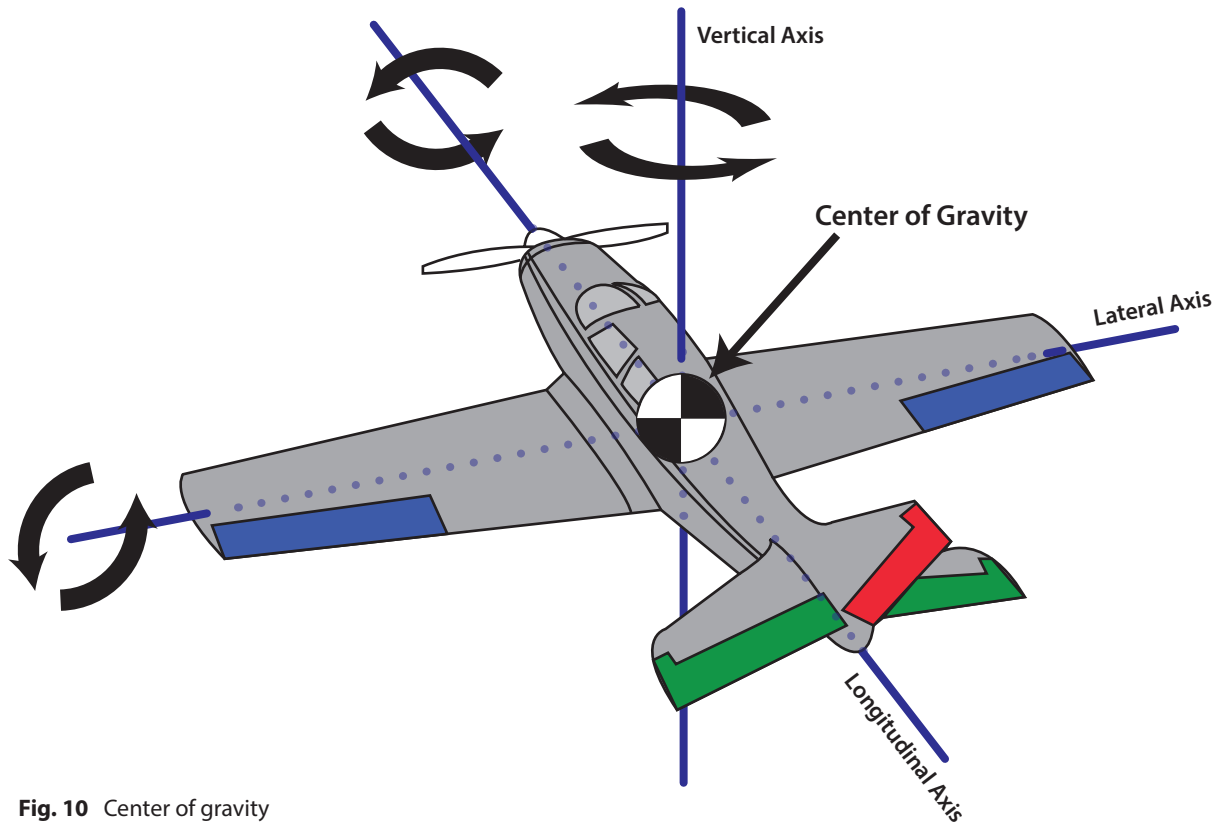


Fig. 10 Center of gravity

For additional information on aerodynamics and the principles of flight in general, please refer to the Museum in a Box lessons "Four Forces" and "Bernoulli Principle".

Activity 1

Parts of an Airplane

GRADES**K-4****Time Requirements:** 20 minutes**Materials:**In the Box

None

Provided by User

Colored pencils or crayons

WorksheetsParts of an Airplane
(Worksheet 1)Reference Materials

None

Key Terms:

Aileron

Elevator

Rudder

Objective:

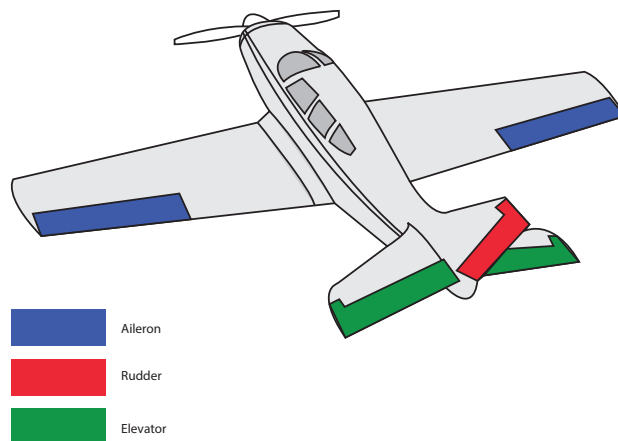
In this activity, students will learn about position and motion of forces as they learn to identify the various parts of the airplane and gain a basic understanding of their functions.

Activity Overview:

Students will label or color various parts of the aircraft, learning the purpose or function of each component in the process.

Activity:

1. Provide each student with a copy of the Parts of an Airplane worksheet.
2. Using the **Background** information, discuss each of the control surfaces with the students as a group.
Remember that younger students may not understand the vast majority of the concepts being presented.
3. Depending on the age and ability of the students, have them either color-code or label each control surface.
You can do this step either during your discussion or afterward.



Discussion Points:**1. Where are the ailerons?**

The ailerons are on the trailing, or rear, edge of the wings.

2. What is their purpose?

The ailerons are used to turn the airplane left and right.

3. Where is the rudder?

The rudder is at the back of the airplane, on the tail.

4. What is its purpose?

The rudder is used to keep the nose and tail of the airplane pointing in the same direction.

5. Where is the elevator?

The elevator is also on the tail of the airplane, below the rudder.

6. What is its purpose?

The elevator is used to turn and make the airplane climb and descend.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

Activity 2

The Axes of Flight

GRADES**K-4****Time Requirements:** 30 minutes**Materials:**In the Box

None

Provided by User

Chair (one per student)

Worksheets

None

Reference Materials

None

Key Terms:

Lateral axis

Longitudinal axis

Pitch

Roll

Vertical axis

Yaw

Objective:

In this activity, students will learn about the position and motion of objects as they gain an understanding of the three axes of flight and how they relate to the movement of an aircraft.

Activity Overview:

Students will work in pairs to visualize the three axes of flight.

Activity:

1. Use the **Background** information to discuss each of the airplane's axes of flight. Then explain to the students that they will pretend to be airplanes in order to demonstrate the ways in which an airplane can move.
2. Divide the students into pairs and have them take turns performing the remaining steps.
3. Have one student in each pair (Student A) stand with their arms outstretched, representing wings. Have the other student in the pair (Student B) place their hands on Student A's waist. Now, have Student B twist Student A around the waist. This demonstrates the effect the rudder has on the airplane, which is a rotation around the vertical axis.



If available, an excellent alternative would be to have Student A lay on the seat of a swivel chair, with arms outstretched, while Student B rotates the chair.

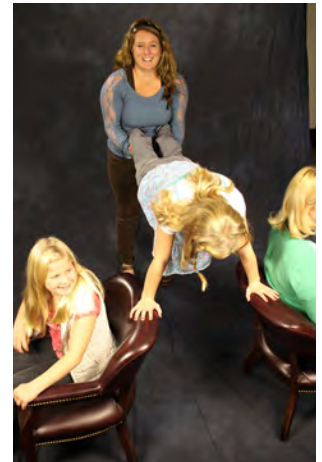
4. Place both students' chairs together so that Student A can lie face down on them, again with arms outstretched. Have Student B hold the waist of Student A, rotating Student A side to side on the chair. This demonstrates the effect ailerons have on an airplane, which is a rotation around the longitudinal axis. For older students, have the students rotate their hands to symbolize the raising and lowering of the individual ailerons. For a left turn, the left hand should be twisted up, while the right hand is twisted down. Do the opposite for a right turn .



Use caution demonstrating the next axis. It should only be performed with mature students on a carpeted area. A second, less accurate, method is also given should it be deemed safer.

5a. The lateral axis demonstration requires two pairs of students.

- a) Place the two chairs back to back, slightly apart. Have two of the students sit on the chairs for support and stability.
- b) Have Student A stand in between the two chairs, placing one hand on the back of each chair. Student A should now take a step backwards while leaning forwards into a



standing push-up position .

- c) Student B should lift Student A's feet off of the ground, so that student A's weight is now supported by their arms on the backs of the chairs.
- d) Student B can now raise and lower Student A's feet, demonstrating movement around the lateral axis.

- 5b. **Alternatively, have each student stand with their arms outstretched as in step 3.** Next, have them bend forwards and backwards at the waist.

Regardless of the step performed above, this demonstrates the effect the elevator has on the airplane, which is a rotation around the lateral axis.



Discussion Points:

1. **What does the aircraft do around the lateral axis?**
The aircraft pitches around the lateral axis. This makes the aircraft climb or descend.
2. **What does the aircraft do around the longitudinal axis?**
The aircraft rolls around the longitudinal axis. This makes the aircraft turn left or right.
3. **What does the aircraft do around the vertical axis?**
The aircraft yaws around the vertical axis. This makes the nose of the aircraft point left or right.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

Activity 3

Paper Axes

GRADES

K-4

Time Requirements: 60 minutes

Materials:In the Box

None

Provided by UserPencils
(3 per student)Tape
ScissorsWorksheetsAirplane Template
(Worksheet 2)Reference Materials

None

Key Terms:Lateral axis
Longitudinal axis
Pitch
Roll
Vertical axis
Yaw**Objective:**

In this activity, students will improve their understanding of motions and forces, and transfer of energy, by studying the three axes the three axes of flight.

Activity Overview:

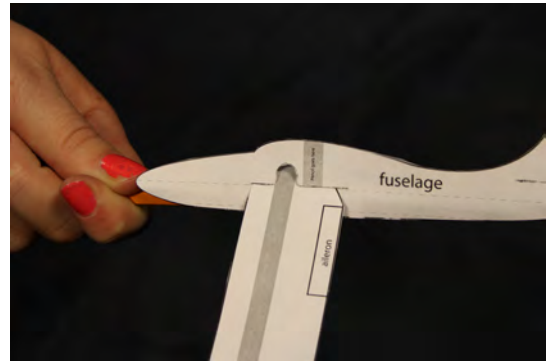
Students will build a model airplane and use pencils to demonstrate how the aircraft moves around each axis.

Activity:

1. If you have not completed **Activity 2 – The Axes of Flight**, use the **Background** information to discuss with the students each of the airplane's axes of motion.
2. Provide each student with a copy of the template (from the **Airplane Template worksheet**), a pair of scissors and 3 pencils. Have the students perform each of the following steps, demonstrating as you go.
If available, printing the worksheet on heavy cardstock will greatly improve the quality of the final product.
3. **Cut out each of the airplane components.** Make holes in the center of the wing and fuselage where directed on the diagram.
4. **Tape one pencil to the fuselage as marked on the diagram.**



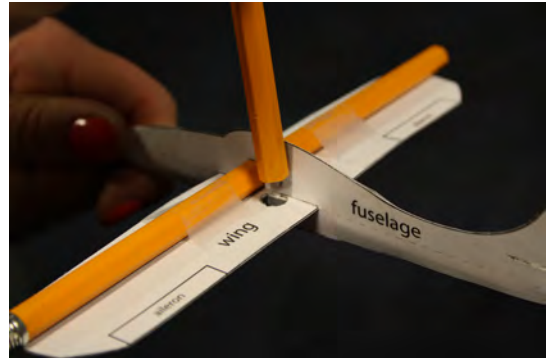
5. Slide the wing through the slot in the fuselage.



6. Insert a pencil through the hole in the fuselage and tape it to the wing.



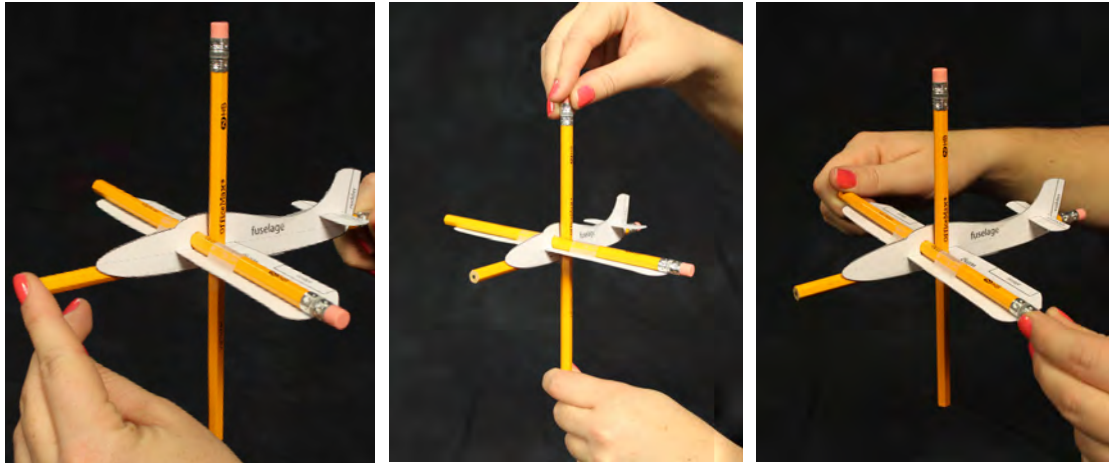
7. Insert the third pencil through the hole made in the left wing, again taping it to the fuselage.



8. Slide the elevator into the slot in the tail and tape it in place on either side.



9. **Demonstrate to the students how the airplane rotates around each axis by twisting the pencils.** Have the students “fly” the aircraft, climbing, descending and turning the aircraft while moving it around the room.



Discussion Points:

1. **What axis does the aircraft pitch around?**
The aircraft pitches around the lateral axis, making the aircraft climb or descend.
2. **What axis does the aircraft roll around?**
The aircraft rolls around the longitudinal axis making the aircraft turn left or right.
3. **What axis does the aircraft yaw around?**
The aircraft yaws around the vertical axis, keeping the nose and tail of the plane flying in a straight line.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology



Reference Materials

Glossary

Aileron:

The part of the airplane, located at the rear of the wing, that increases the lift on one wing while reducing the lift on the other in order to roll the aircraft sideways and allow it to turn

Axis:

An imaginary line around which an airplane can turn

Center of gravity (CG):

The effective point whereby all weight is considered to be; the same point where the axes of flight meet

Control surface:

Any part of an aircraft which can be moved to direct airflow, enabling the aircraft to roll, pitch and yaw

Drag:

The resistance of air against an aircraft's forward motion

Elevator:

The control surface usually located on the tail of an aircraft, used to stabilize the plane and enable pitch adjustments

Fuselage:

The body of an aircraft

Lateral axis:

The imaginary line, from wingtip to wingtip, about which an airplane pitches

Lift:

The force generated primarily by the motion of air passing over an aircraft's wings

Longitudinal axis:

The imaginary line, from nose to tail, about which an airplane rolls

Operational envelope:

A range in which the aircraft's center of gravity must be located in order to fly

Pitch:

The motion of an aircraft about the lateral axis, resulting in the nose and tail moving upwards and downwards

Roll:

The motion of an aircraft about the longitudinal axis, resulting in one wing raising while the other lowers (the plane rolls side-to-side)

Rudder:

An airplane's control surface, located on the tail, which helps to steer the aircraft

Thrust:

The force generated by the aircraft's propulsion system

Vertical axis:

The imaginary line that runs vertically (perpendicular to the longitudinal and lateral axes) through an aircraft's center of gravity, about which the plane yaws

Weight:

The force due to gravity which acts upon every object on Earth

Yaw:

The motion of an aircraft about the vertical axis, resulting in the plane moving horizontally left and right

Fig. 1 Four forces of flight

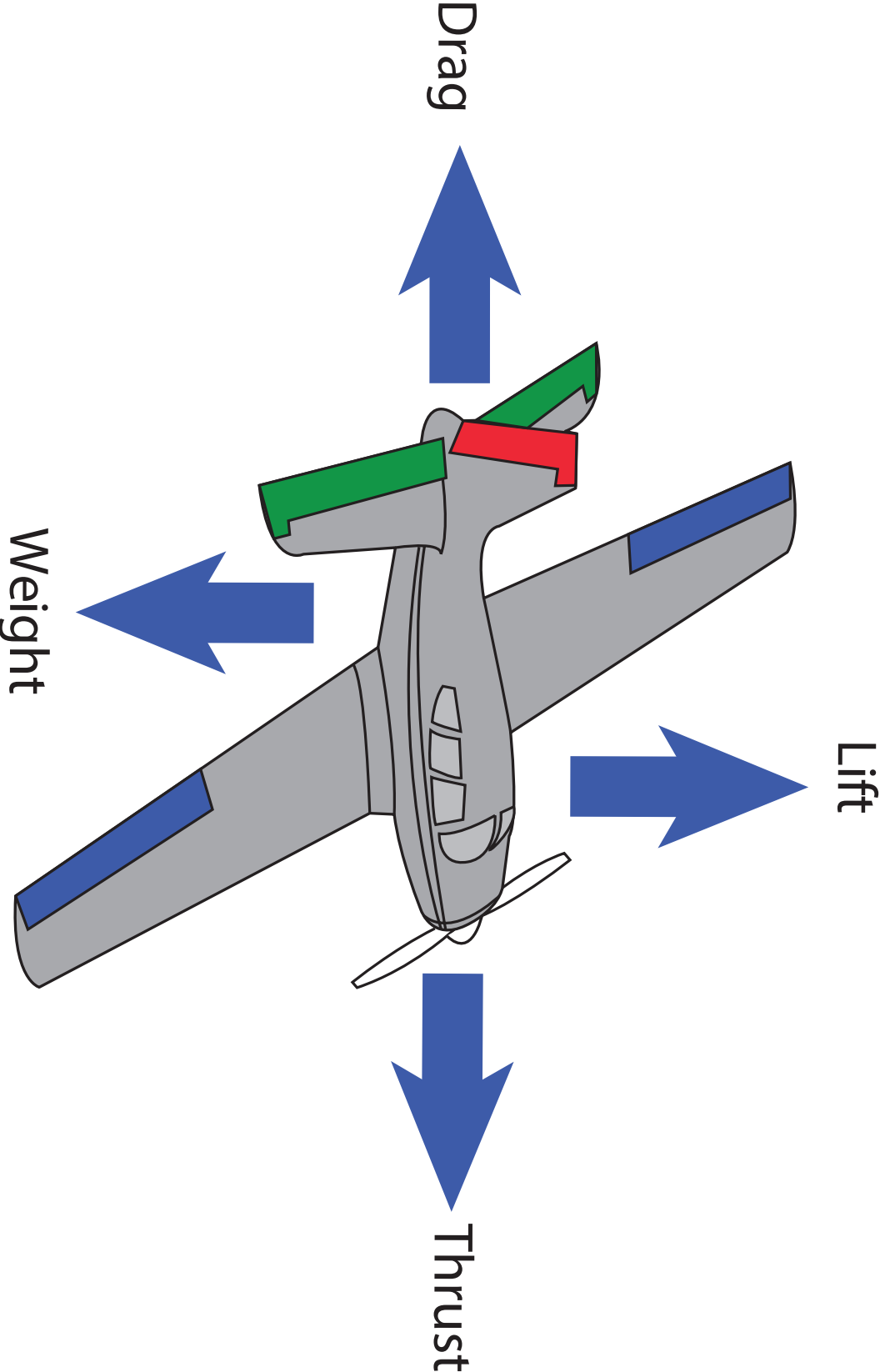


Fig. 2 The lift and weight forces of flight

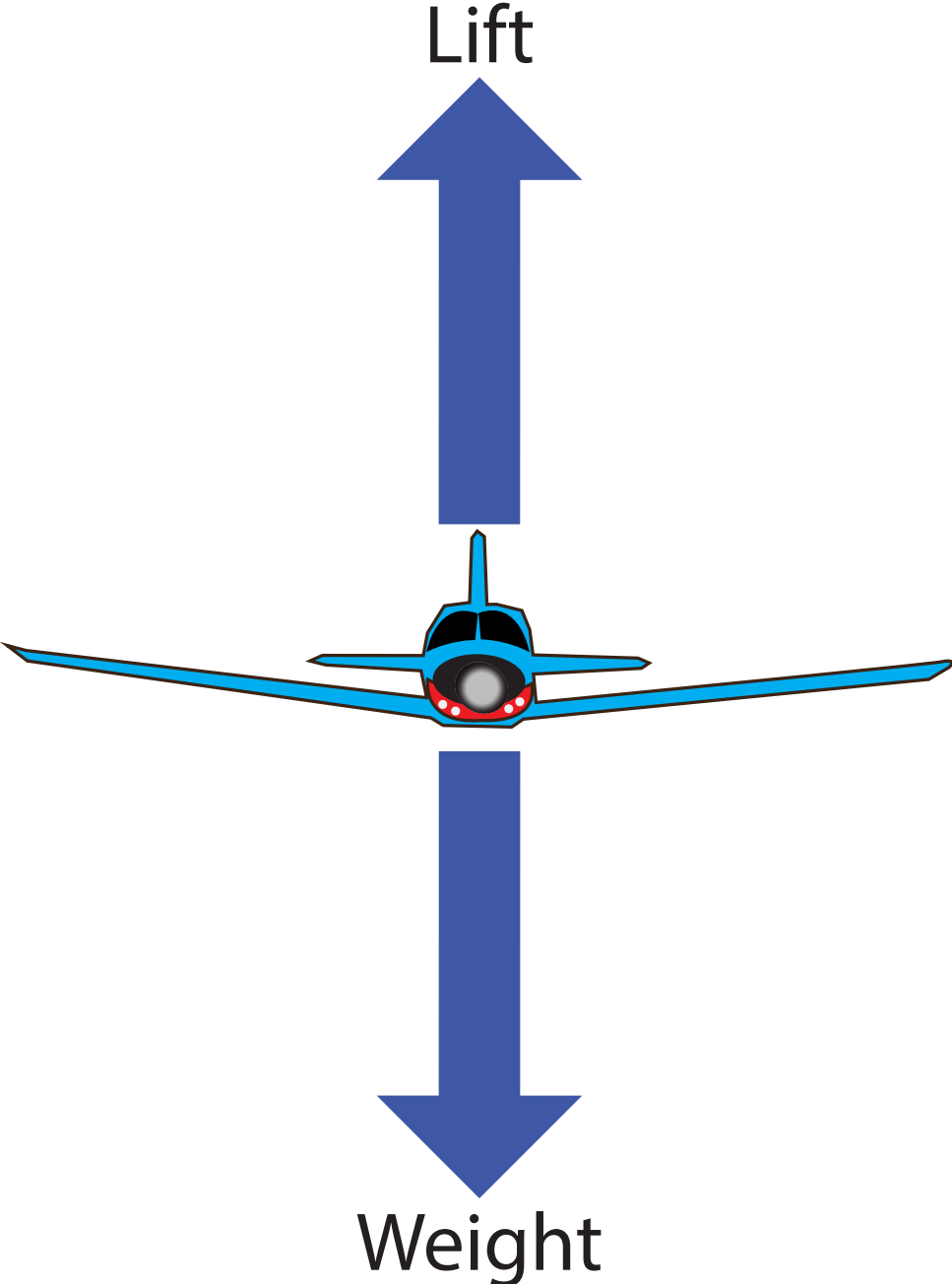


Fig. 3 Aircraft control surfaces

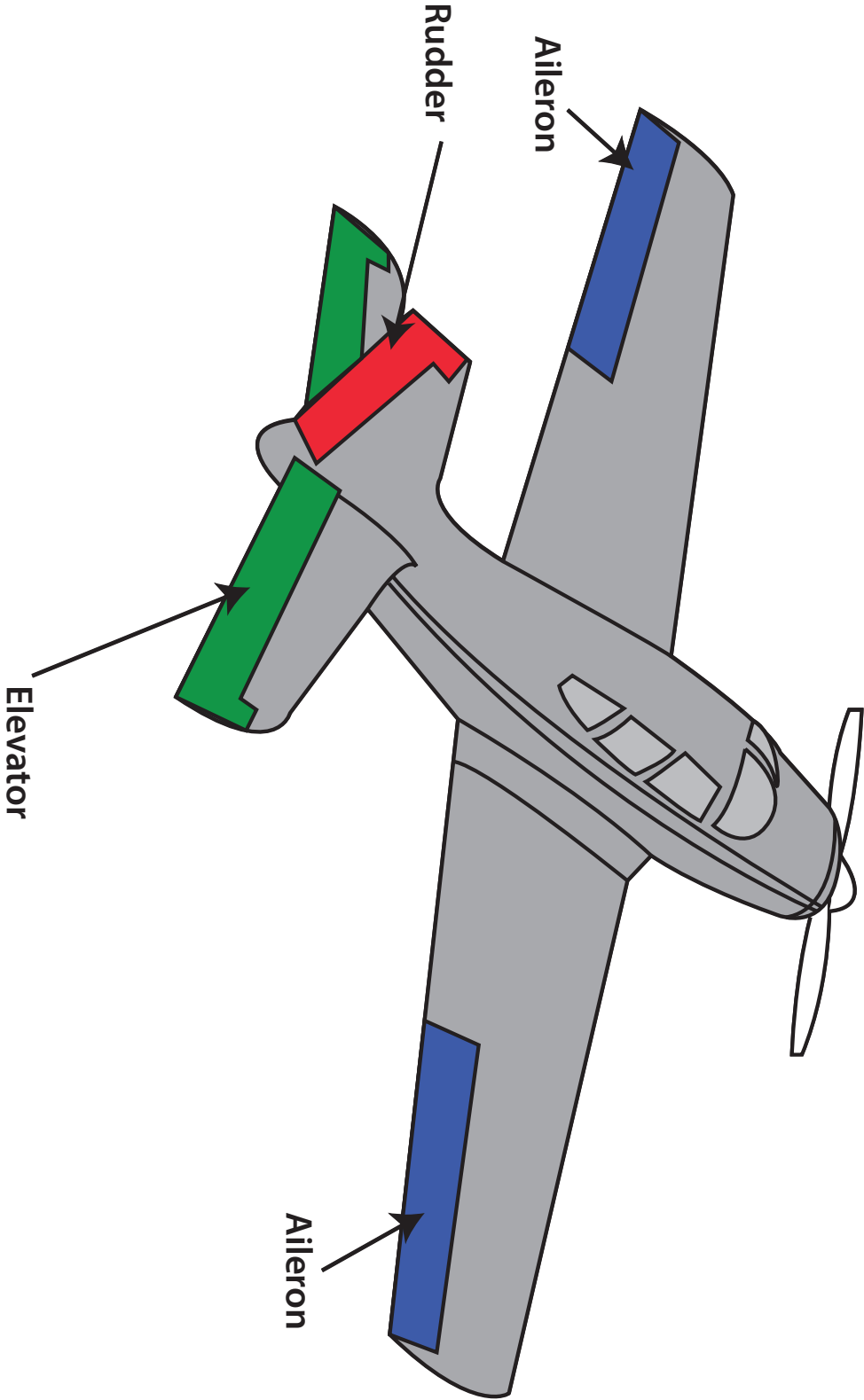


Fig. 4 Elevator and pitch movement

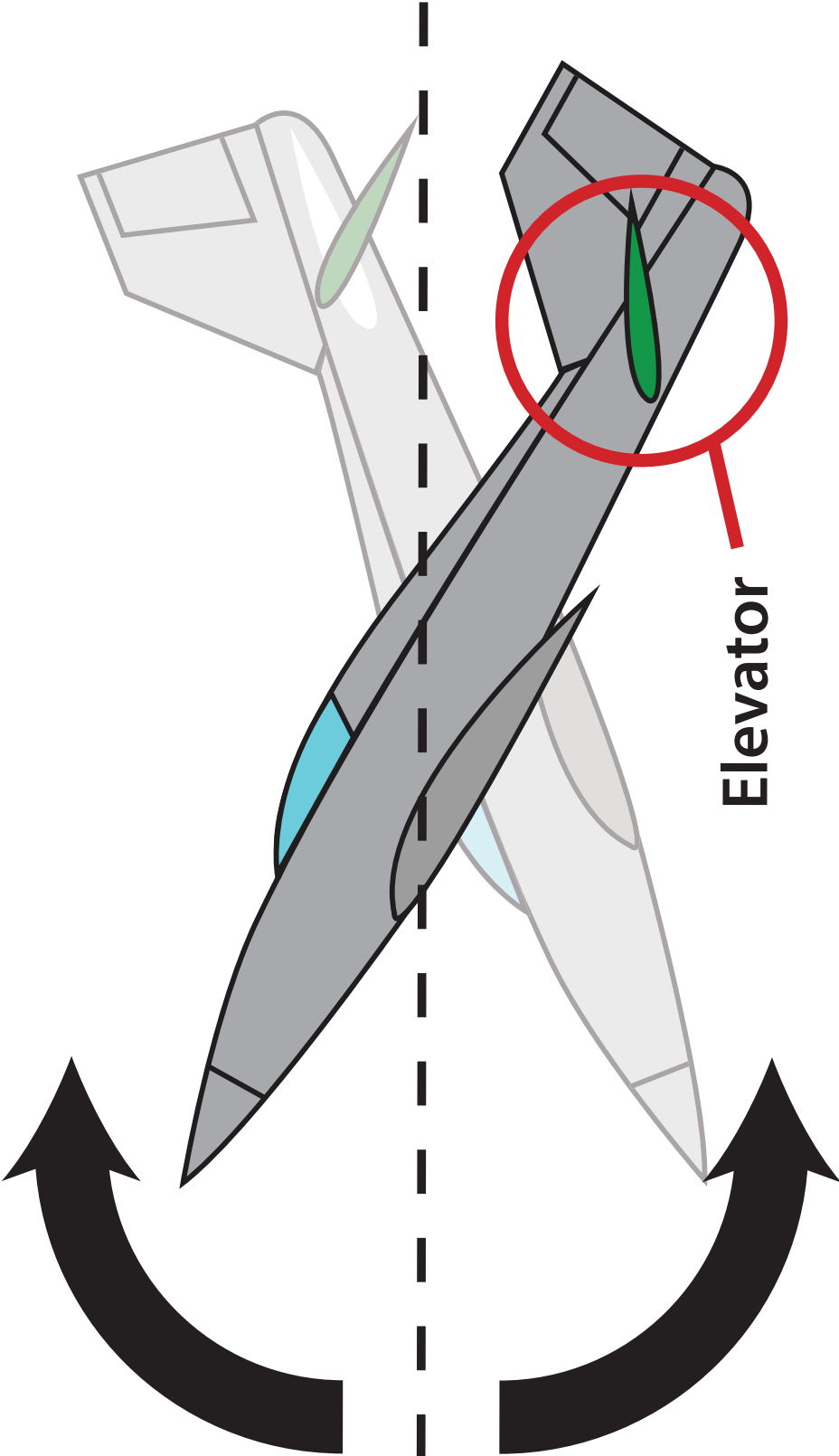


Fig. 5 Ailerons and roll movement

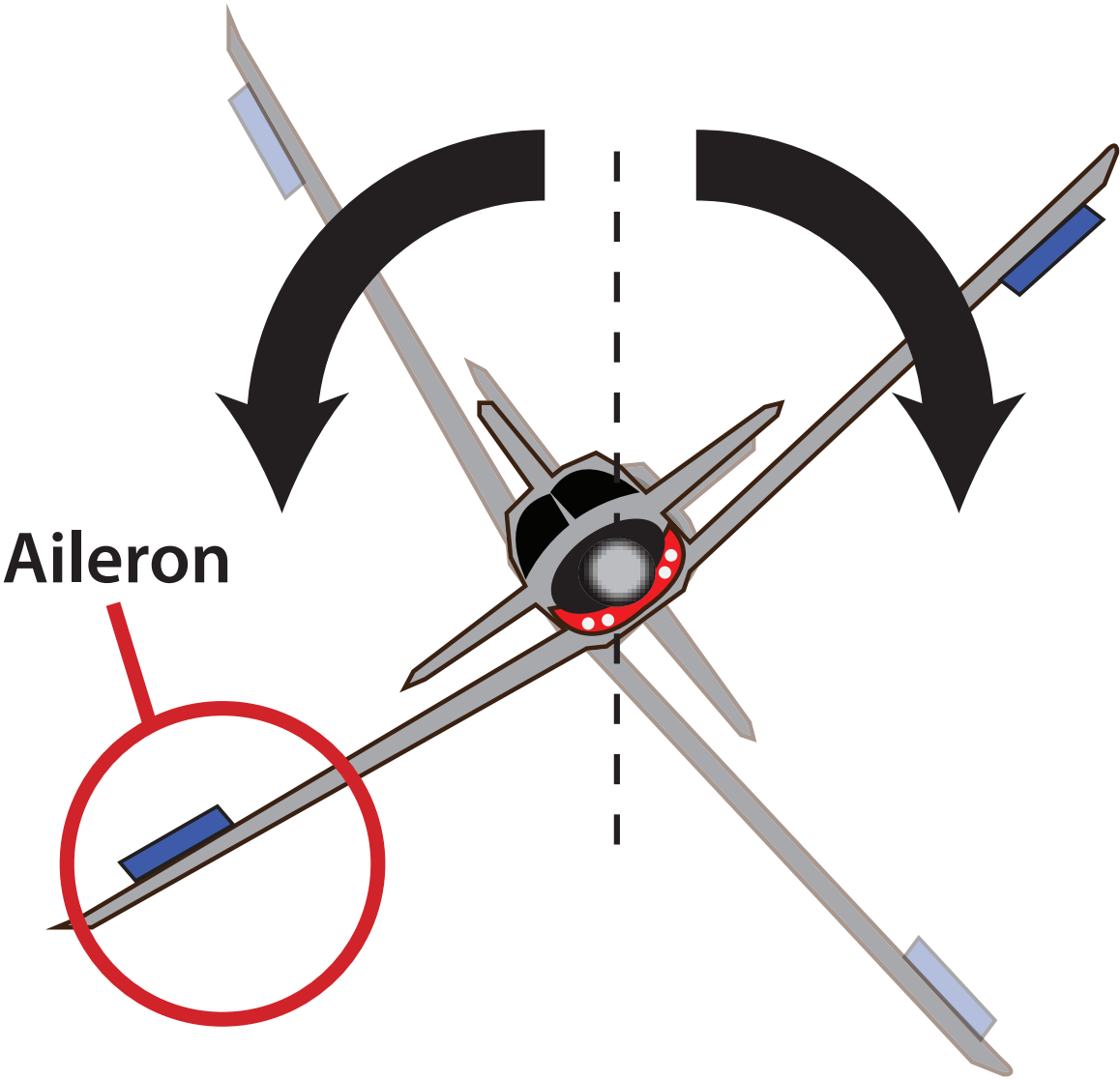


Fig. 6 Rudder and yaw movement

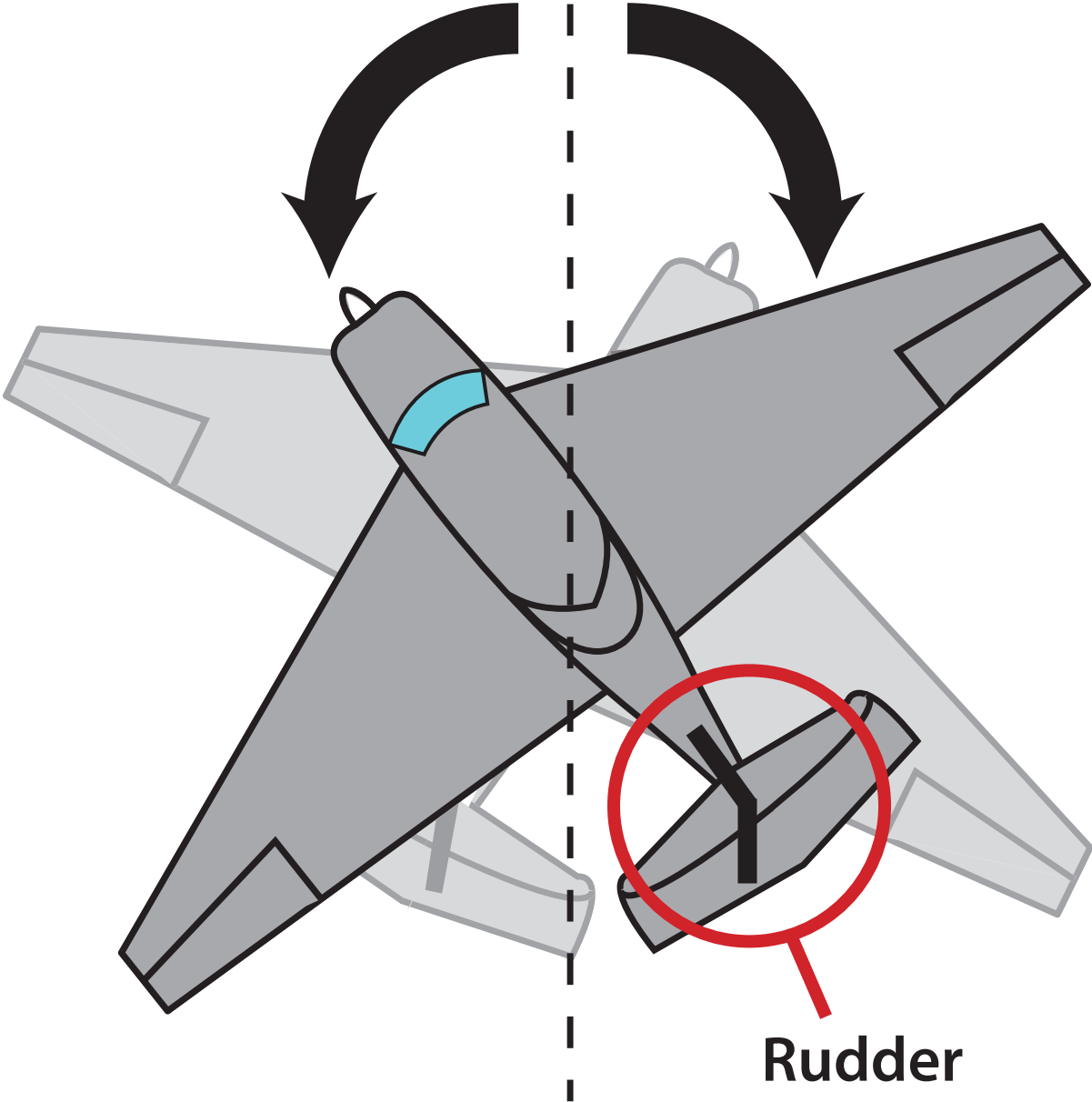


Fig. 7 The lateral axis

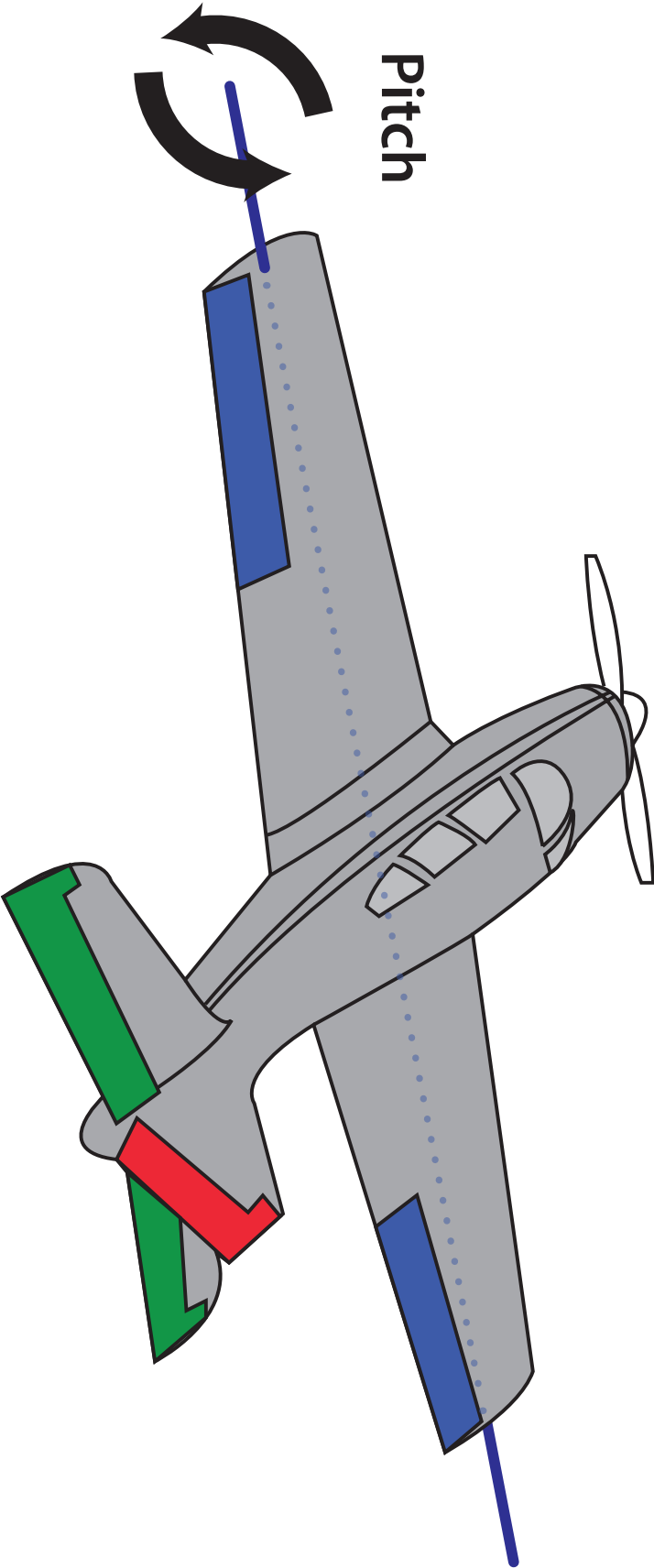


Fig. 8 The longitudinal axis

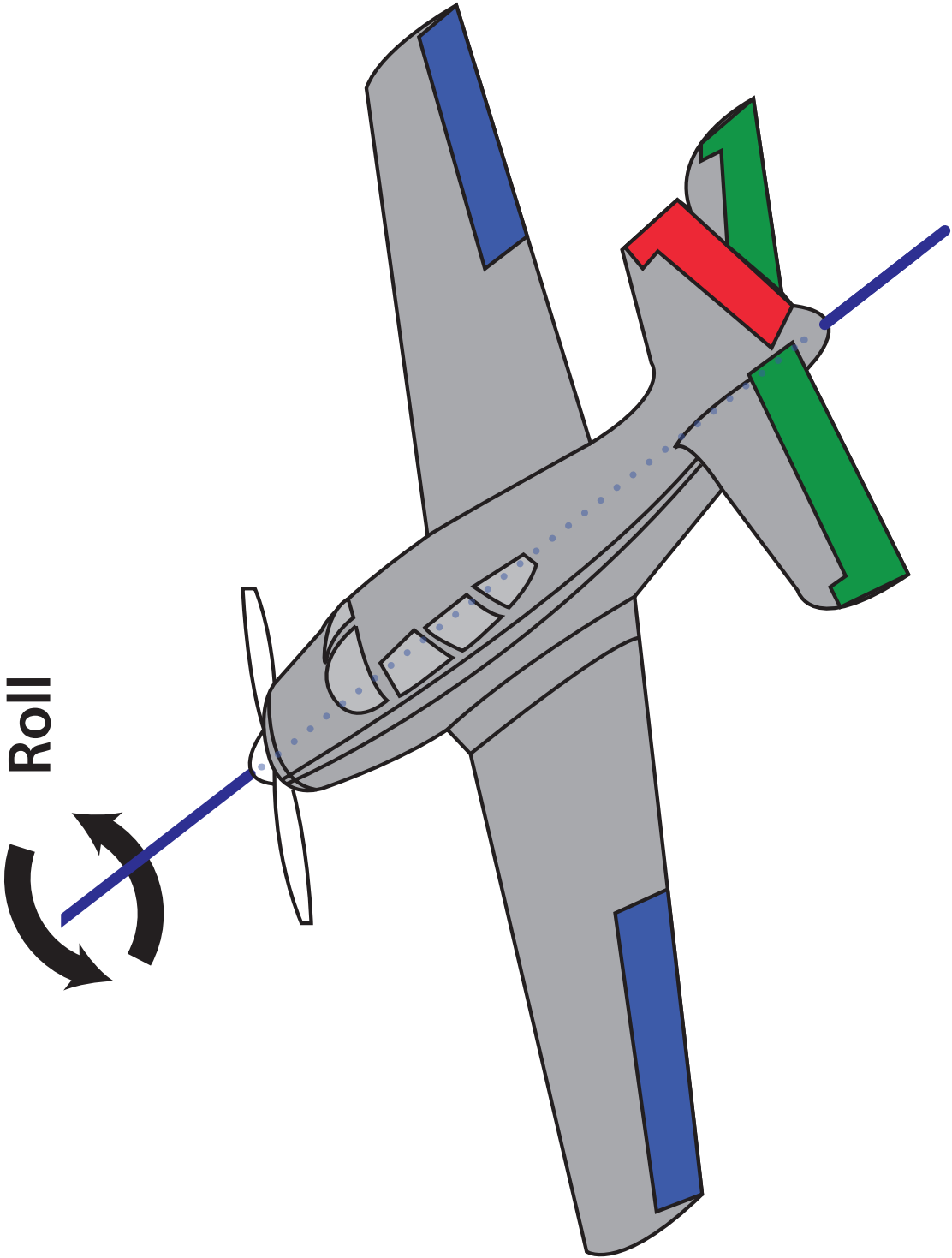
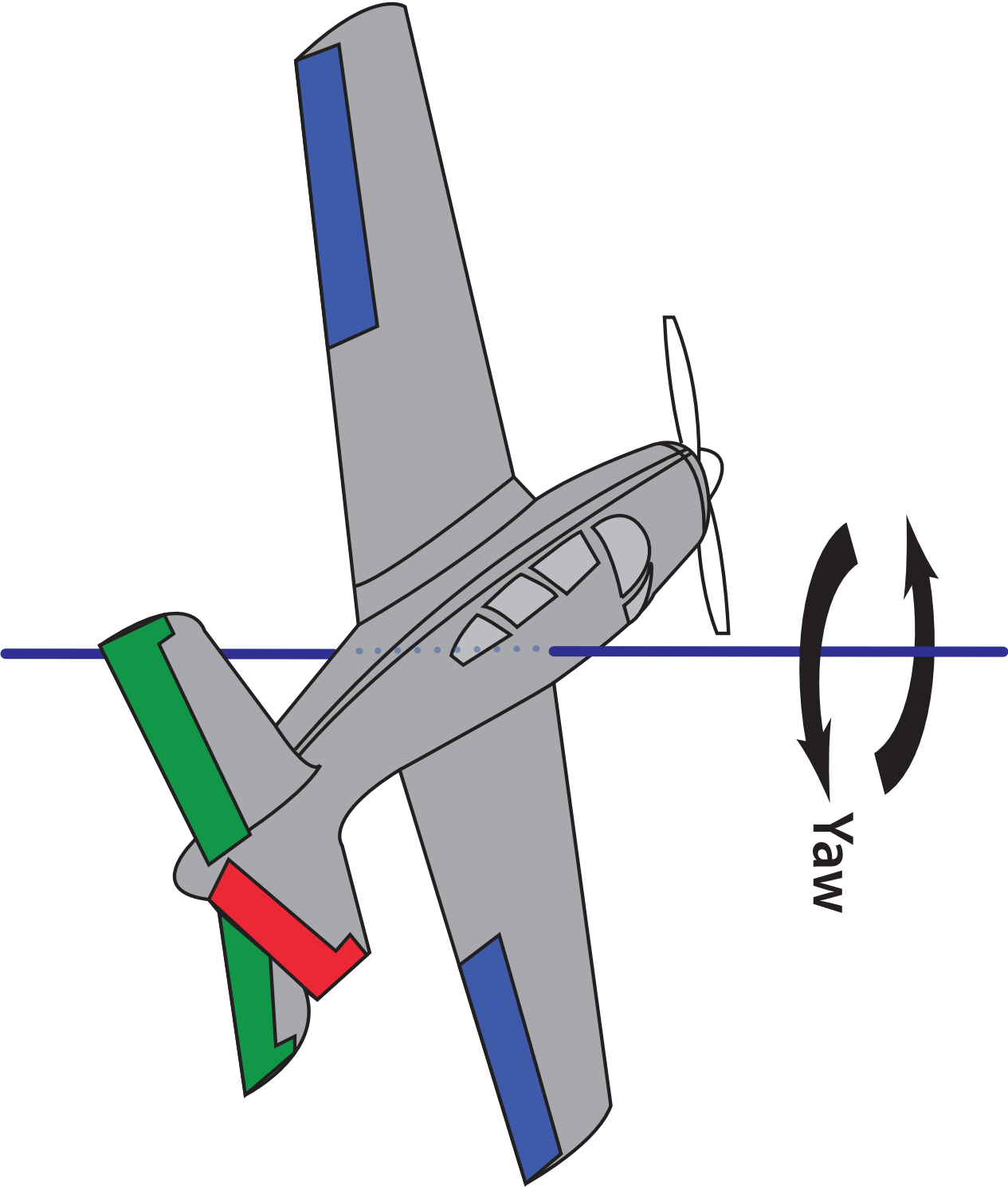


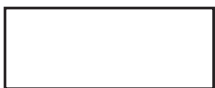
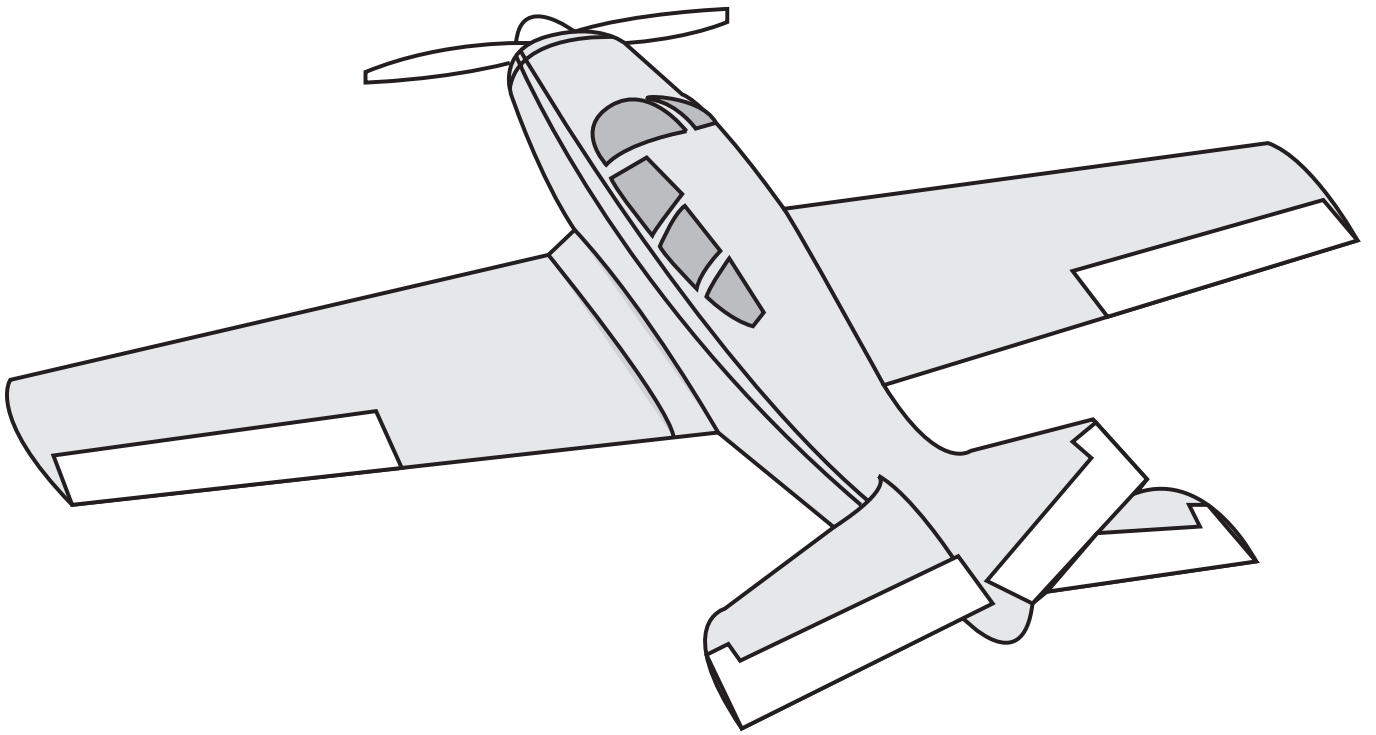
Fig. 9 The vertical axis





Worksheets

Color code each of the airplane's control surfaces.



Aileron

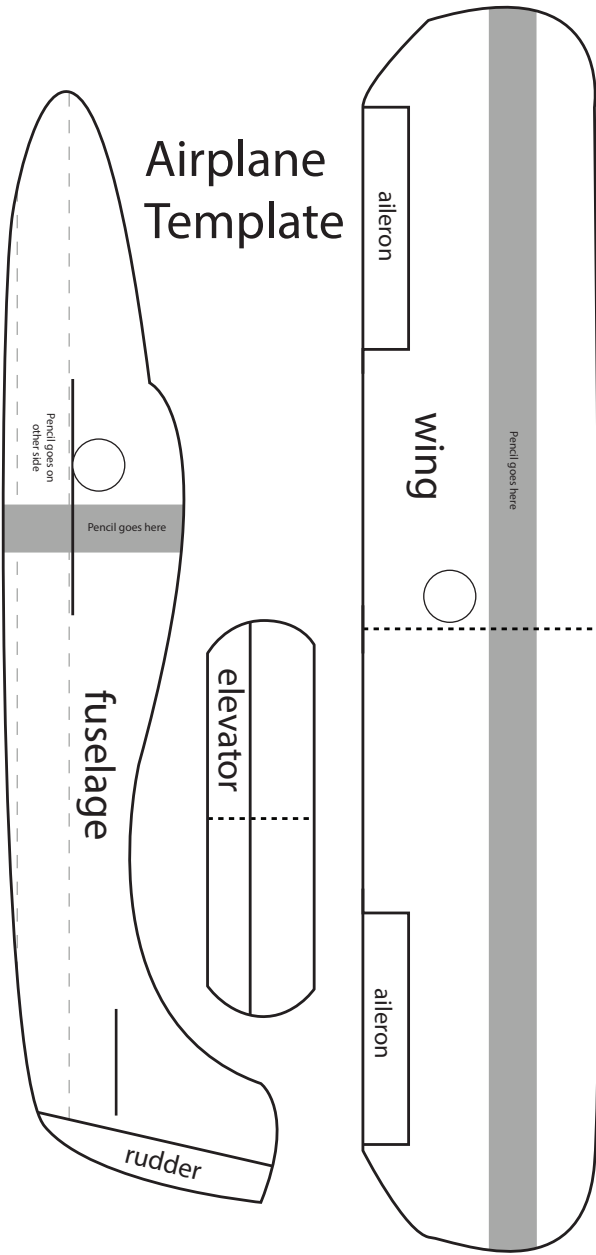


Rudder

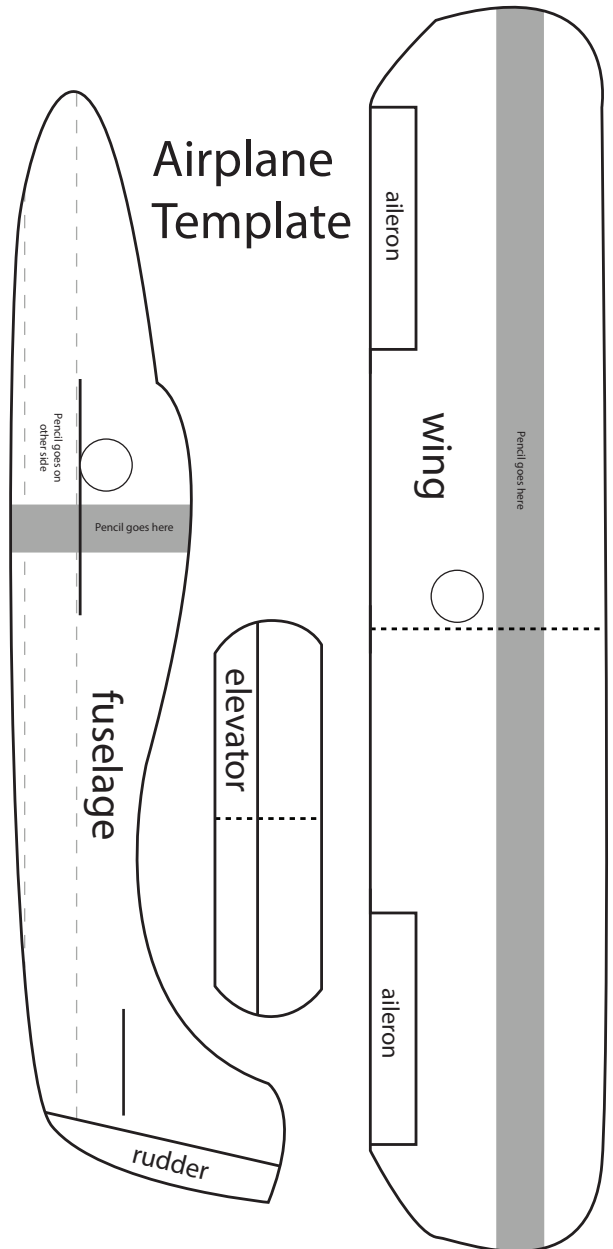


Elevator

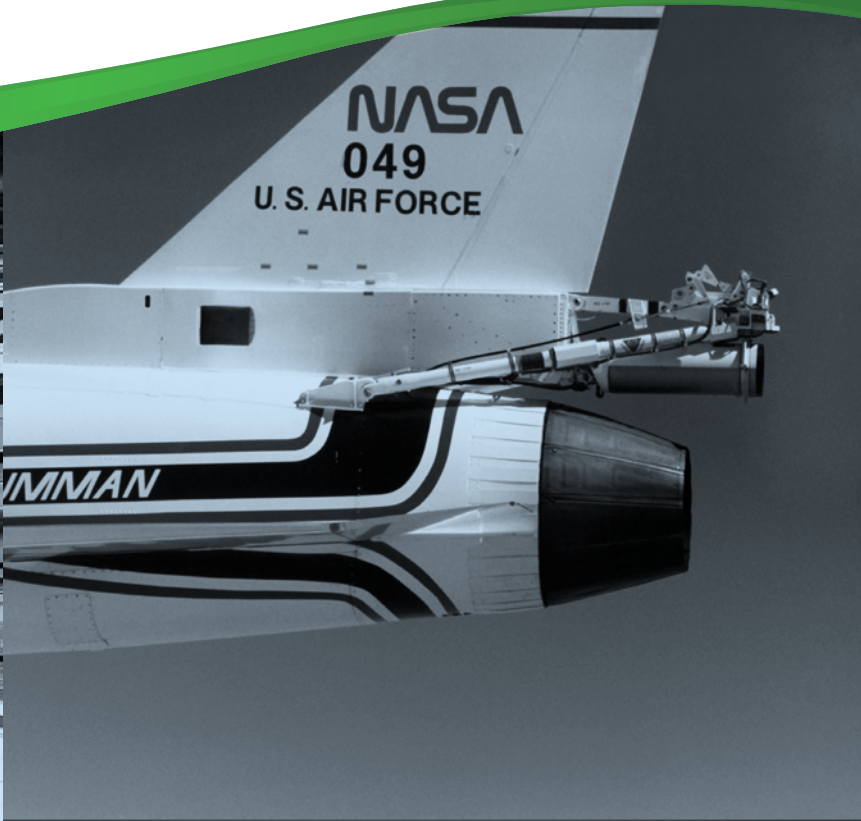
Airplane Template



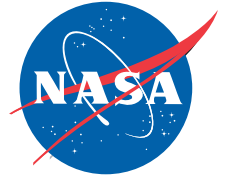
Airplane Template



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principles of flight



GRADES

5-8

Axes / Control Surfaces



principles of flight

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Axes / Control Surfaces

Lesson Overview

Through hands-on experiments and physical demonstrations, students will learn about motions and forces, transfer of energy, and the abilities of technological design as they study some of the basic concepts of flight, including the three axes of flight and the control surfaces that guide the aircraft.

Objectives

Students will:

1. Learn how to identify the various parts of the airplane and gain a basic understanding of their functions.
2. Gain an understanding of the three axes of flight.

Materials:

In the Box

None

Provided by User

Pencils (3 per student)

Tape

Scissors

GRADES

5-8

Time Requirements: 1 hour 20 minutes

Background

The mechanics of flight are highly complex, encompassing principles such as the four forces and axes, as well as technical terms such as control surfaces, adverse yaw and coordinated flight. While this lesson covers all of these topics, its purpose is to provide just a very basic insight into the true mechanics of flight and body-axis systems. Wind-axis systems, which refer to aircraft forces in relation to the direction of the aircraft's velocity, are not discussed here to avoid confusion. Also, some of the explanations given are highly simplified in order to allow educators to help students visualize the principle being discussed. For educators with an aviation background and capable students, modification of these activities and background information is encouraged.

The Forces of Flight

Every aircraft, whether an airplane, helicopter or rocket, is affected by four opposing forces: Thrust, Lift, Drag and Weight (Fig. 1). Control surfaces, such as the rudder or ailerons, adjust the direction of these forces, allowing the pilot to use them in the most advantageous way possible.

A force can be thought of as a push or pull in a specific direction. It is a vector quantity, which means a force has both a magnitude (amount) and a direction.

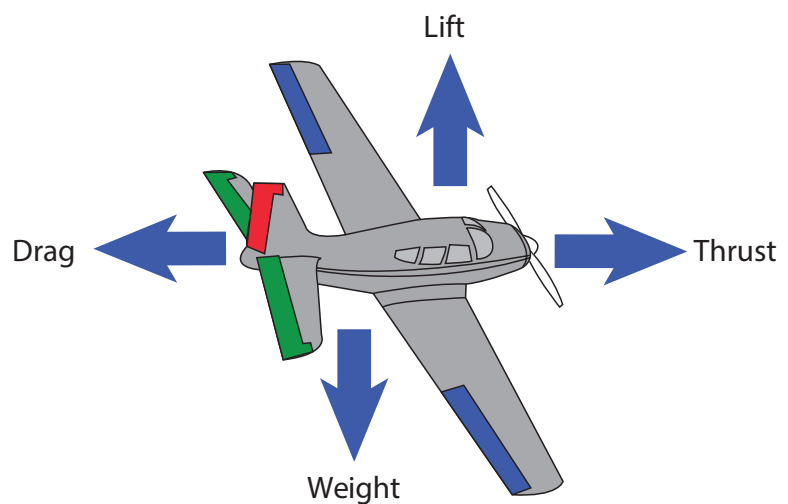


Fig. 1 Four forces of flight

For this lesson we will deal specifically with fixed-wing airplanes. Other aircraft, such as hot-air balloons and helicopters, use the same basic principles but the physics are very different.

Thrust

Thrust is produced by an aircraft's propulsion system or engine. The direction of the thrust dictates the direction in which the aircraft will move. For example, the engines on an airliner point backwards, which means that generally speaking, the airplane's thrust vector will point forwards.

Lift

Lift is generated by the motion of air passing over the aircraft's wings. The direction of lift is always perpendicular to the flight direction (Fig. 2) and its magnitude depends on several factors, including the shape, size and velocity of the aircraft.

Drag

Drag is simply resistance of the aircraft against the air. There are many types of drag, but each is a force opposing thrust.

Weight

Weight is a force that is always directed toward the center of the earth due to gravity. The magnitude of the weight is the sum of all the airplane parts, plus the fuel, people and cargo. While the weight is distributed throughout the entire airplane, its effect is on a single point called the center of gravity.

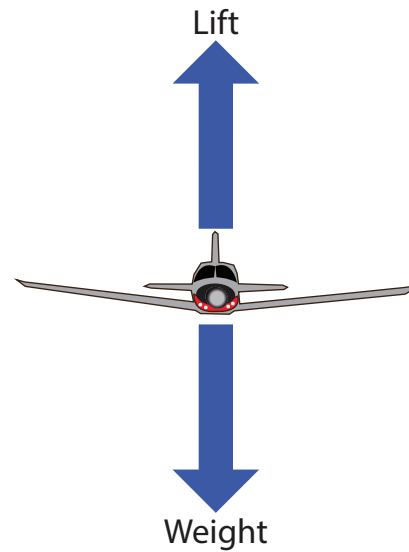


Fig. 2 The lift and weight forces of flight

Controlling the Motion of Flight

In order for an aircraft to reach its destination, the forces of flight have to be precisely manipulated. To do this, the aircraft has control surfaces (Fig. 3) which can direct airflow in very specific ways.

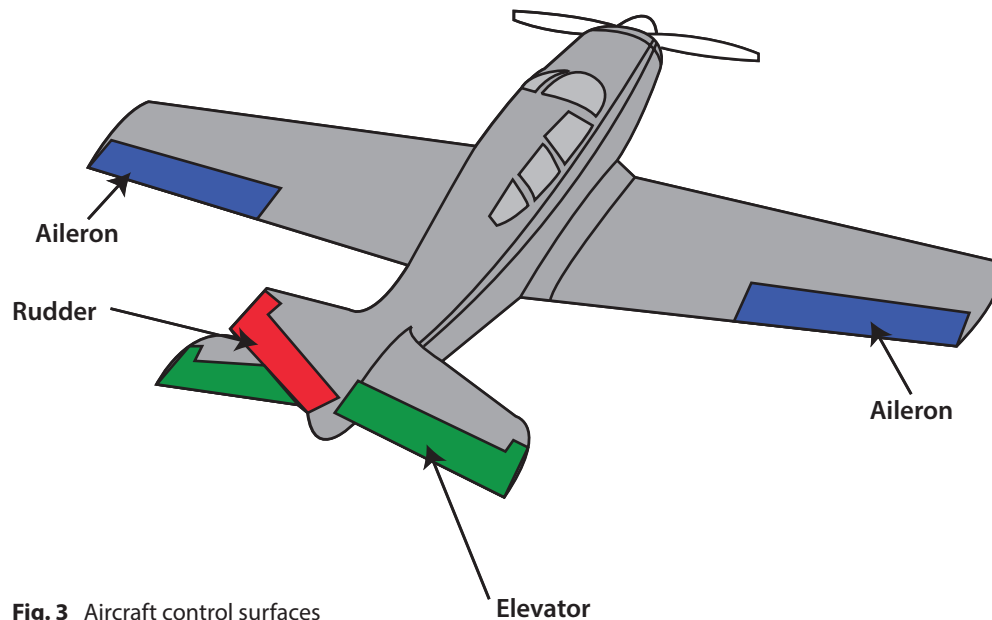


Fig. 3 Aircraft control surfaces

Elevator | Pitch

As the name implies, the elevator helps “elevate” the aircraft. It is usually located on the tail of the aircraft and serves two purposes. The first is to provide stability by producing a downward force on the tail. Airplanes are traditionally nose-heavy and this downward force is required to compensate for that. The second is to direct the nose of the aircraft either upwards or downwards, known as pitch, in order to make the airplane climb and descend. (Fig. 4).

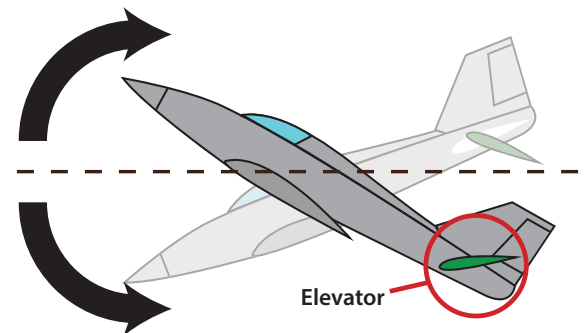


Fig. 4 Elevator and pitch movement

Ailerons | Roll

The ailerons are located at the rear of the wing, one on each side. They work opposite to each other, so when one is raised, the other is lowered. Their job is to increase the lift on one wing, while reducing the lift on the other. By doing this, they roll the aircraft sideways, which allows the aircraft to turn. This is the primary method of steering a fixed-wing aircraft (Fig. 5).

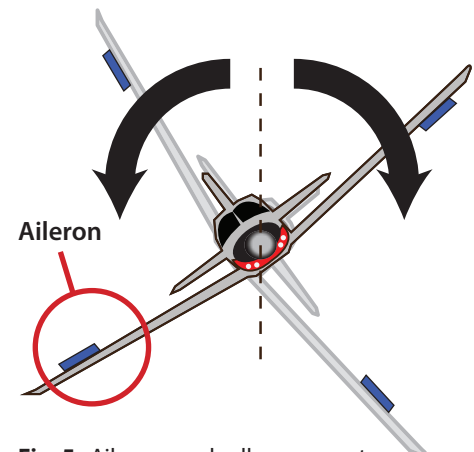


Fig. 5 Ailerons and roll movement

Rudder | Yaw

The rudder is located on the tail of the aircraft. It works identically to a rudder on a boat, steering the nose of the aircraft left and right. Unlike the boat however, it is not the primary method of steering. Its main purpose is to counteract the drag caused by the lowered aileron during a turn. This adverse yaw, as it is known, causes the nose of the airplane to point away, or outwards, from the direction of the turn. The rudder helps to correct this by pushing the nose in the correct direction, maintaining what is known as coordinated flight (Fig. 6).

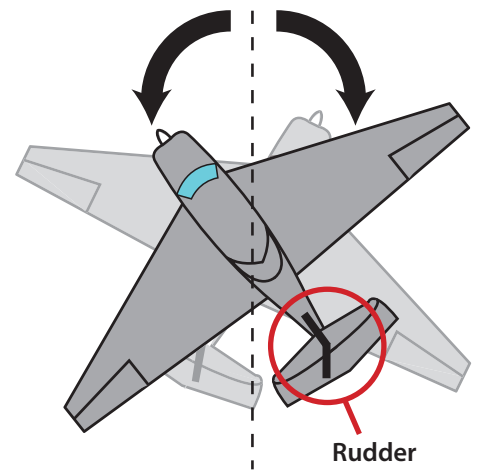


Fig. 6 Rudder and yaw movement

The Axes of Flight

Each axis of flight is an imaginary line around which an airplane can turn. Think of an airplane rotating around an axis like a wheel rotates around an axle.

Regardless of the type of aircraft, there are three axes upon which it can move: Left and Right, Forwards and Backwards, Up and Down. In aviation though, their technical names are the lateral axis, longitudinal axis and vertical axis.

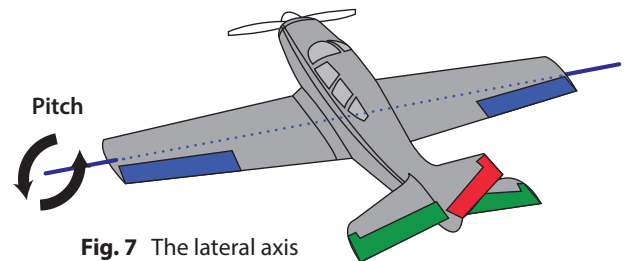


Fig. 7 The lateral axis

The Lateral Axis (Pitch)

The lateral axis runs from wing tip to wing tip. The aircraft pitches around this axis (Fig. 7).

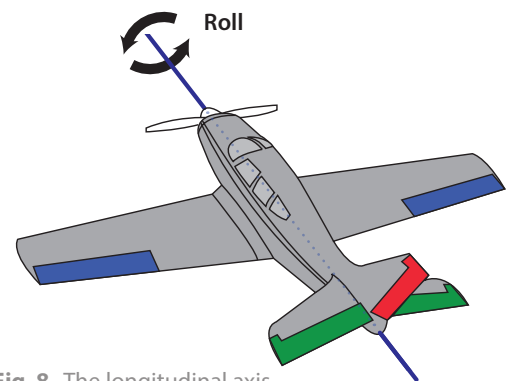


Fig. 8 The longitudinal axis

The Longitudinal Axis (Roll)

The longitudinal axis runs from the nose of the aircraft to the tail. This is the axis around which the aircraft rolls (Fig. 8).

The Vertical Axis (Yaw)

The vertical axis is slightly different to the others, running vertically through the center of the aircraft. The aircraft yaws around this axis (Fig. 9).

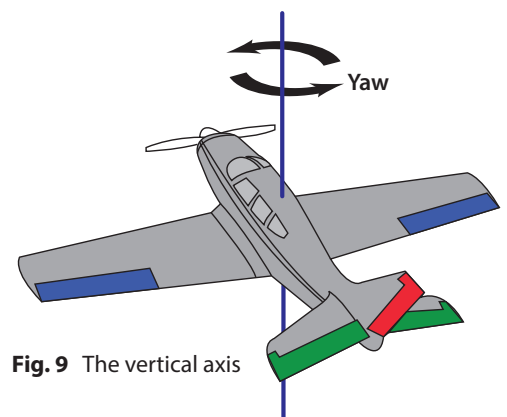


Fig. 9 The vertical axis

The Center of Gravity

The center of gravity, also known as CG, is the effective point whereby all weight is considered to be. The CG is also the same point where the axes of flight meet (Fig. 10). This point isn't fixed on any aircraft, but moves forwards or backwards along the longitudinal axis, depending on how the aircraft is loaded. It is vital that its center of gravity remain within certain limits however, as an aircraft that is too nose- or tail-heavy will either not fly, or be so difficult to control that it becomes too dangerous to try. These limits are referred to as its operational envelope.

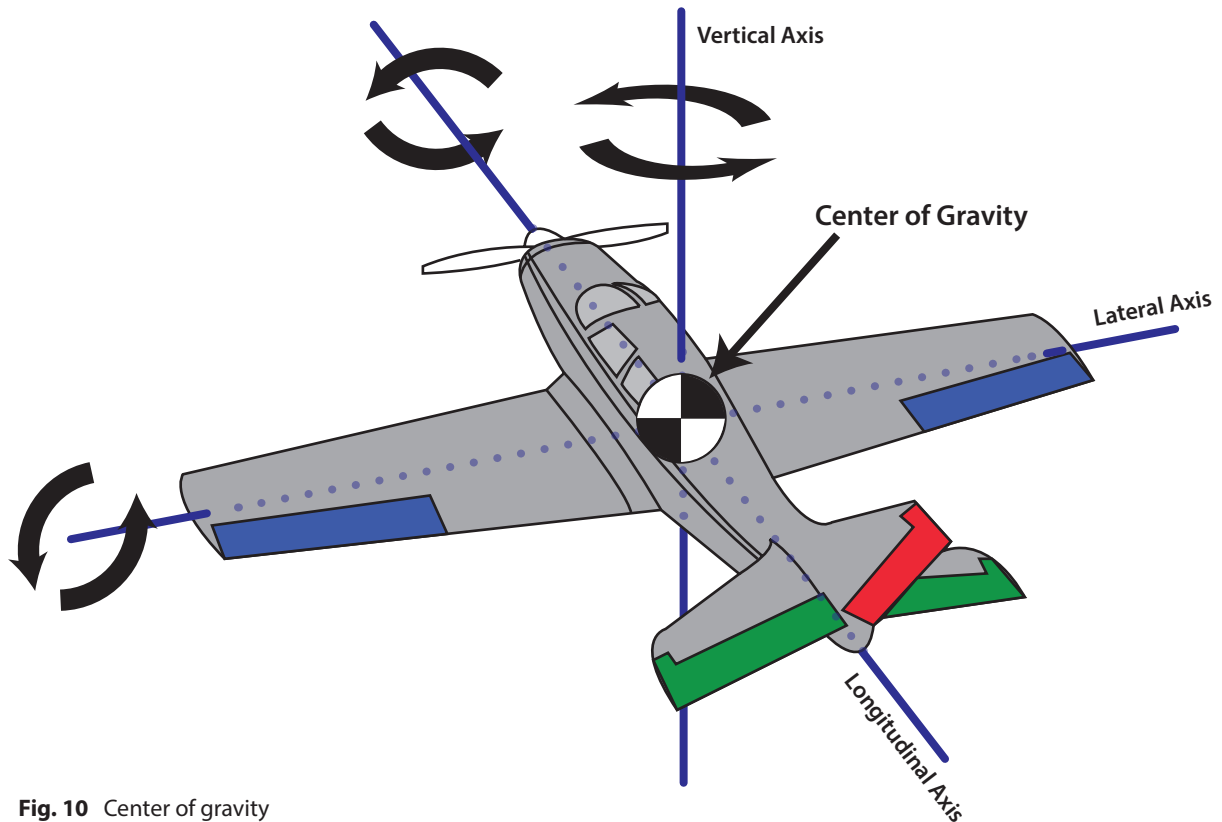


Fig. 10 Center of gravity

For additional information on aerodynamics and the principles of flight in general, please refer to the Museum in a Box lessons "Four Forces" and "Bernoulli Principle".

Activity 1

Parts of an Airplane

GRADES

5-8

Time Requirements: 20 minutes

Materials:

- In the Box
- None
- Provided by User
- None
- Worksheets
- Parts of an Airplane (Worksheet 1)
- Reference Materials
- None

Key Terms:

- Aileron
- Drag
- Elevator
- Force
- Lift
- Pitch
- Roll
- Rudder
- Thrust
- Weight
- Yaw

Objective:

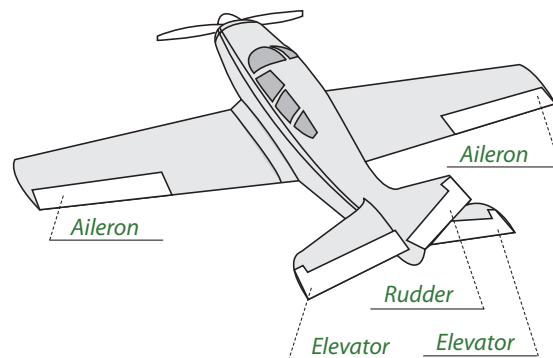
In this activity, students will learn the abilities of technological design as they identify the various parts of the airplane and gain a basic understanding of their functions.

Activity Overview:

Students will label the aircraft’s control surfaces, learning the purpose or function of each component in the process.

Activity:

1. Provide each student with a copy of the Parts of an Airplane worksheet.
2. Using the **Background** information, discuss each of the control surfaces with the students as a group.
3. Ask the students to label each of the control surfaces on their worksheets.
4. Have the students complete the first two columns of the table. The final column will be completed in the next activity.



	CONTROL SURFACE	MOVEMENT	AXIS
PITCH	<i>Elevator</i>	<i>Nose Up/Down</i>	<i>Lateral</i>
ROLL	<i>Aileron</i>	<i>Wings Up/Down</i>	<i>Longitudinal</i>
YAW	<i>Rudder</i>	<i>Nose Left/Right</i>	<i>Vertical</i>

Discussion Points:**1. Where are the ailerons?**

The ailerons are on the trailing, or rear, edge of the wings.

2. What is their purpose?

The ailerons are used to turn the airplane left and right.

3. Where is the rudder?

The rudder is at the back of the airplane, on the tail.

4. What is its purpose?

The rudder is used to keep the nose and tail of the airplane pointing in the same direction.

5. Where is the elevator?

The elevator is also on the tail of the airplane, below the rudder.

6. What is its purpose?

The elevator is used to turn and make the airplane climb and descend.

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Properties and changes of properties in matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

Activity 2

The Axes of Flight

GRADES 5-8**Time Requirements:** 60 minutes**Materials:**In the Box

None

Provided by UserPencils
(3 per student)

Tape

Scissors

WorksheetsAirplane Template
(Worksheet 2)Reference Materials

None

Key Terms:

Center of Gravity (CG)

Lateral axis

Longitudinal axis

Pitch

Roll

Vertical axis

Yaw

Objective:

In this activity, students will gain an understanding of motions, forces, and energy transfer by studying the three axes of flight.

Activity Overview:

Students will build a model airplane and use pencils to demonstrate how the aircraft moves around each axis.

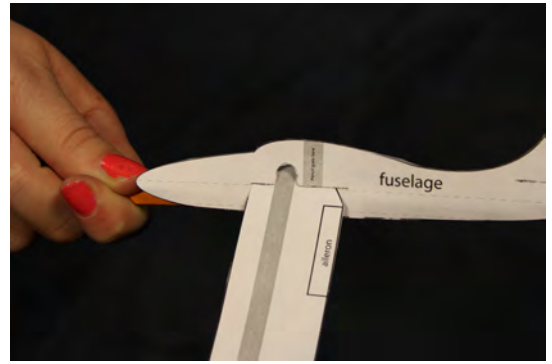
Activity:

1. It is recommended that **Activity 1** be completed before starting this activity.
2. Using the **Background** information, begin by discussing the three axes of flight with the students.
3. Provide each student with a copy of the worksheet, a pair of scissors and 3 pencils. Have the students perform each of the following steps, demonstrating as you go.
If available, printing the worksheet on heavy cardstock will greatly improve the quality of the final product.

4. **Cut out each of the airplane components.** Make holes in the center of the wing and fuselage where directed on the diagram.
5. **Tape one pencil to the fuselage as marked on the diagram.**



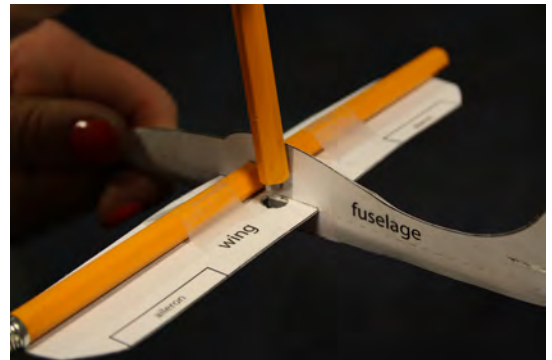
6. Slide the wing through the slot in the fuselage.



7. Insert a pencil through the hole in the fuselage and tape it to the wing.



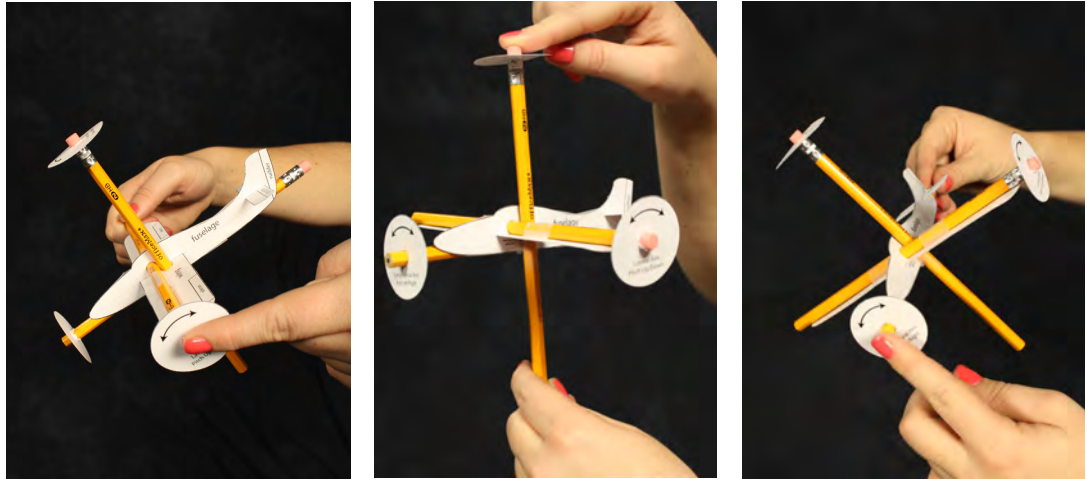
8. Insert the third pencil through the hole made in the left wing, again taping it to the fuselage.



9. Slide the elevator into the slot in the tail and tape it in place on either side.



10. Demonstrate to the students how the airplane rotates around each axis by twisting the pencils. Have the students mark each axis, using the labels provided.



11. Have the students complete the table from **Activity 1**.

	CONTROL SURFACE	MOVEMENT	AXIS
PITCH	<i>Elevator</i>	<i>Nose Up/Down</i>	<i>Lateral</i>
ROLL	<i>Aileron</i>	<i>Wings Up/Down</i>	<i>Longitudinal</i>
YAW	<i>Rudder</i>	<i>Nose Left/Right</i>	<i>Vertical</i>

Discussion Points:**1. With regard to an airplane, what is pitch?**

Pitch is a rotation around the lateral axis of the aircraft. An aircraft pitches its nose up and down to climb and descend.

2. What is roll?

Roll is a rotation around the longitudinal axis of the aircraft. An aircraft rolls its wings side-to-side to make turns.

3. What is yaw?

Yaw is a rotation around the vertical axis of the aircraft. An aircraft yaws its nose left and right to maintain coordinated flight.

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Properties and changes of properties in matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology



Reference Materials

Glossary

Adverse yaw:

The drag caused by the lowered aileron during a turn, causing the nose of the airplane to point away, or outwards, from the direction of the turn

Aileron:

The part of the airplane, located at the rear of the wing, that increases the lift on one wing while reducing the lift on the other in order to roll the aircraft sideways and allow it to turn

Axis:

An imaginary line around which an airplane can turn

Body-Axis System:

A system whereby the forces acting upon an aircraft are measured from the center of gravity, used when defining the pitch, roll and yaw axes

Center of gravity (CG):

The effective point whereby all weight is considered to be; the same point where the axes of flight meet

Control surface:

Any part of an aircraft which can be moved to direct airflow, enabling the aircraft to roll, pitch and yaw

Coordinated flight:

Flight during which the plane's ailerons and rudder work together to keep the nose and tail traveling in the same direction

Drag:

The resistance of air against an aircraft's forward motion

Elevator:

The control surface usually located on the tail of an aircraft, used to stabilize the plane and enable pitch adjustments

Fuselage:

The body of an aircraft

Lateral axis:

The imaginary line, from wingtip to wingtip, about which an airplane pitches

Lift:

The force generated primarily by the motion of air passing over an aircraft's wings

Longitudinal axis:

The imaginary line, from nose to tail, about which an airplane rolls

Operational envelope:

A range in which the aircraft's center of gravity must be located in order to fly

Pitch:

The motion of an aircraft about the lateral axis, resulting in the nose and tail moving upwards and downwards

Roll:

The motion of an aircraft about the longitudinal axis, resulting in one wing rising while the other lowers (the plane rolls side-to-side)

Rudder:

An airplane's control surface, located on the tail, which helps to steer the aircraft as well as maintain coordinated flight

Thrust:

The force generated by the aircraft's propulsion system

Vertical axis:

The imaginary line that runs vertically (perpendicular to the longitudinal and lateral axes) through an aircraft's center of gravity, about which the plane yaws

Weight:

The force due to gravity which acts upon every object on Earth

Wind-Axis System:

Similar to the Body-Axis System, the wind-axis system describes aircraft movement in relation to the direction of flight and wind flow

Yaw:

The motion of an aircraft about the vertical axis, resulting in the plane moving horizontally left and right

Fig. 1 Four forces of flight

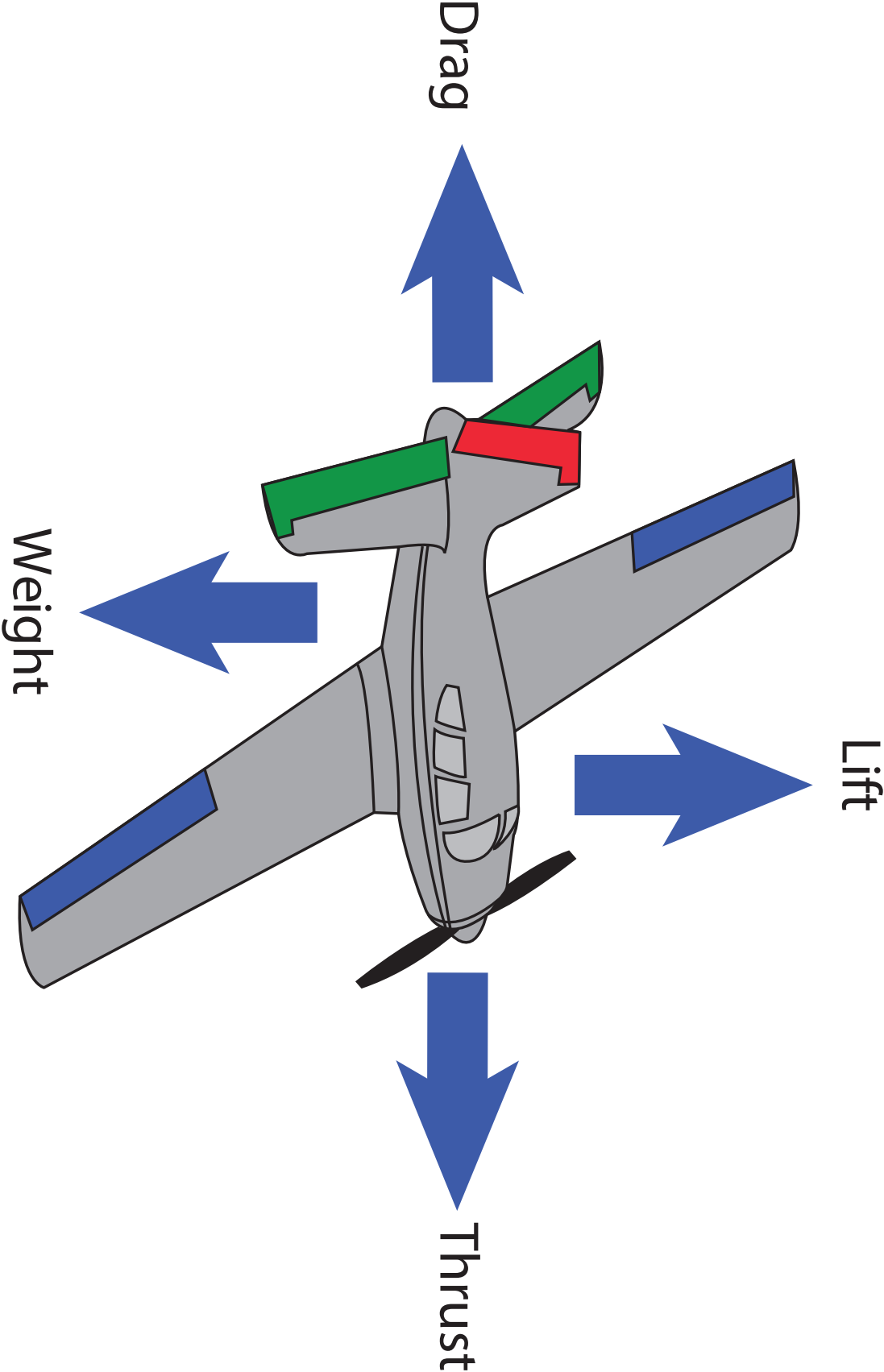


Fig. 2 The lift and weight forces of flight

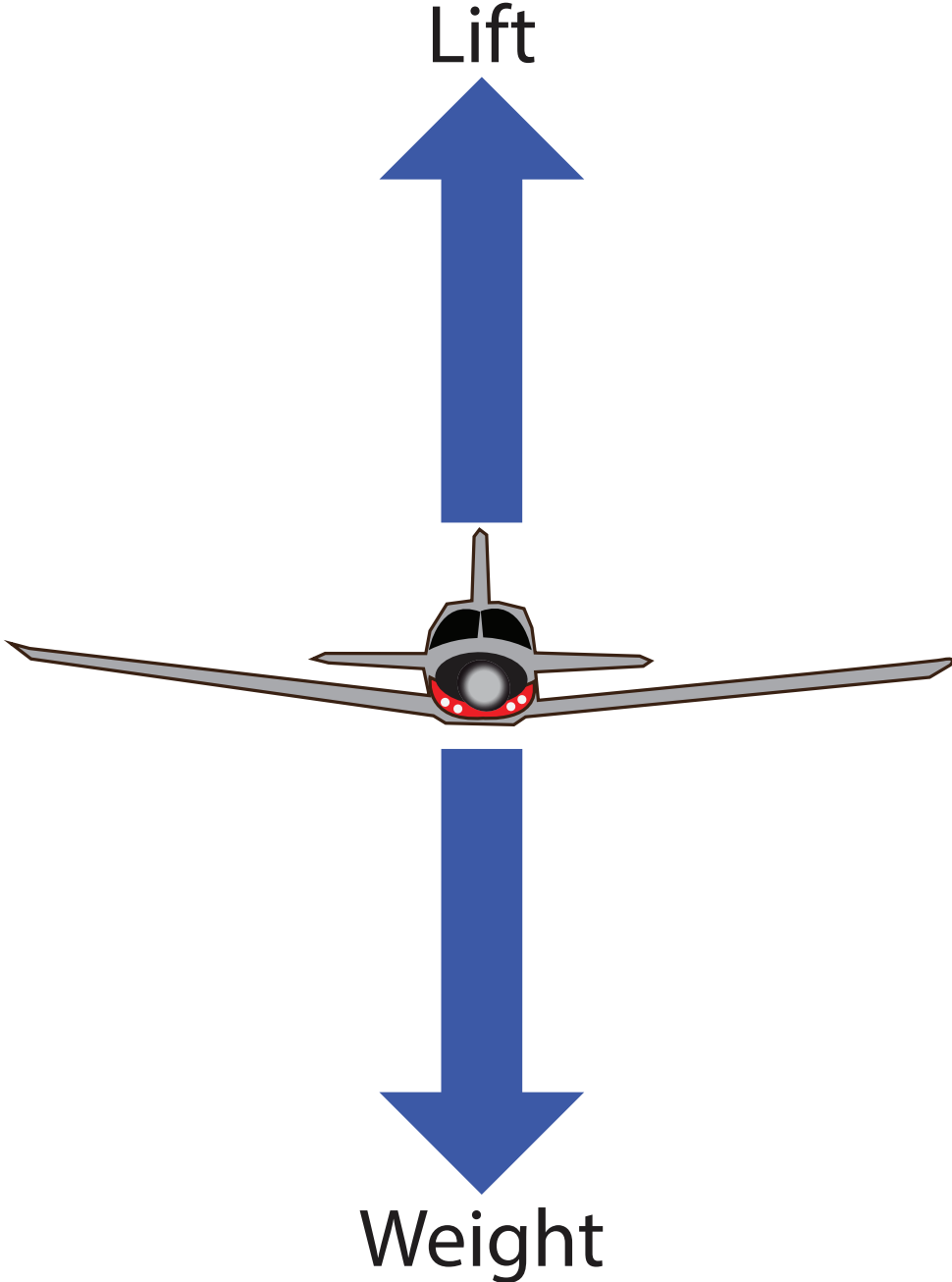


Fig. 3 Aircraft control surfaces

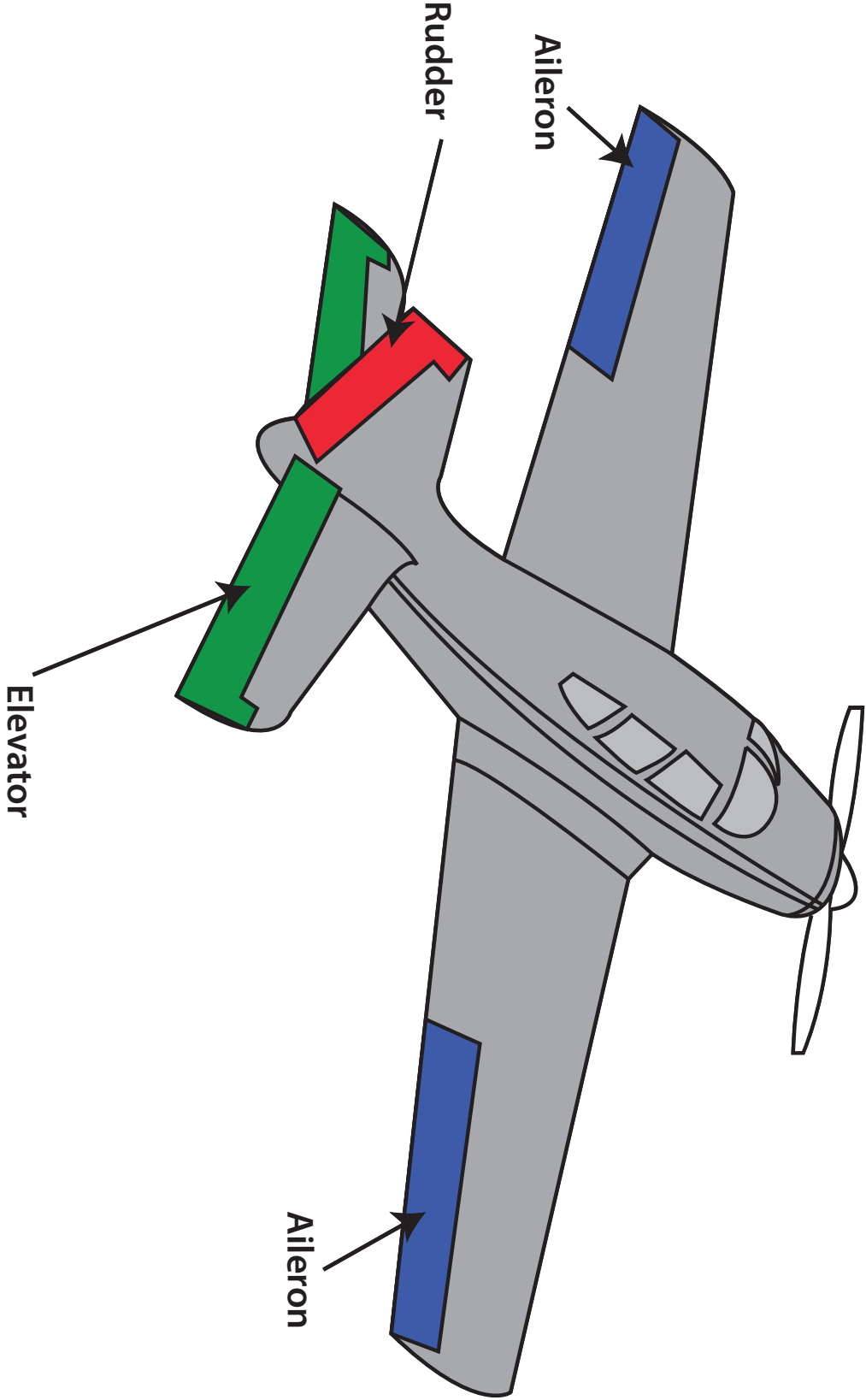


Fig. 4 Elevator and pitch movement

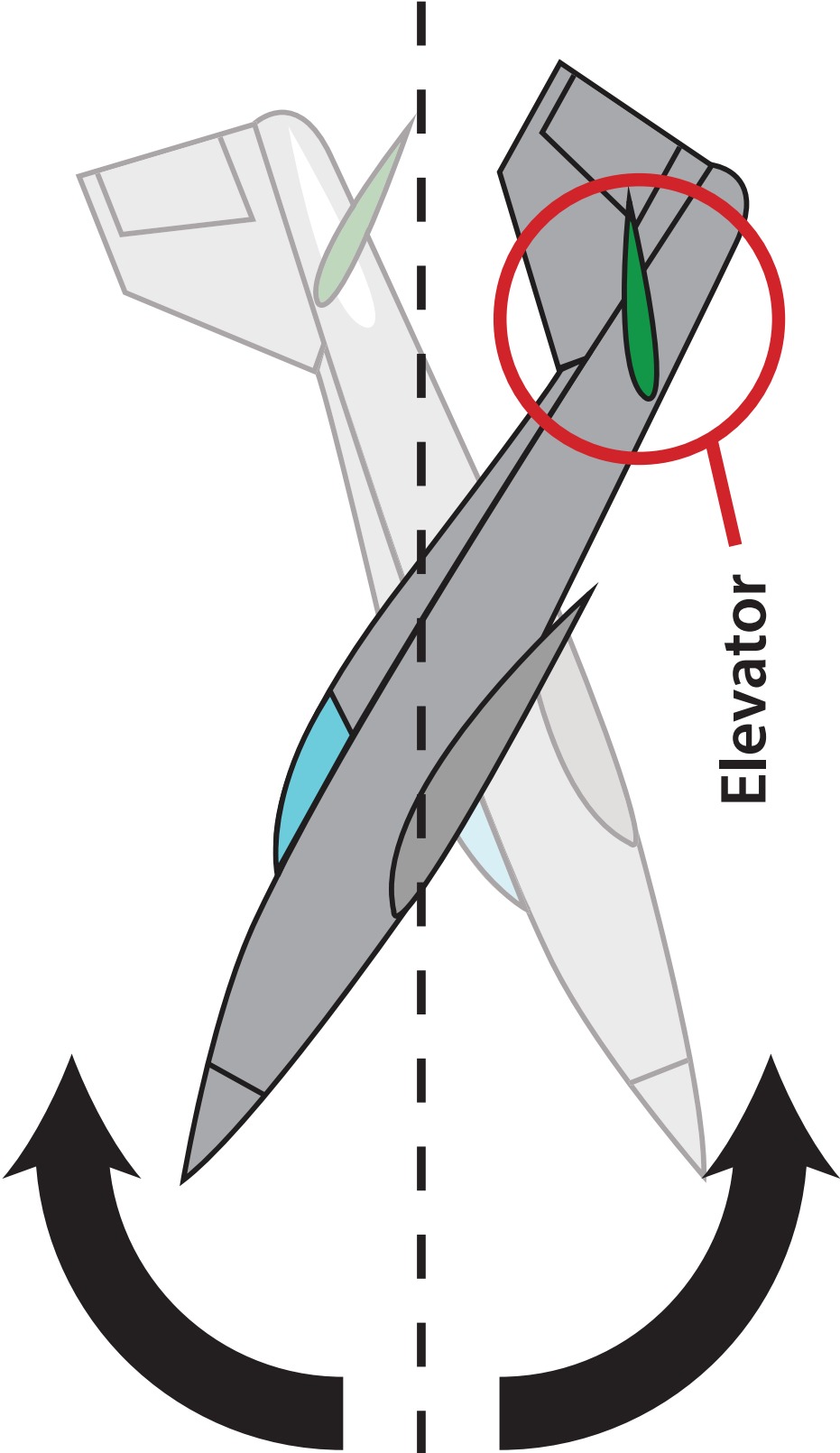


Fig. 5 Ailerons and roll movement

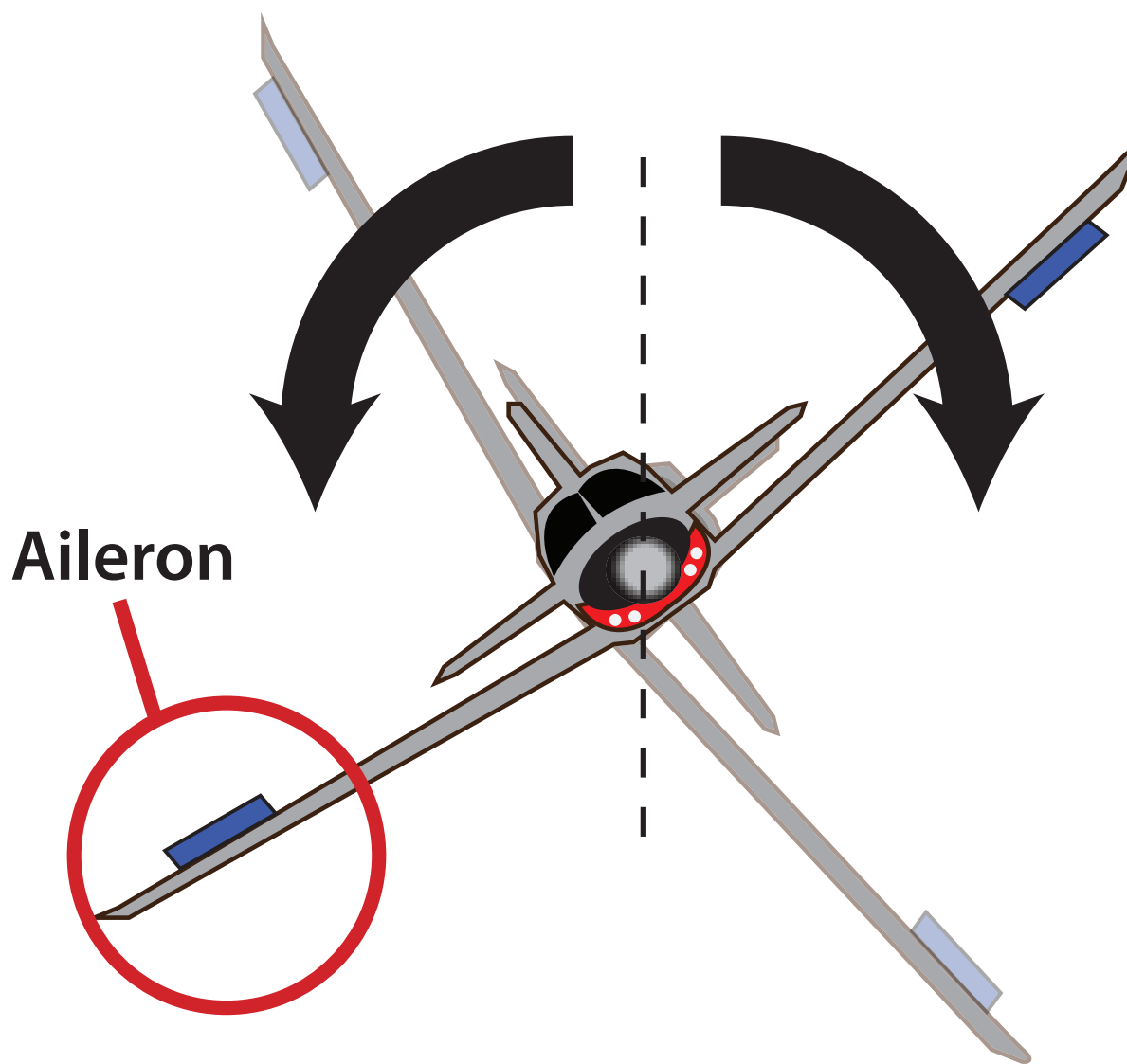


Fig. 6 Rudder and yaw movement

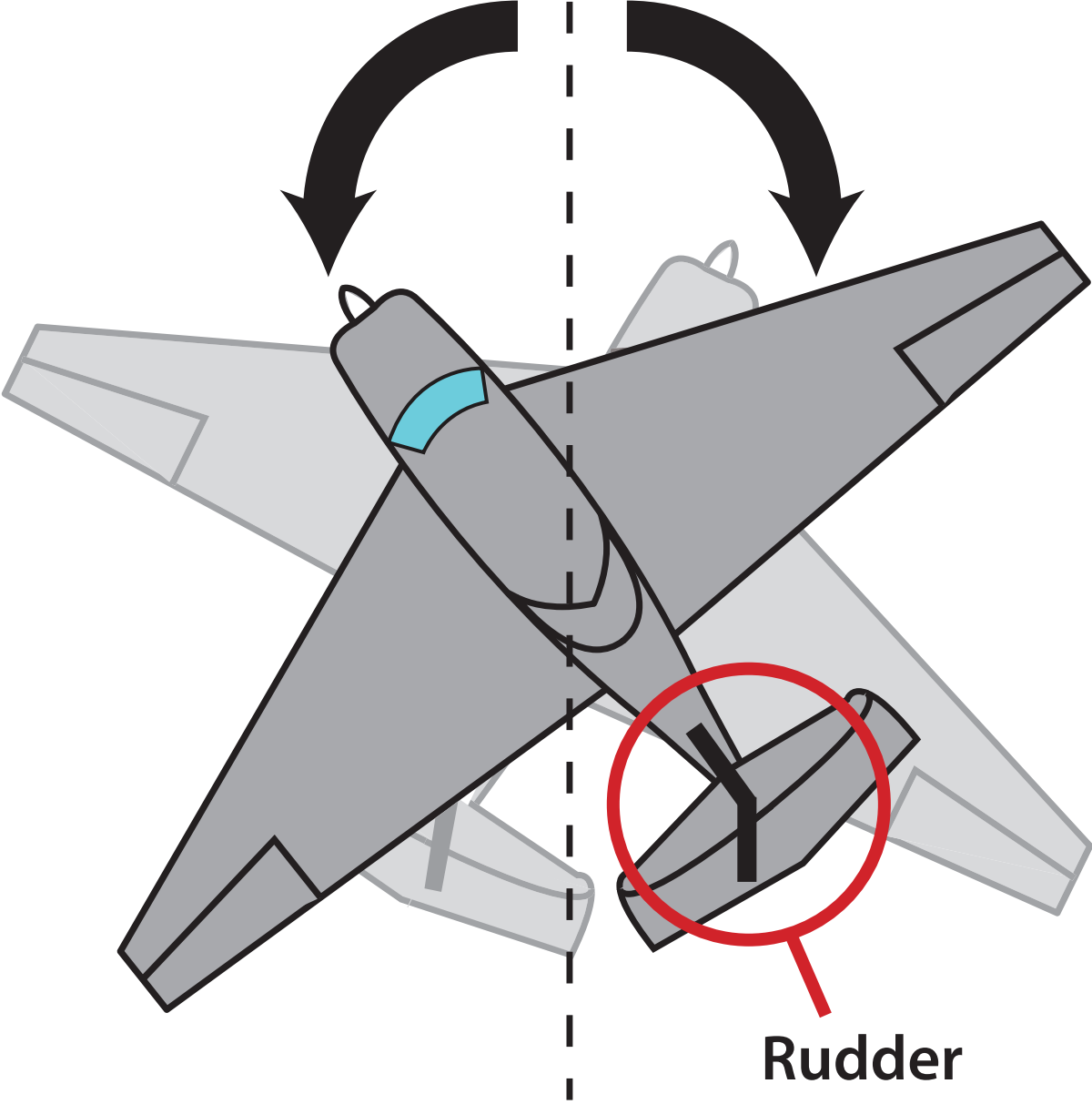


Fig. 7 The lateral axis

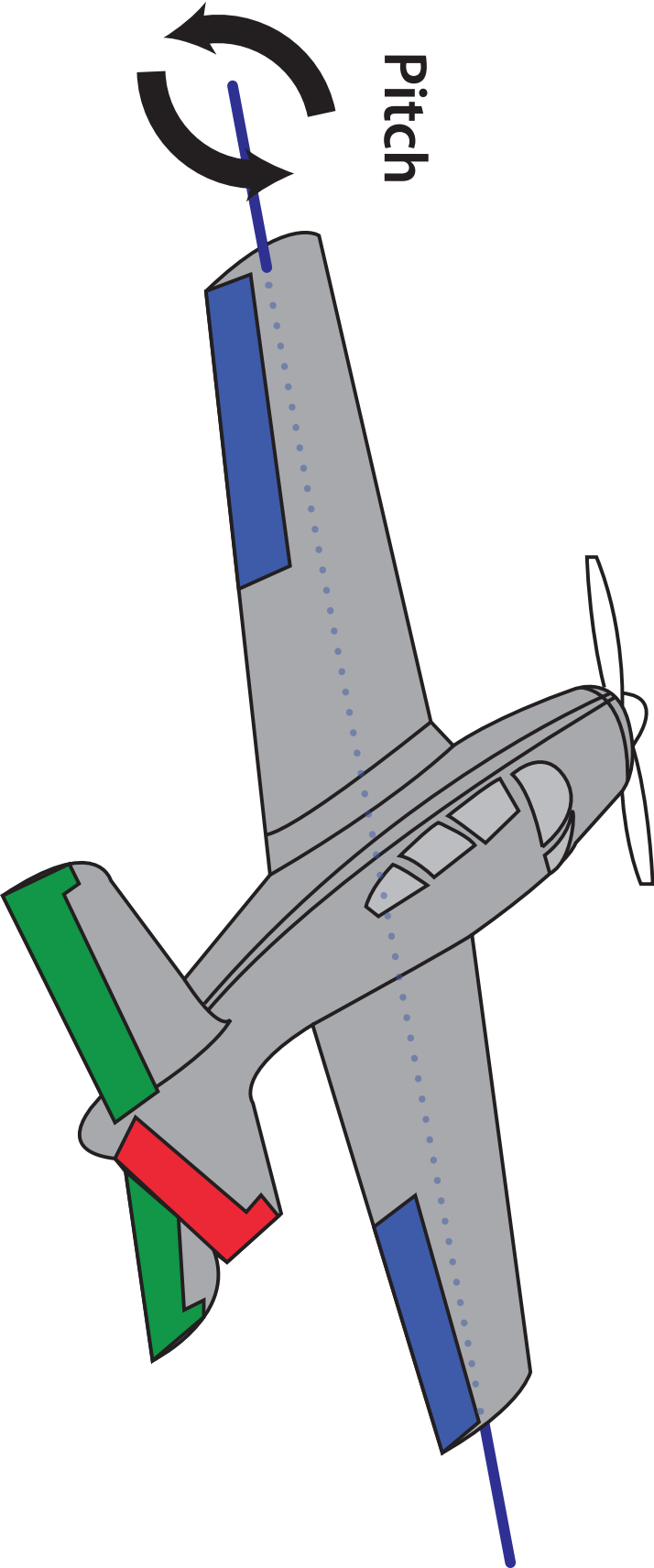


Fig. 8 The longitudinal axis

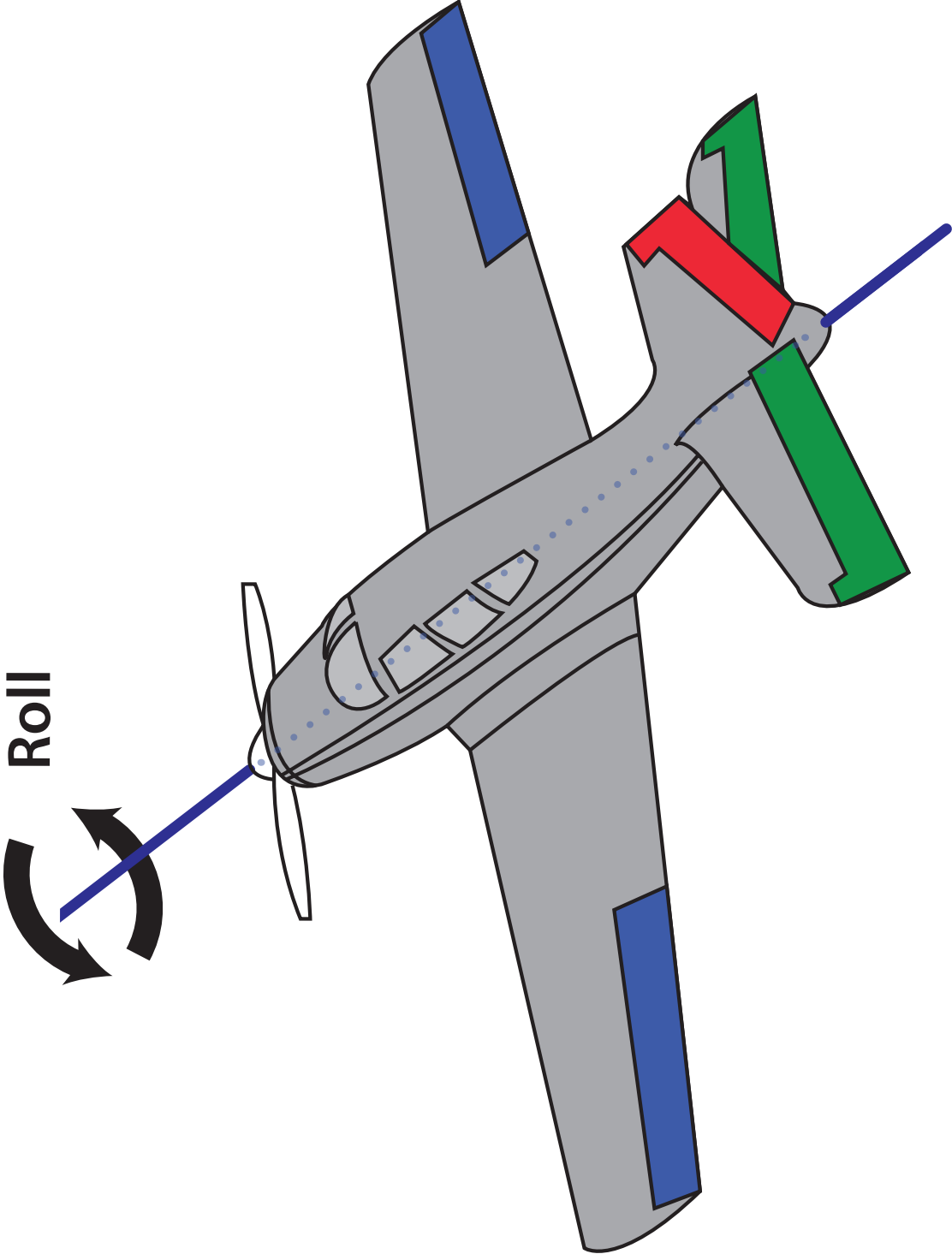


Fig. 9 The vertical axis

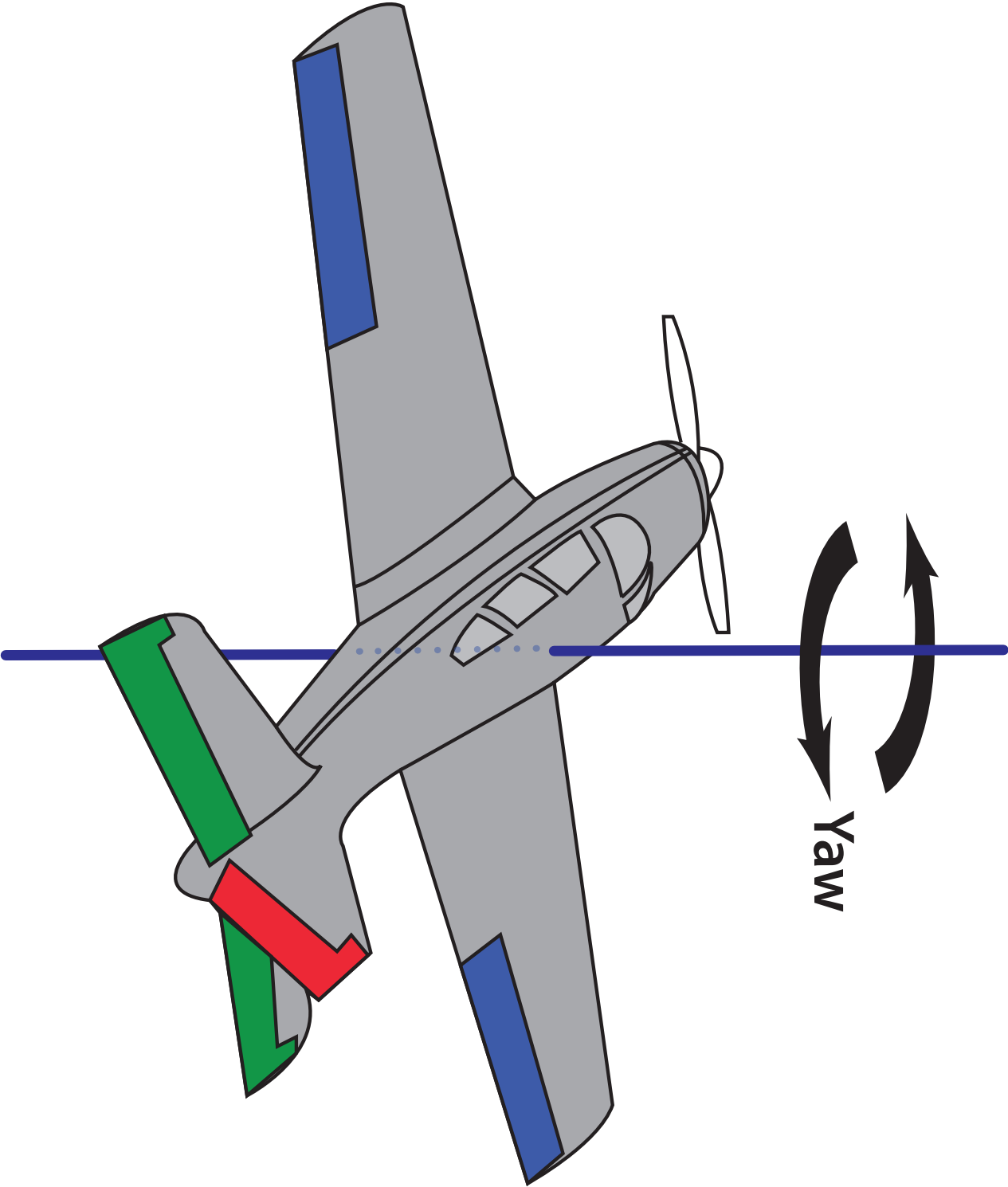
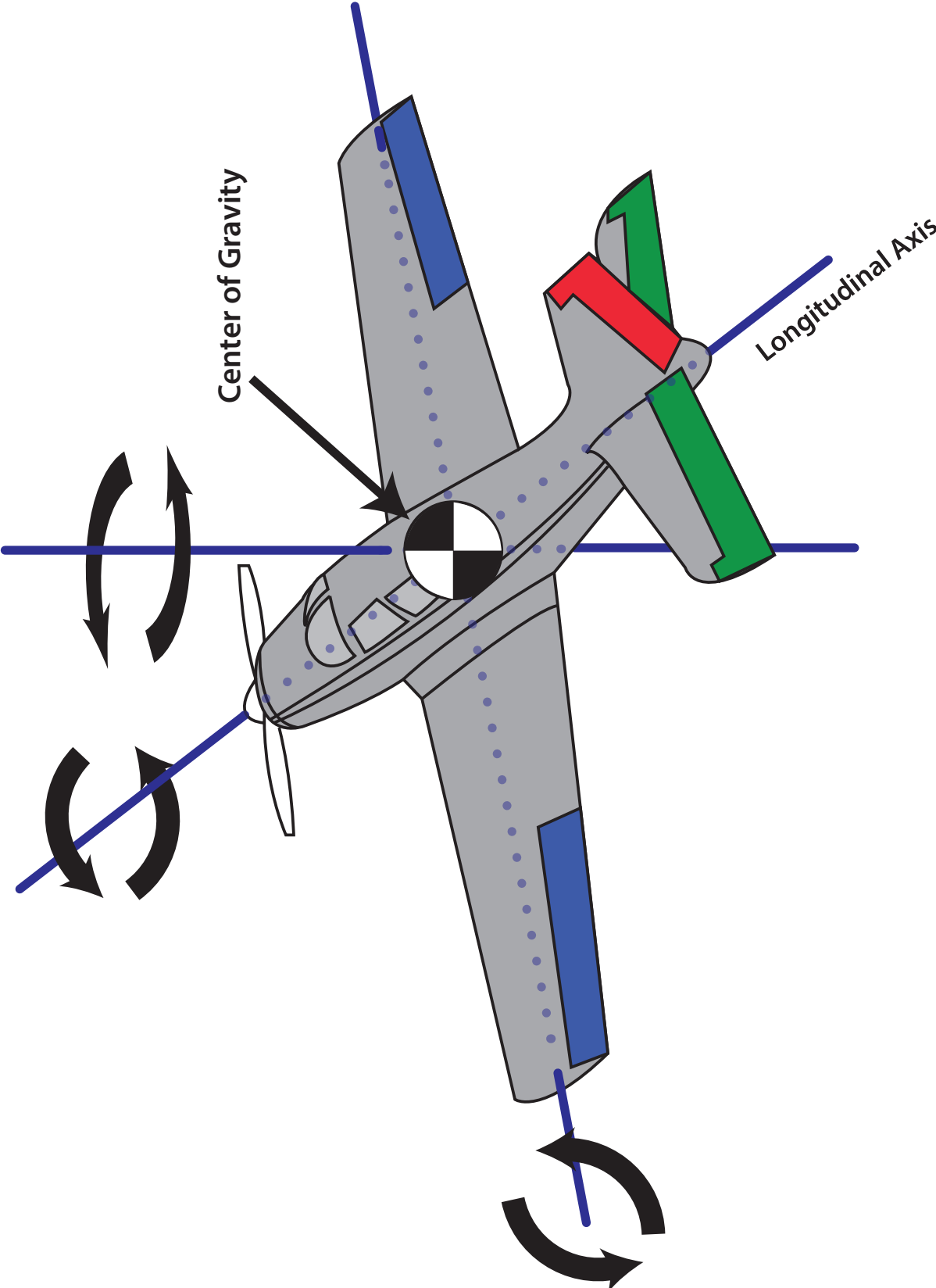


Fig. 10 Center of gravity



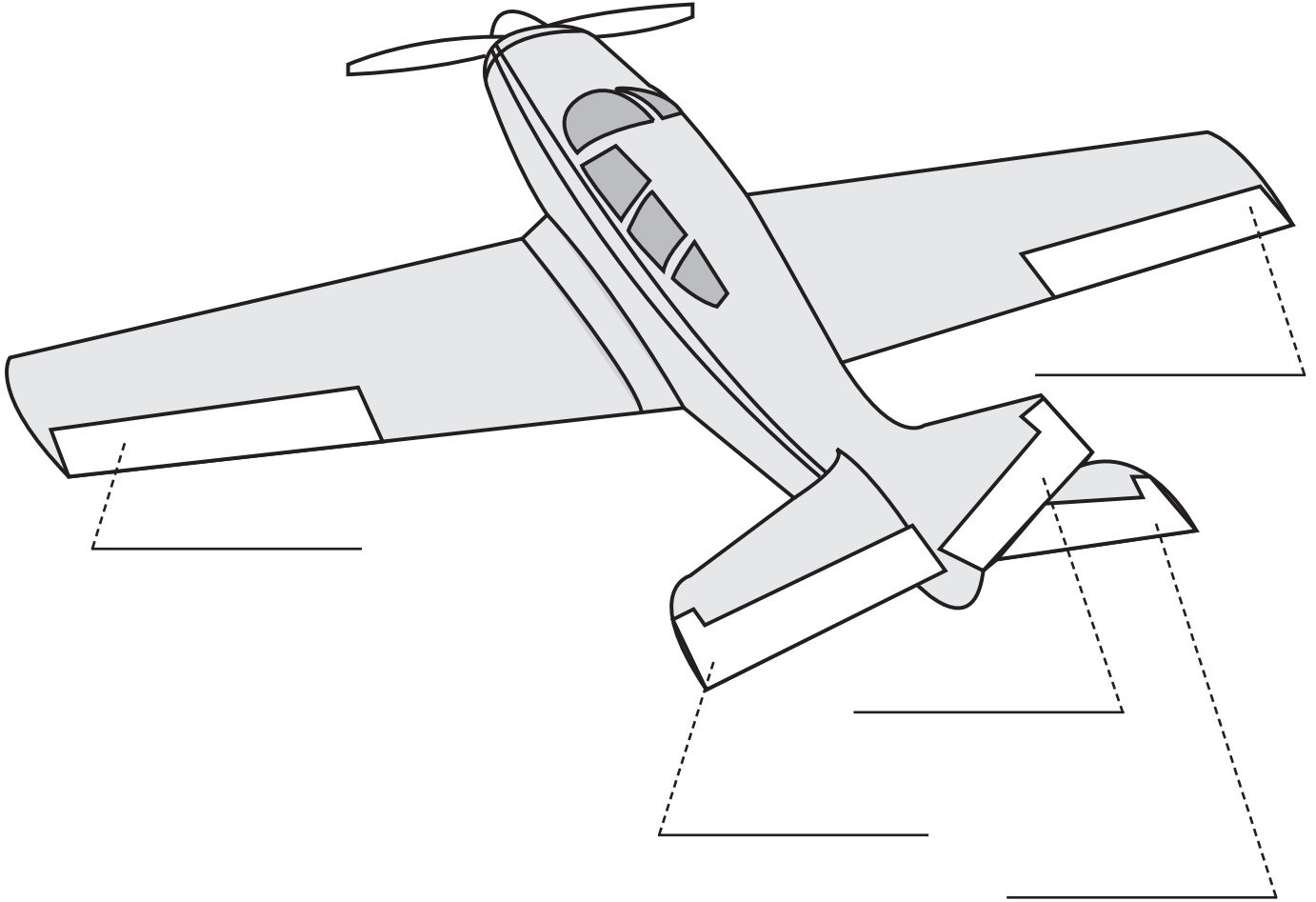


Worksheets

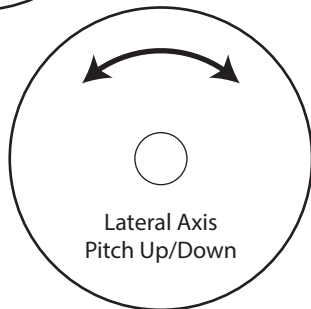
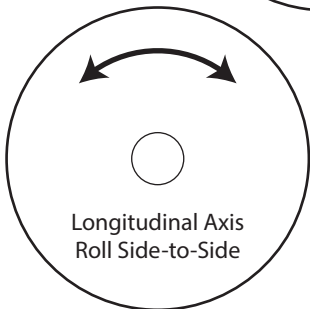
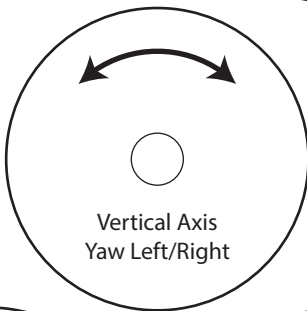
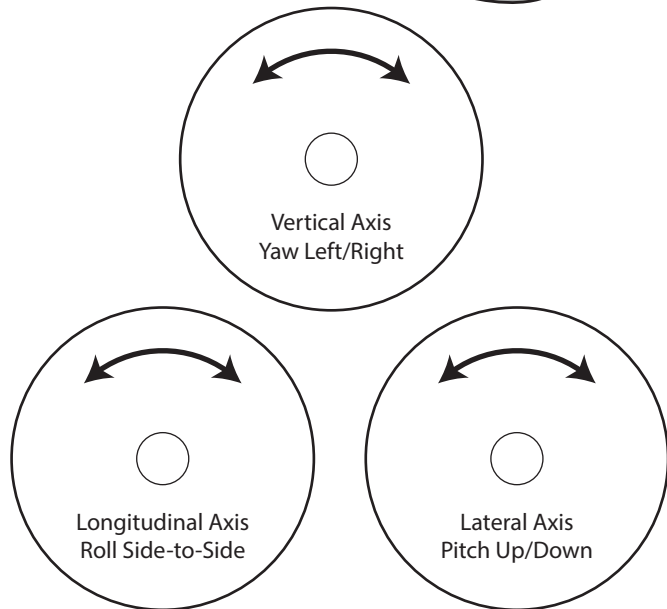
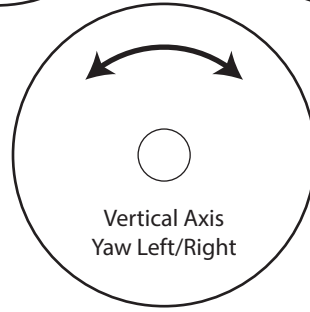
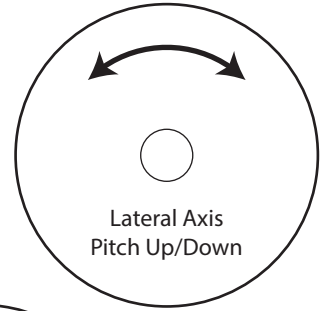
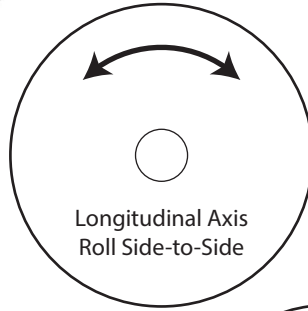
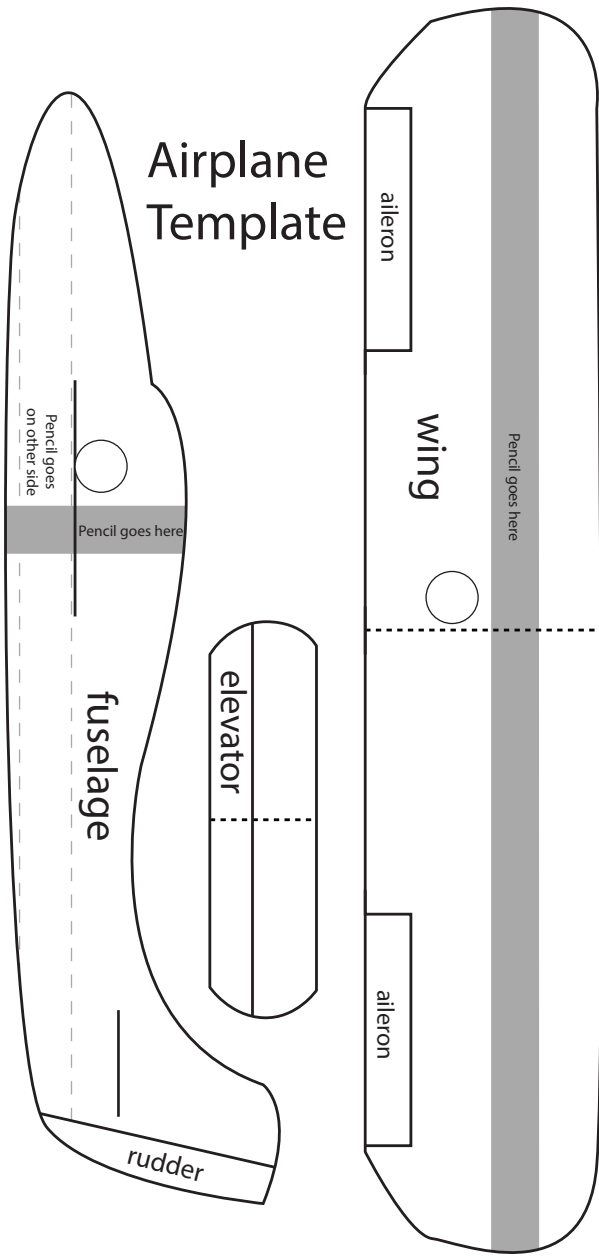
Worksheet 1

Parts of an Airplane

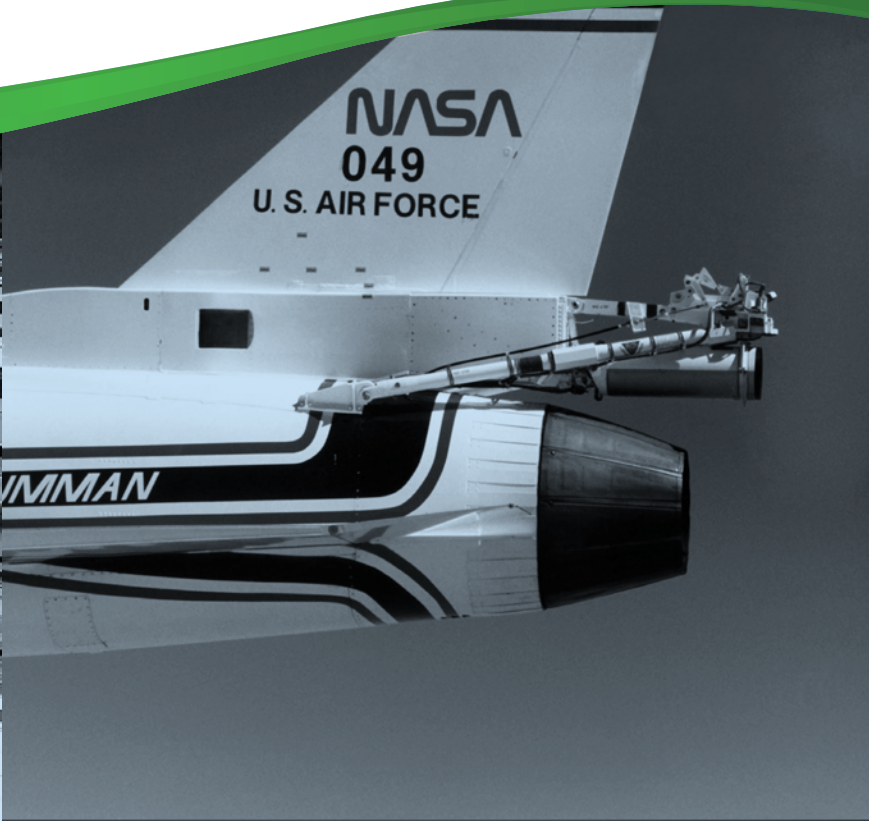
Label each of the airplane's control surfaces.



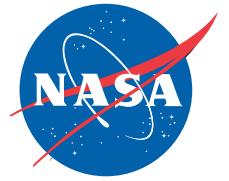
	CONTROL SURFACE	MOVEMENT	AXIS
PITCH			
ROLL			
YAW			



Aeronautics
Research
Mission
Directorate



principles of flight



GRADES

K-4

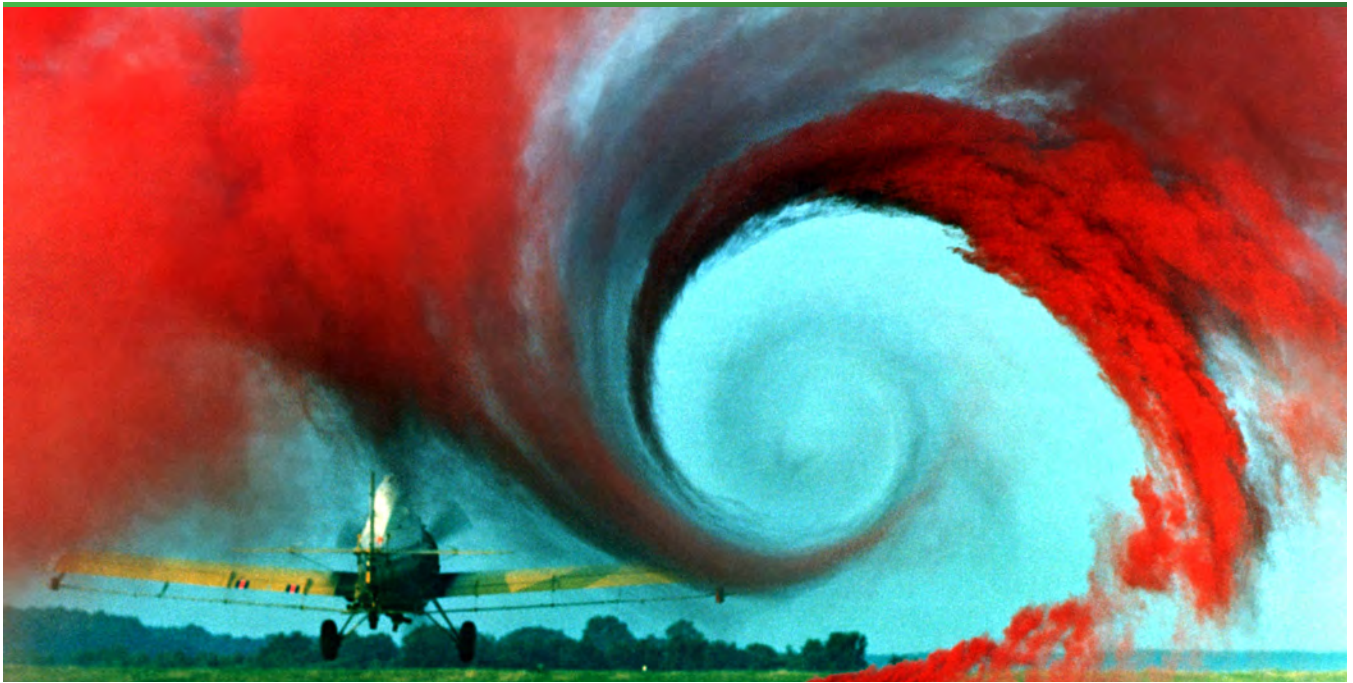
Four Forces



principles of flight

Aeronautics
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Four Forces

Lesson Overview

Through physical experimentation, students will learn about the position and motion of objects and the properties of objects and materials as they explore the basics behind the four forces of flight. Students will be divided into four groups and witness the effects of gravity on a tennis ball, the thrust provided by an inflated balloon, the drag created by friction and the lift produced by their own hands in a stream of air.

Objectives

Students will:

1. Gain, through experimentation, a basic understanding of the four forces of flight.

Materials:

In the Box

Balloons

Provided by User

Balloon pump (optional)

Tennis ball (or similar)

Box fan

High friction material (sandpaper, carpeted floor, or similar)

Large book (telephone directory or similar)

Tables (2-4)

GRADES

K-4

Time Requirements: 1 hour 30 minutes

Background

The Forces of Flight

Every vehicle, whether it's a car, truck, boat, airplane, helicopter or rocket, is affected by four opposing forces: Thrust, Lift, Drag and Weight (Fig. 1). It is the job of the vehicle's designer to harness these forces and use them in the most advantageous way possible, providing the pilot with an efficient way to control the aircraft.

A force can be thought of as a pushing or pulling motion in a specific direction. It is referred to as a vector quantity, which means it has both a magnitude (quantity or amount) and a direction. In some cases, the goal is to remove as much of a specific force as possible. Race cars, for example, have very little weight in comparison to its thrust, while aircraft use all four forces working in harmony, although not always in equilibrium, in order to achieve successful flight.

Within this lesson we specifically refer to these principles in relation to fixed-wing airplanes. While other aircraft, such as helicopters and airships, use the same basic principles, the methods they use to harness these forces are quite different. With a helicopter for example, the rotor blades on the top of the aircraft produce both lift and thrust forces, controlling them using gyroscopic principles far outside of the scope of this lesson.

Thrust

Thrust should be thought of as the driving force and is produced by an aircraft's propulsion system, or engine. The direction of the thrust dictates the direction in which the aircraft will move. It works using Sir Isaac Newton's (Img. 1) Third Law of Motion which states that "To every action, there is always an equal and opposite reaction." He demonstrated quite simply that if Object A exerts a force on Object B, then Object B must exert an equal force on Object A but in the opposite direction (Fig. 2). So for example, the engines on an airplane propel the aircraft forwards by moving a large quantity of air backwards. In technical terms, it is said that the airplane's thrust vector points forwards. (Reverse thrust simply uses metal components known as clamshells to reverse the direction of the airflow, thereby reversing the thrust vector.)

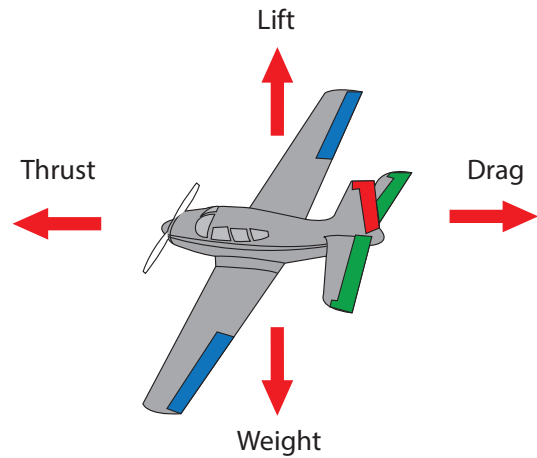
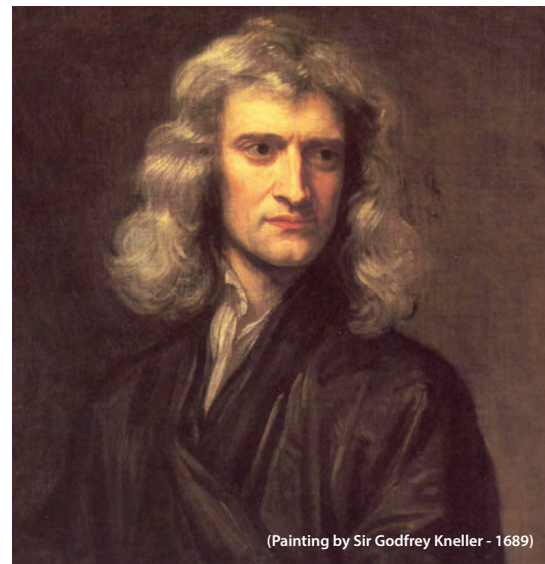


Fig. 1 Four forces of flight



Img. 1 Sir Isaac Newton (age 46)

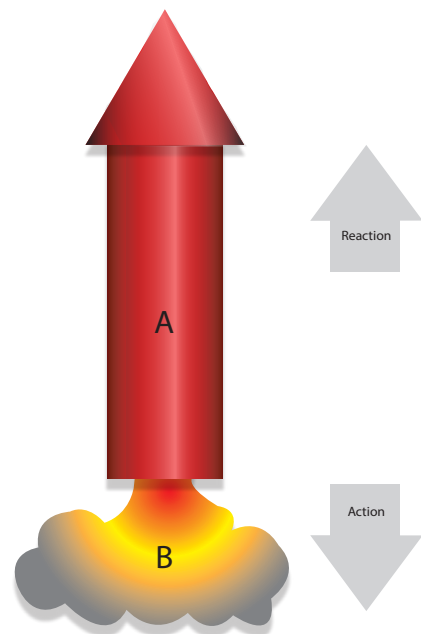


Fig. 2 Action & Reaction

The magnitude of the thrust depends on many factors such as the number and type of engines installed, environmental conditions such as temperature and air density, and the throttle or thrust setting. As a general rule of thumb, propeller-driven aircraft (Img. 2) produce less thrust and are therefore slower than those aircraft powered by jet engines (Img. 3).

One important item of note is that the job of the engine is to propel the aircraft, not to provide lift. It is primarily the wings that perform the task of lifting, not the engines.

Lift

Lift occurs when a moving flow of gas is turned by a solid object. The flow is turned in one direction, and the lift is generated in the opposite direction, according to Newton's Third Law of action and reaction. Because air is a gas and the molecules are free to move about, any solid surface can deflect a flow. For an aircraft wing, both the upper and lower surfaces contribute to the flow turning. Because the air moving over the top of a curved wing tends to go faster than the air under the wing, there is also less pressure at the top of curved wings, and more pressure below the wings. This principle of fast moving air having less pressure is known as Bernoulli's Principle, and also helps generate lift (Fig. 3).

To learn more about what causes lift, and three examples of incorrect theories of lift that people often believe, visit: <http://www.grc.nasa.gov/WWW/k-12/airplane/lift1.html>



(Photo courtesy of NASA)

Img. 2 A NASA modified Cessna 190



(Photo courtesy of NASA)

Img. 3 A NASA modified Boeing 747

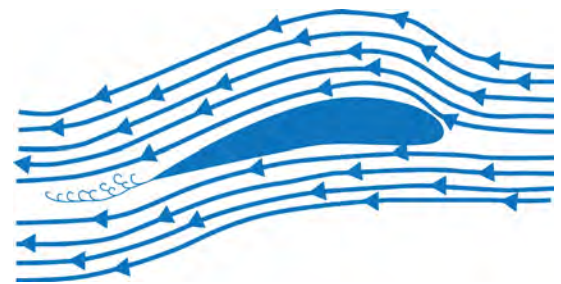


Fig. 3 Air approaching and passing over the surface.

Drag

Drag is produced any time a solid object tries to pass through a liquid or gas. In the case of an aircraft, drag is simply the resistance of the air against the aircraft. There are two types of drag, of which the first, Parasitic Drag, has three categories.

Skin-Friction Drag: The resistance to movement created just by trying to pass an object through the air. It can be thought of as the same feeling a runner might experience when running into a strong wind. Just the act of physically pushing through the air creates resistance which must be overcome to move forwards. This can be reduced by polishing or smoothing the surface exposed to the air. The runner in a tightly fitted running suit would experience much less skin-friction drag than if running in a fitted fluffy coat.

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The second type of drag is Induced Drag. It is a by-product of lift, created by the higher pressure air below the wing traveling around the side of the wing to the lower pressure area, rather than pushing upwards (Fig. 7). This causes a swirling motion of the air, creating what are known as wingtip vortices, which can occasionally be seen when flying through clouds. These vortices disturb the smooth airflow over the wing, creating additional drag. The magnitude of this drag is usually inversely proportional to the magnitude of the lift being produced.

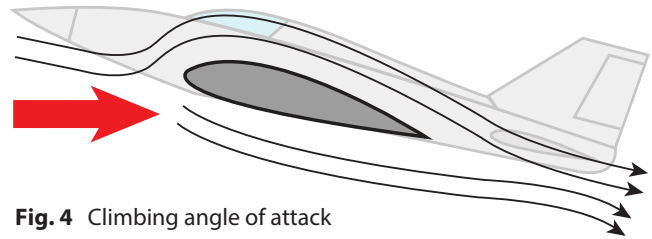


Fig. 4 Climbing angle of attack

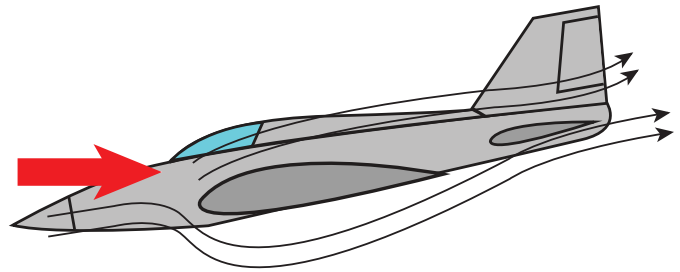


Fig. 5 Descending angle of attack

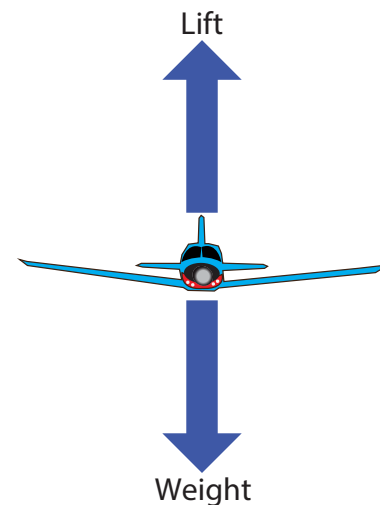


Fig. 6 Forces of straight and level flight

To reduce the amount of induced drag, some aircraft have an additional part to their wings, called winglets (Img 4). Winglets prevent the air from rotating around to the lower pressure area, thereby reducing the induced drag produced (Fig. 8).

NASA has performed many wingtip vortex studies in an attempt to reduce or eliminate the effects of induced drag on an aircraft. Typically these tests are performed by attaching smoke generators to the wing tips of aircraft and watching the resultant formations (Imgs. 5 & 6).

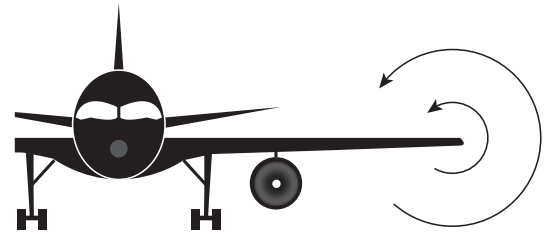


Fig. 7 Induced drag

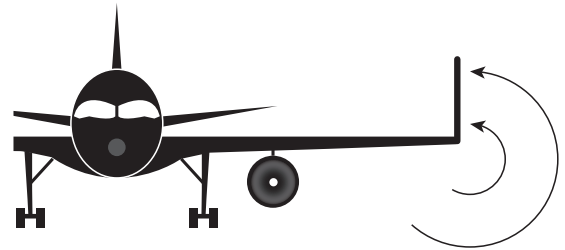


Fig. 8 Winglets' affect on drag



Img. 4 A NASA-modified C-135



Img. 5 A Boeing 727 vortex study



Img. 6 A wake vortex study at Wallops Island, VA

Weight

Weight is a force that is always directed toward the center of the earth due to gravity. The magnitude of the weight is the sum of all the airplane's parts, plus its payload, which is the sum of all the fuel, people and cargo. While the weight is distributed throughout the entire airplane, its effect is centered on a single point called the center of gravity. When an aircraft is loaded, it is vital that its center of gravity remain within certain limits. An aircraft that is too nose- or tail-heavy will either not fly, or be so difficult to control that it becomes too dangerous to try.

The goal of any aircraft design is to keep the weight to a minimum. The lighter an aircraft is, the less fuel it requires for flight, and the more payload it can carry.

The Forces in Flight

While each of the forces is completely independent of the others, in flight they work opposite each other to guide the aircraft as directed by the pilot. In straight and level, un-accelerated flight the total amount of thrust is equal to the total drag, while the total amount of lift is equal to the total weight (Fig. 9). For the aircraft to accelerate, the pilot must add additional thrust to overpower the drag and cause the aircraft to gain speed. If the need is to slow down however, the pilot will reduce the thrust to a value less than that of the drag, allowing the drag to slowly decelerate the aircraft.

The same is true for the weight and lift vectors, although once in flight, the weight of the aircraft remains mostly constant, becoming only slightly lighter as fuel is consumed. Once again, with the aircraft at cruise altitude, it has no need to climb or descend and therefore the total lift produced equals the total weight and is sufficient to do no more than support the weight of the aircraft. If the aircraft must climb, the pilot pitches the nose of the aircraft slightly upwards, increasing the difference in air pressure between the top and bottom surfaces of the wings and therefore producing more lift.

It is important to remember that changing one vector typically results in a change to the other three as well. For example, typically increasing thrust also increases the speed of the air over the wings, which in turn increases lift. If there was no need to climb, the pilot would have to also lower the nose, reducing the angle of attack of the wing and therefore the lift produced, restoring the balance between lift and weight. The opposite is true for a climb where an increase in lift would also increase the induced drag, requiring the pilot to add additional thrust not to accelerate, but to simply compensate for the increased drag component.

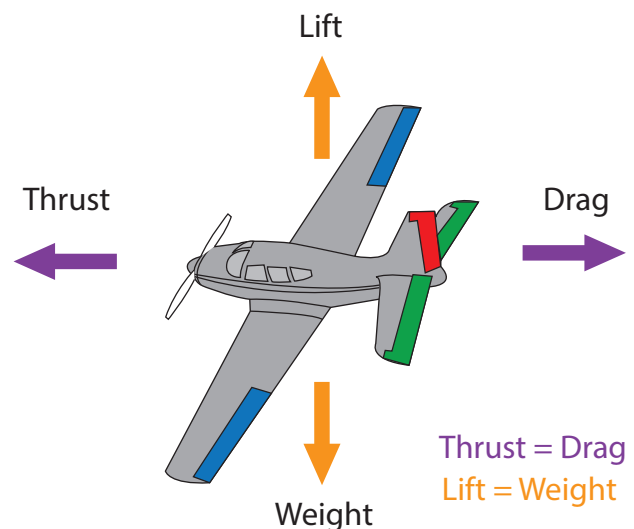


Fig. 9 The four forces of flight in balance

Activity 1

Understanding the Forces

GRADES

Materials:

In the Box

Balloons

Provided by User

Balloon pump (optional)

Tennis ball (or similar)

Box fan

High friction material (sandpaper,
carpeted floor or similar)Large book (telephone directory
or similar)

Tables (2-4)

Worksheets

Table Toppers (Worksheet 1)

Reference Materials

None

Key Terms:

None

Time Requirements: 1 hour 30 minutes

Objective:

Through experimentation, students will learn about position and motion of objects as they gain a basic understanding of the four forces of flight.

Activity Overview:

The work area will be divided into four stations, with one station specific to each force. Students will be divided into four teams and each team assigned to a station. After performing the listed tasks at that station, the groups will rotate to the next.

Note: This activity works best when four adults are available and can each be assigned to monitor a specific station. Depending on the size of the group and the number of adults available, you may find it more convenient to keep all of the students in a single group and rotate between stations together.

Activity:

1. Prior to performing this activity, print Worksheet 1 onto thick card stock, then fold as indicated to make the table toppers required for each station.

Prepare the area by dividing the room into 4 stations. Each station should be comprised of a table, its table topper from Worksheet 1 and the following items:

- a. Station One: Thrust
 - Balloons (one per student, plus a few extra in case any break)
 - Balloon pump (optional)
- b. Station Two: Drag
 - Large book
 - A high friction material such as sandpaper, carpet, a thick sweater, etc.
- c. Station Three: Weight
 - Tennis ball (or similar)
- d. Station Four: Lift
 - A box fan

3. **As a single group, discuss the **Background** information with the students.**

The topics discussed are quite detailed in nature. As such, it should be simplified as required to suit the abilities of the students. It is more important to convey the basic concepts of thrust, weight/gravity, lift and drag than it is to understand how they interact together in flight.

4. **If appropriate, divide the class into four approximately equal-sized groups and assign each group a station.** Have each group perform the activities described at each station.

As noted previously, this can also be performed as a single group if class size or number of adults available to assist dictates as such.

Station One: Thrust

- Have each student, or designated students, blow up a balloon using either their mouths or a balloon pump. Let them discover how thrust is produced when they let go of the balloon.

Station Two: Drag

- Each student should slide the book across a smooth surface such as the table. Next, ask them to slide the book again, but this time over a sandpaper or carpeted surface. Ensure they discover how much harder it is to push the book on the rougher surface.

Station Three: Weight

- Ask each student, or designated students, to roll the ball along the table and watch what happens as it reaches the end of the table.

Station Four: Lift

- Have each student hold one hand flat against the blowing stream of air. Now have them tilt the front of their hands slightly. They should feel their hands start to rise. This is due to lift being produced as the air travelling over the top of the hand is moving quicker than the air underneath.

If a box fan is not available, students can also see the same effect by blowing a stream of air across a strip of paper.

Note: Encourage the students to relax their arms. Holding them stiff will not allow the students to feel the lift.

5. **After all students have had an opportunity to complete the four activities, gather them back into a single group to review the discussion points that follow.**

Discussion Points:

1. **What are the four forces that allow an airplane to fly?**
Thrust, lift, drag and weight.
2. **What is thrust?**
Thrust is a force that moves the airplane forwards through the air.
3. **Why did the balloon fly around the room?**
When the balloon was let go, the air escaped out of the rear of the balloon, creating thrust.
4. **What is lift?**
Lift is a force that allows an aircraft to climb or stay in the air, rather than fall to the ground.
5. **Why did your hand rise when you turned it upwards slightly?**
When we turned our hands, it caused the air passing over the top of our hands to move faster than the air on the bottom. This produced a lower air pressure on top, which meant the higher air pressure underneath could push our hands upwards.
6. **What is drag?**
Drag is a force that opposes thrust. It is a type of friction and makes objects harder to move.
7. **Why was the book harder to push the second time?**
It was harder to push the second time because it had to move across a rough surface. When pushed along the table it had very little resistance and slid easily, but the rough texture created drag, which had to be overcome by pushing the book harder.
8. **What is gravity?**
Gravity is a force that pulls objects towards the center of the Earth.
9. **What is weight?**
Weight is the effect of gravity on an object (mass). A 200lb man on Earth weighs almost nothing in space due to the much lower levels of gravity.
10. **Why did the ball fall to the floor rather than just keep moving sideways?**
If there were no gravity, the ball would have just kept moving sideways. Instead, once the table was no longer there to support the ball, the effects of gravity took over, pulling the ball to the floor. Had the floor not been there, it would have continued falling until reaching the center of the Earth!

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology



Reference Materials

Fig. 1 Four forces of flight

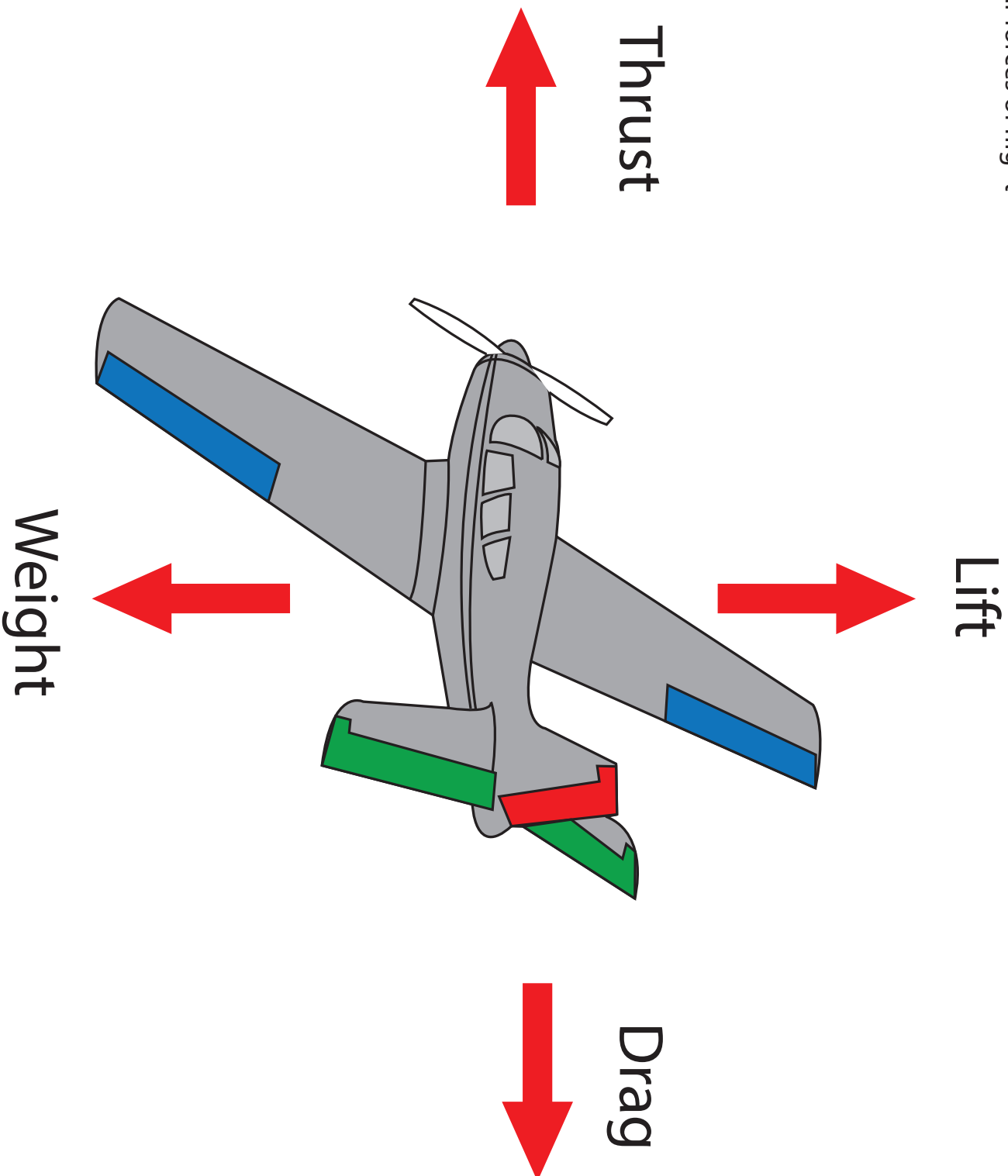
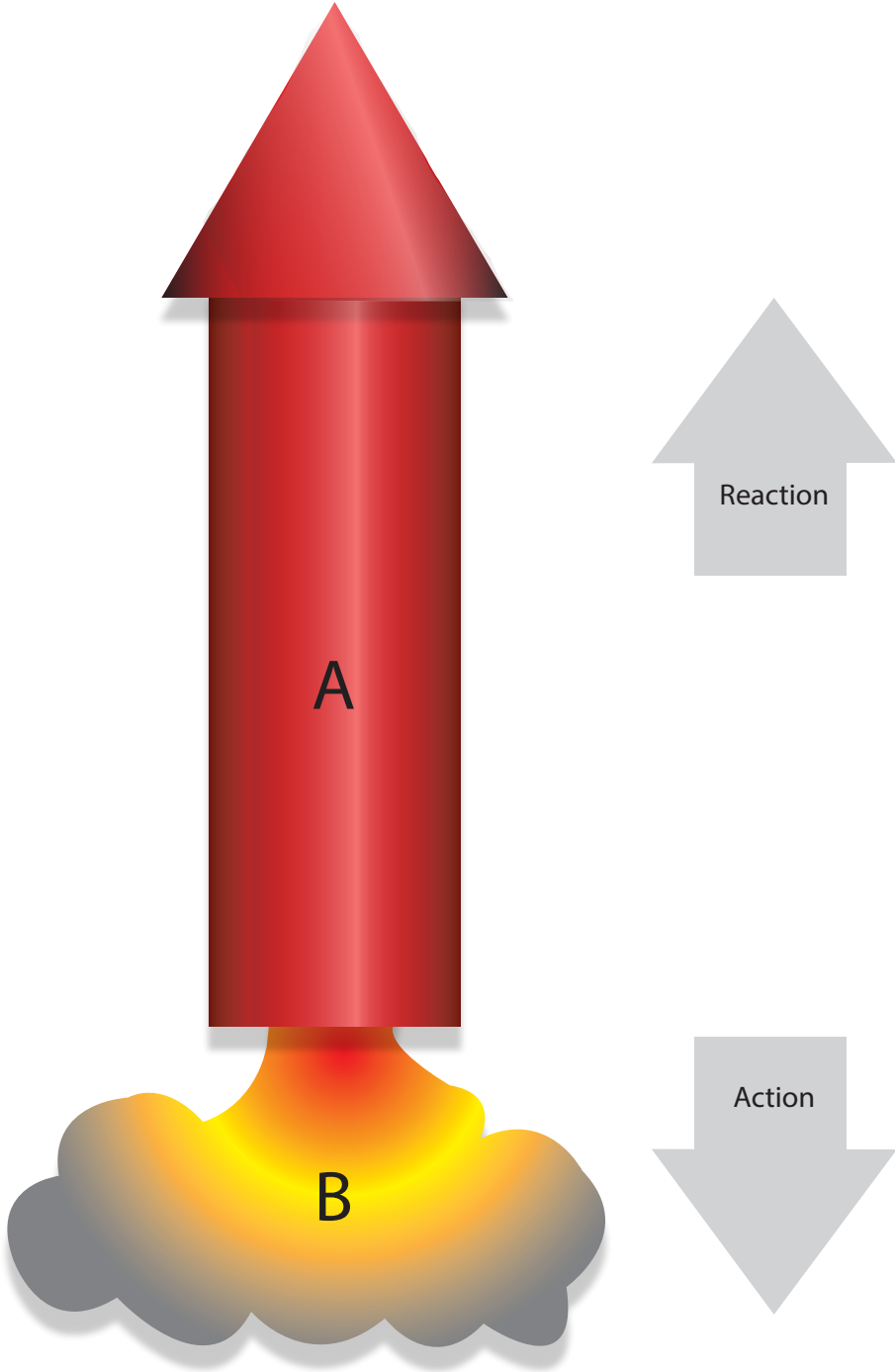


Fig. 2 Action & Reaction



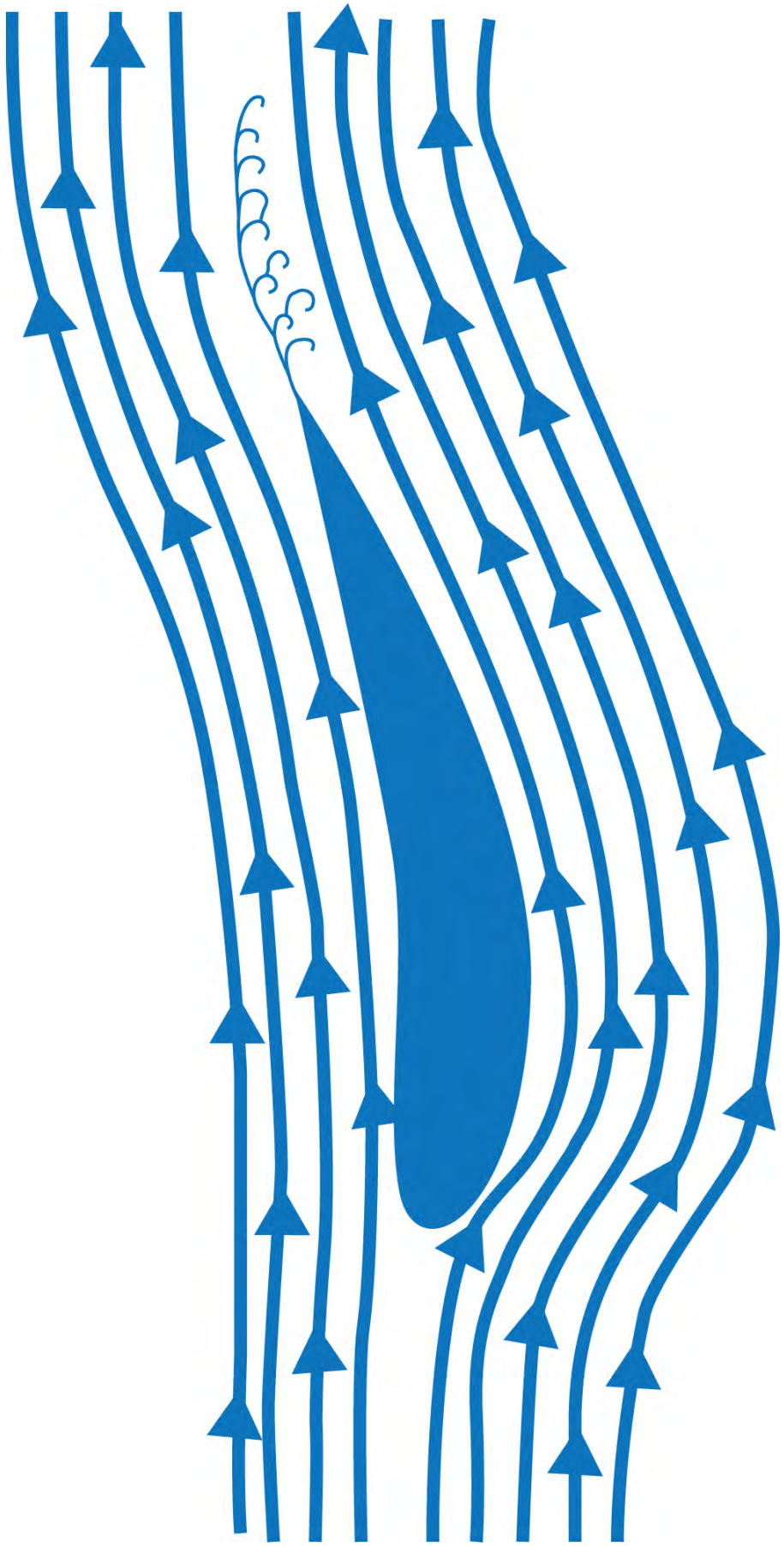


Fig. 3 Air approaching and passing over the surface.

Fig. 4 Climbing angle of attack

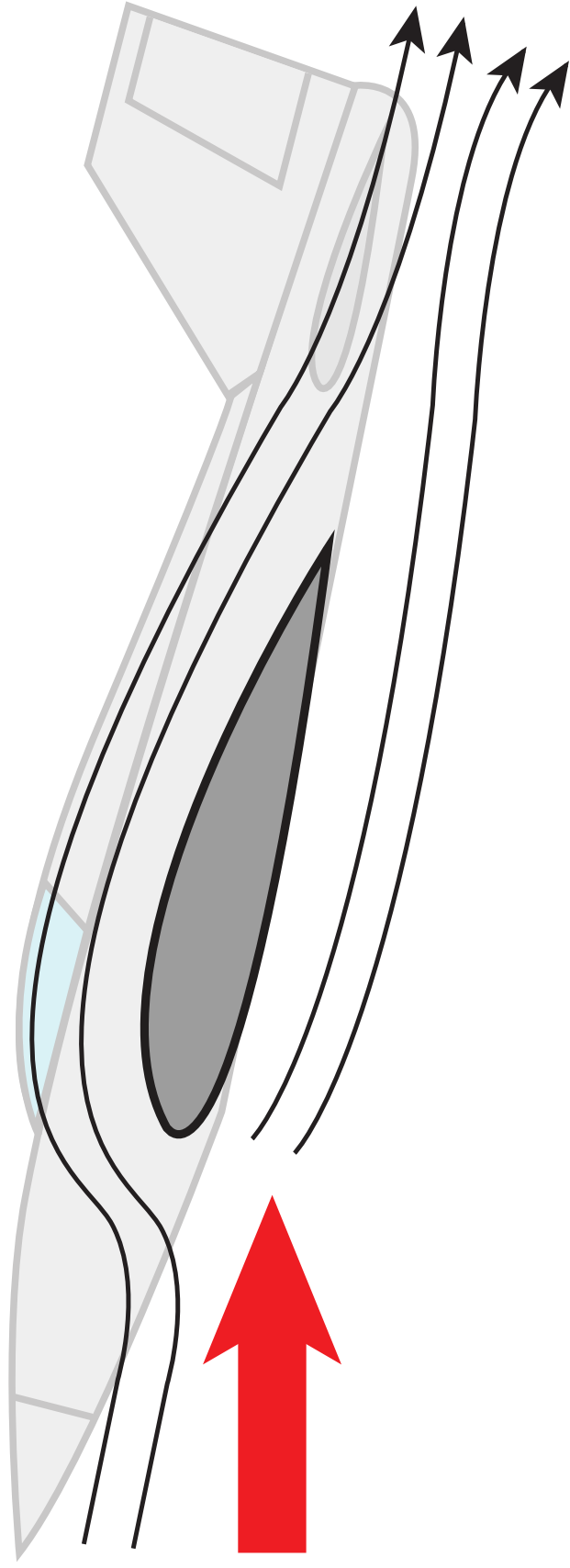


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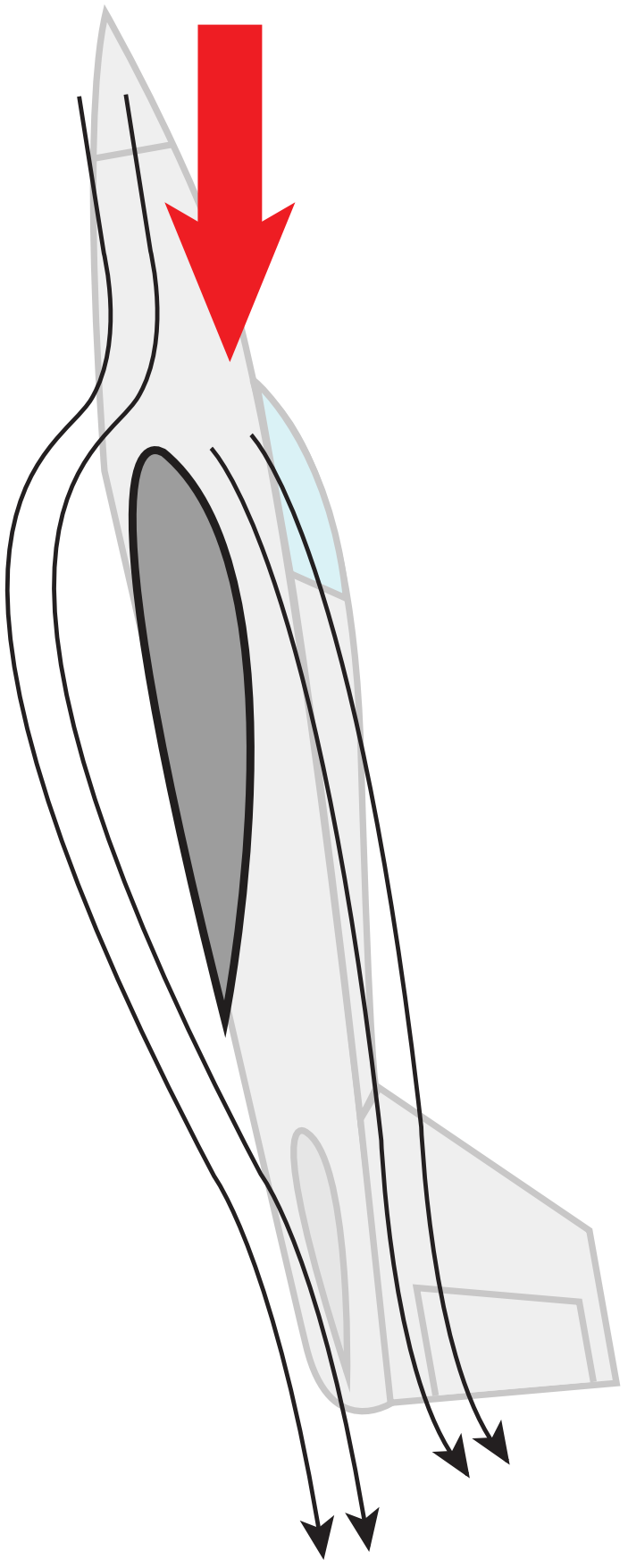


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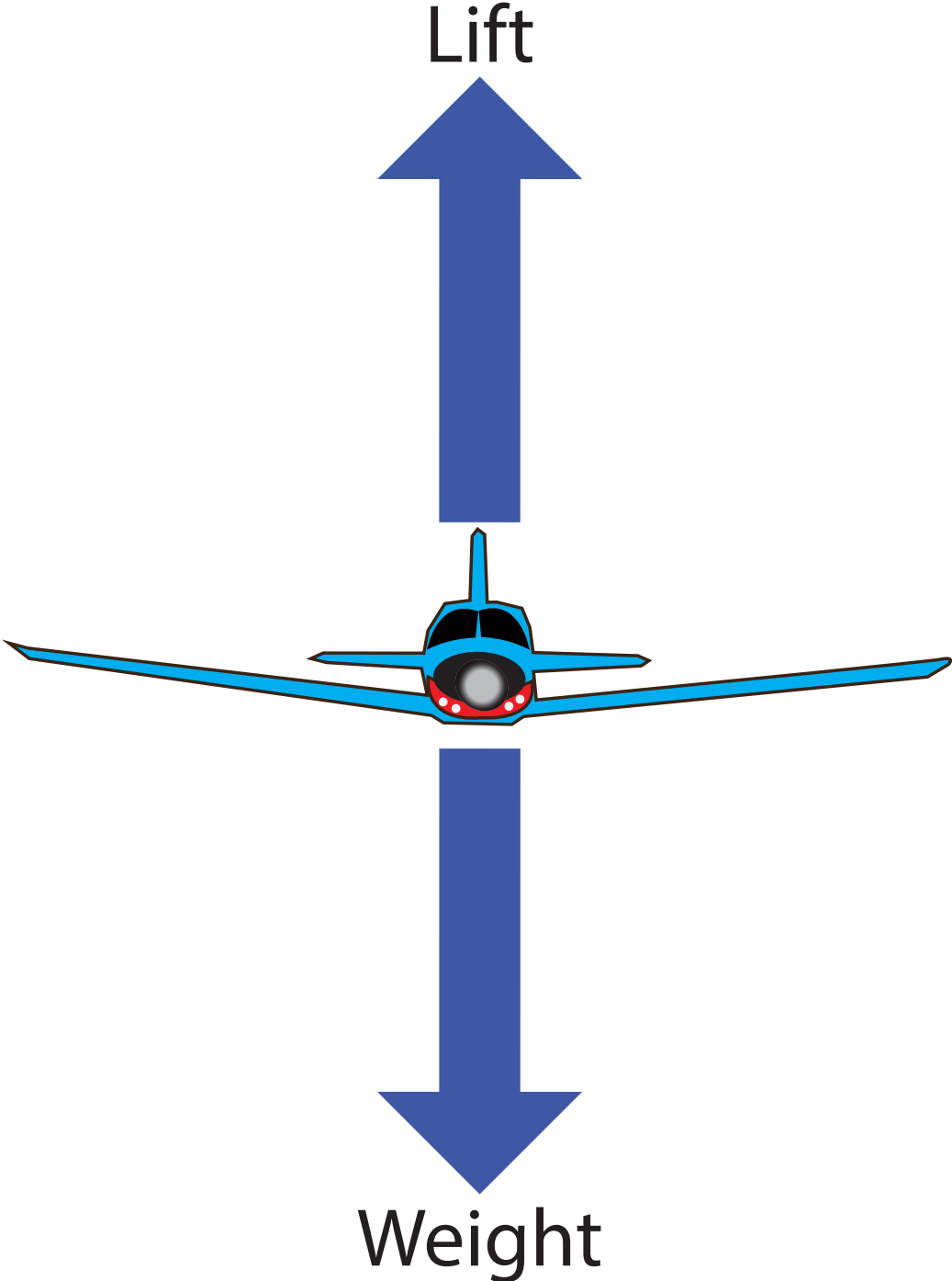


Fig. 7 Induced drag

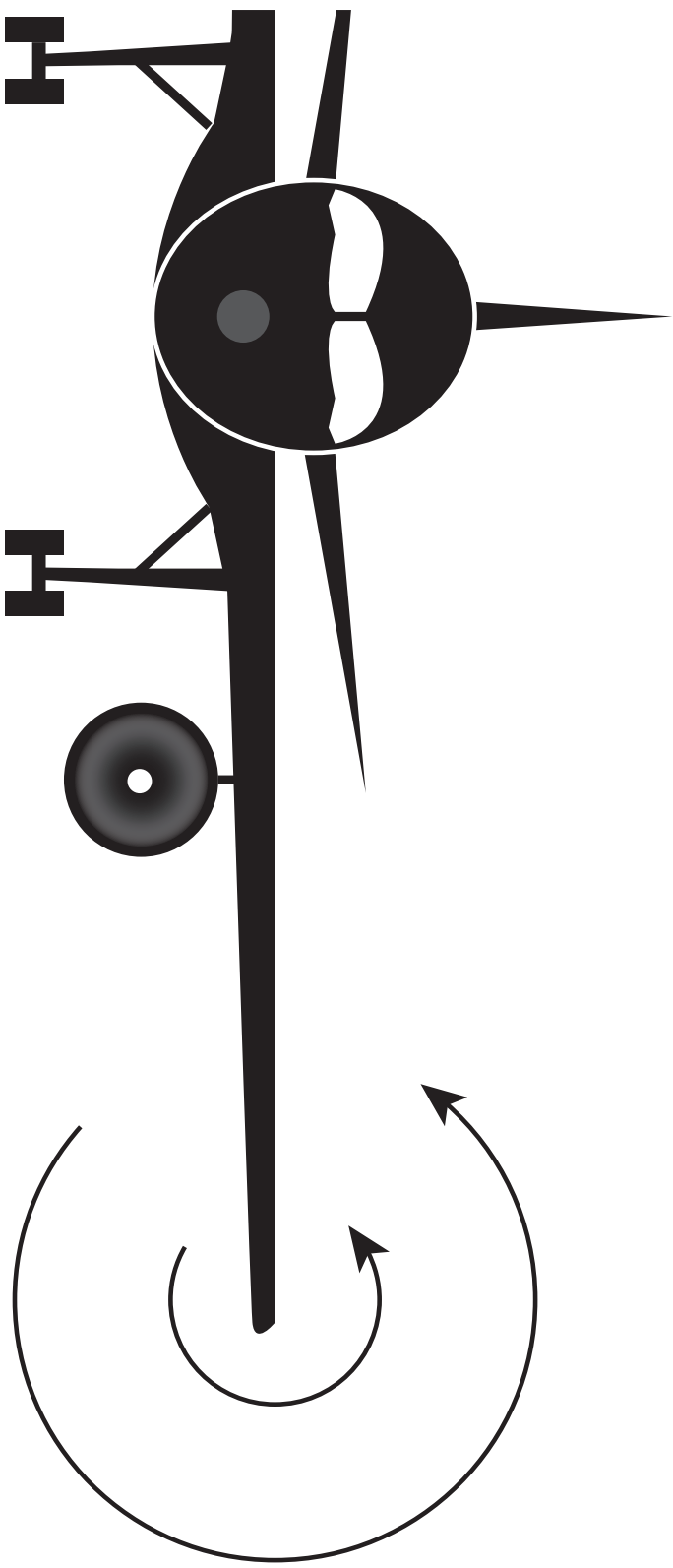


Fig. 8 Winglets' affect on drag

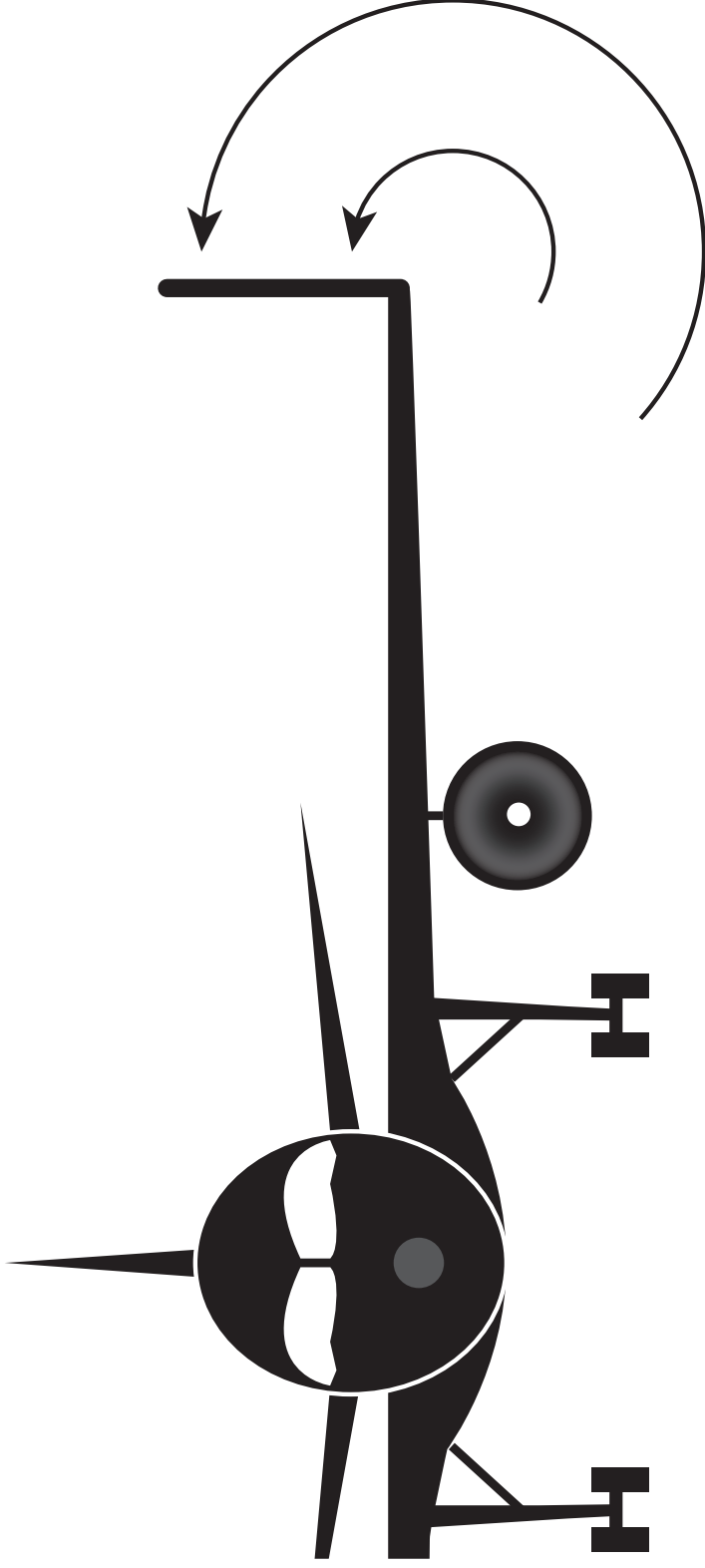
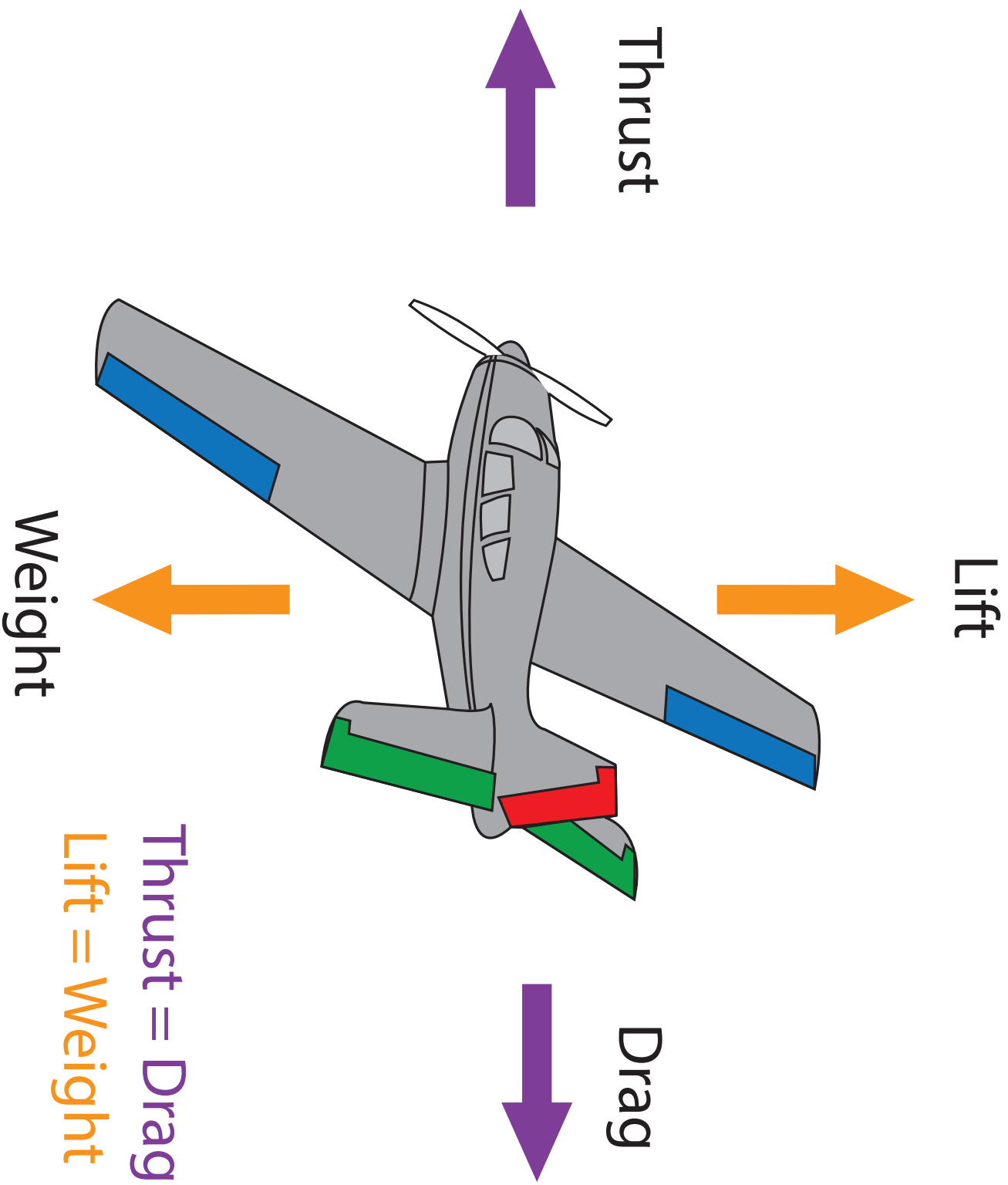


Fig. 9 The four forces of flight in balance





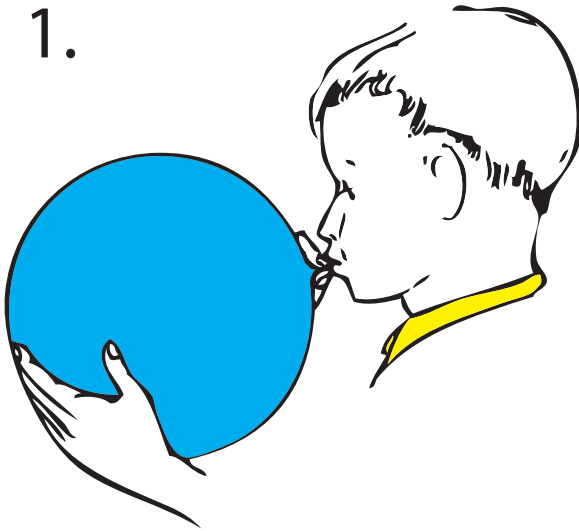
Worksheets

fold

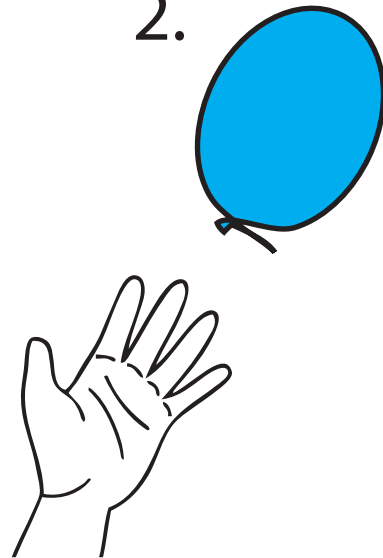
fold

Station One: Thrust

1.



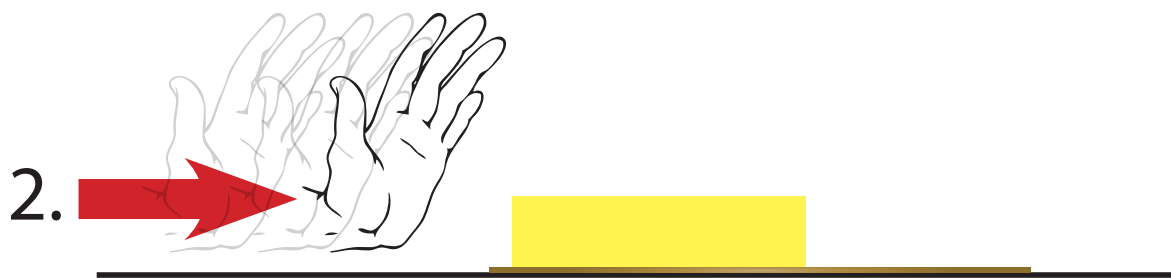
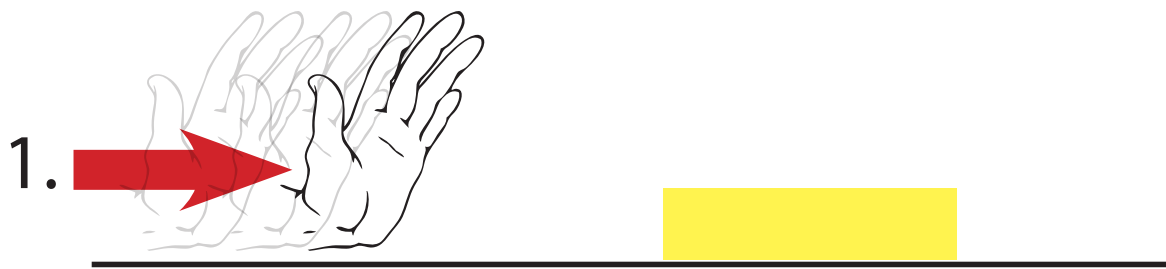
2.



fold

fold

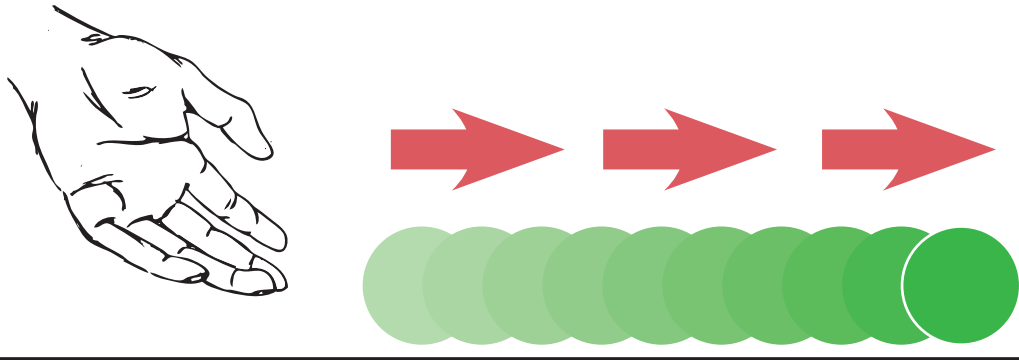
Station Two: Drag



fold

fold

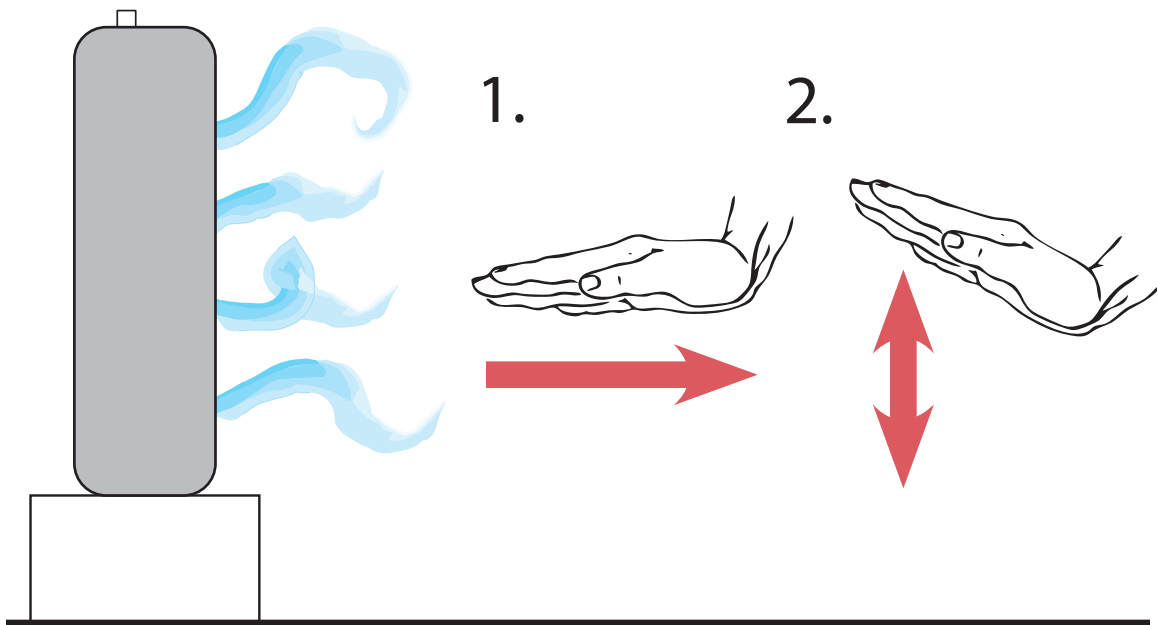
Station Three: Weight



fold

fold

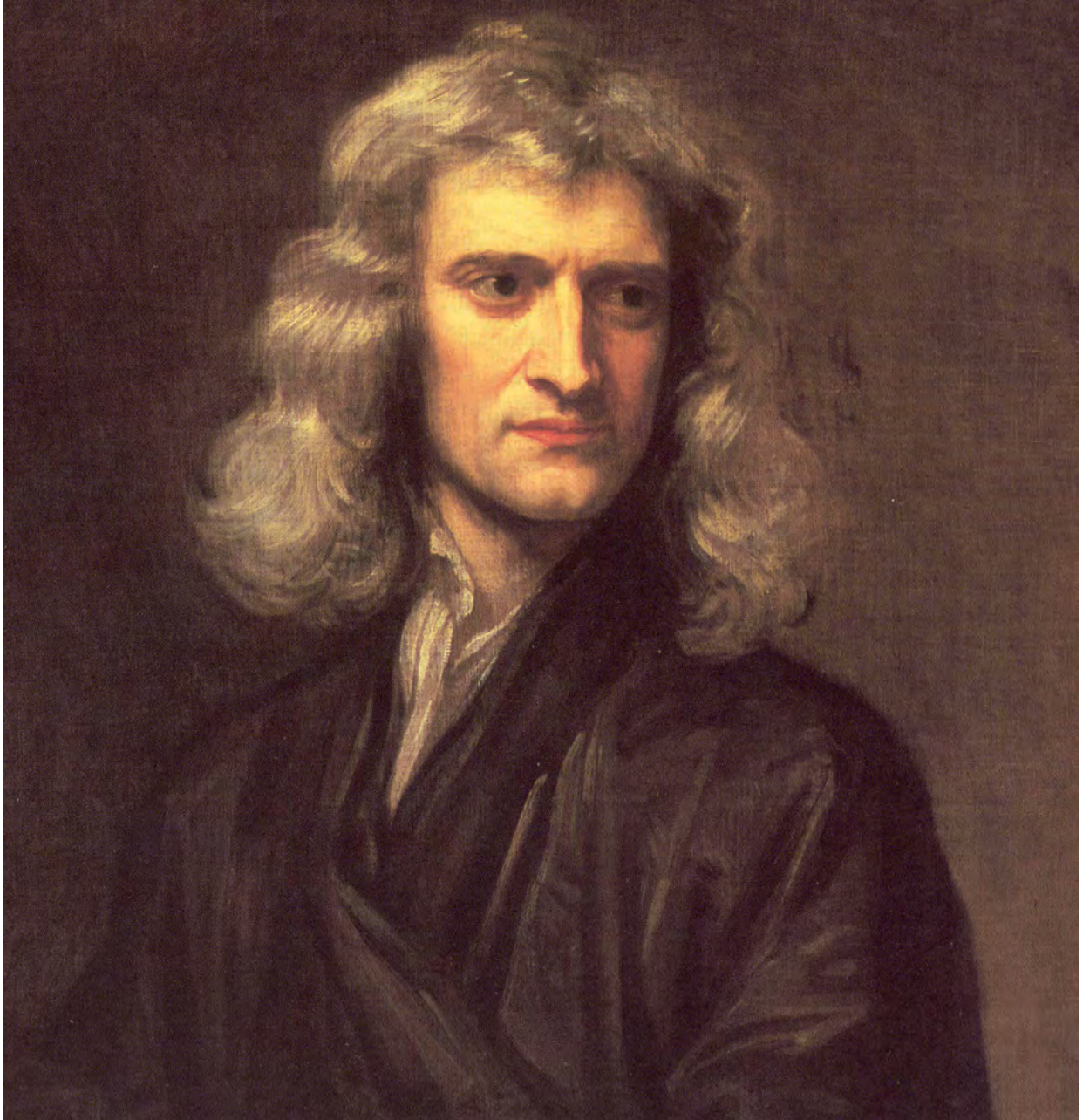
Station Four: Lift





Images

Img. 1 Sir Isaac Newton (age 46)



(Painting by Sir Godfrey Kneller - 1689)

Img. 2 A NASA modified *essna 190*



(Photo courtesy of NASA)

Img. 3 A NASA modified Boeing 747



(Photo courtesy of NASA)

Img. 4 A NASA-modified C-135



(Photo courtesy of NASA)

Img. 5 A Boeing 727 vortex study



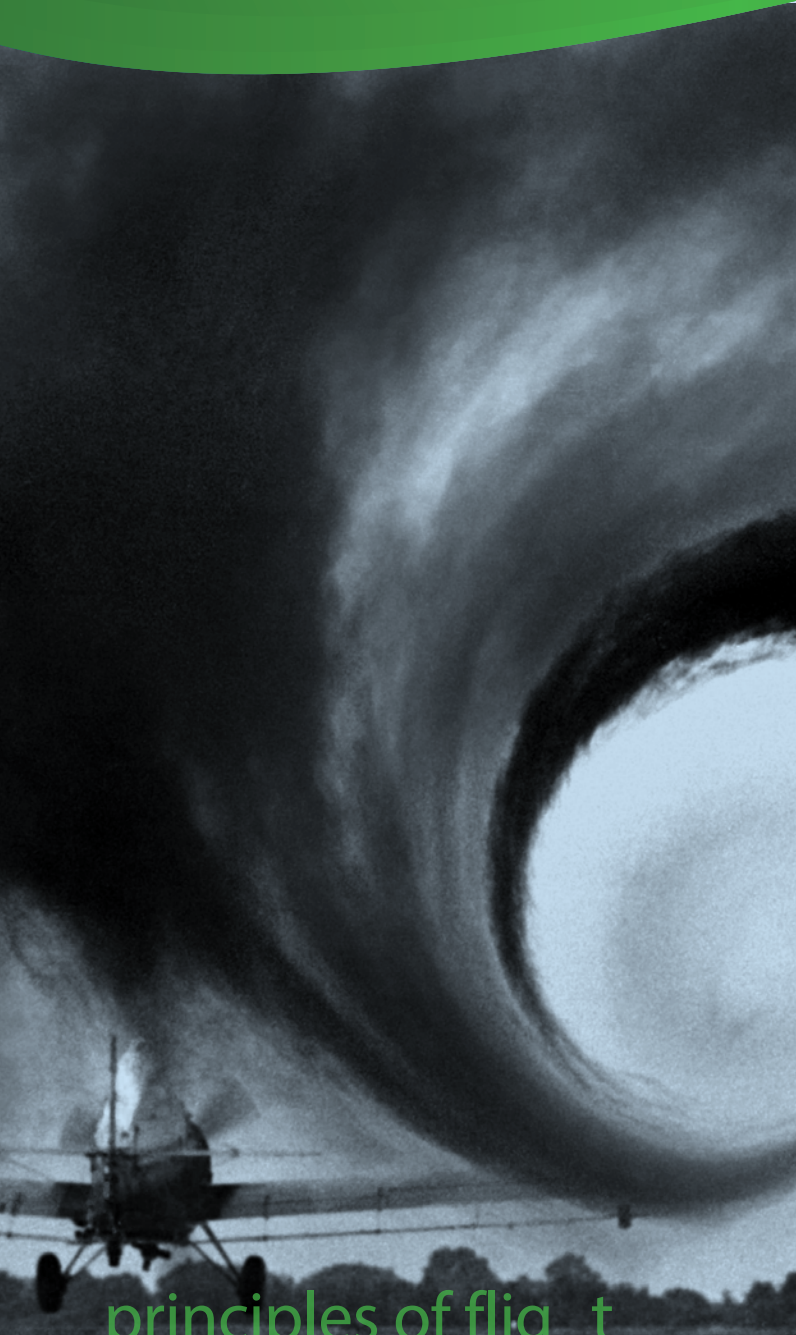
(Photo courtesy of NASA)

Img. 6 A wake vortex study at Wallops Island, VA

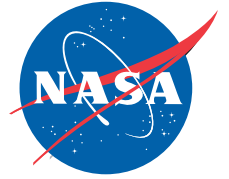


(Photo courtesy of NASA)

Aeronautics
Research
Mission
Directorate



principles of flight



GRADES

5-8

Four Forces



principles of flight

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Four Forces

Lesson Overview

Through physical experimentation, students will learn about motions and forces, and transfer of energy as they explore the basics behind the four forces of flight. Students will be divided into four groups and witness the effects of gravity on a tennis ball, the thrust provided by an inflated balloon, the drag created by air resistance and the lift produced by their own hands in a stream of air.

Objectives

Students will:

1. Gain through experimentation a basic understanding of the four forces of flight.

Materials:

In the Box

Balloons
 Stopwatch (2)
 Scale
 2 balls of similar size but different weights
 Fan
 Umbrella

Provided by User

Balloon pump (optional)
 Copy paper (8 sheets)

GRADES

5-8

Time Requirements: 1 hour 30 minutes

Background

The Forces of Flight

Every vehicle, whether it's a car, truck, boat, airplane, helicopter or rocket, is affected by four opposing forces: Thrust, Lift, Drag and Weight (Fig. 1). It is the job of the vehicle's designer to harness these forces and use them in the most advantageous way possible, providing the pilot with an efficient way to control the aircraft.

A force can be thought of as a pushing or pulling motion in a specific direction. It is referred to as a vector quantity, which means it has both a magnitude (quantity or amount) and a direction. In some cases, the goal is to remove as much of a specific force as possible. Race cars, for example, have very little weight in comparison to its thrust, while aircraft use all four forces working in harmony, although not always in equilibrium, in order to achieve successful flight.

Within this lesson we specifically refer to these principles in relation to fixed-wing airplanes. While other aircraft, such as helicopters and airships, use the same basic principles, the methods they use to harness these forces are quite different. With a helicopter for example, the rotor blades on the top of the aircraft produce both lift and thrust forces, controlling them using gyroscopic principles far outside of the scope of this lesson.

Thrust

Thrust should be thought of as the driving force and is produced by an aircraft's propulsion system, or engine. The direction of the thrust dictates the direction in which the aircraft will move. It works using Sir Isaac Newton's (Img. 1) Third Law of Motion which states that "To every action, there is always an equal and opposite reaction." He demonstrated quite simply that if Object A exerts a force on Object B, then Object B must exert an equal force on Object A but in the opposite direction (Fig. 2). So for example, the engines on an airplane propel the aircraft forwards by moving a large quantity of air backwards. In technical terms, it is said that the airplane's thrust vector points forwards. (Reverse thrust simply uses metal components known as clamshells to reverse the direction of the airflow, thereby reversing the thrust vector.)

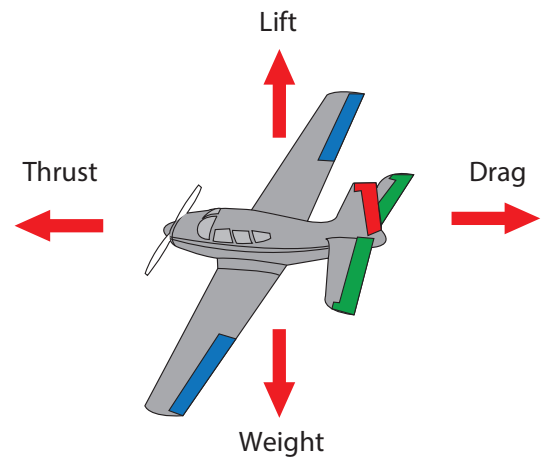
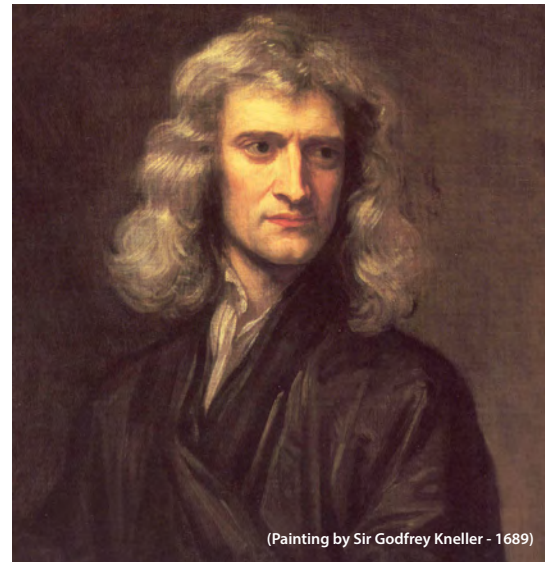


Fig. 1 Four forces of flight



Img. 1 Sir Isaac Newton (age 46)

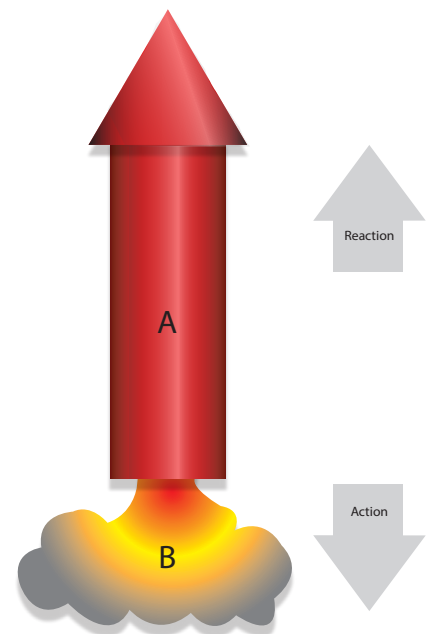


Fig. 2 Action & Reaction

The magnitude of the thrust depends on many factors such as the number and type of engines installed, environmental conditions such as temperature and air density, and the throttle or thrust setting. As a general rule of thumb, propeller-driven aircraft (Img. 2) produce less thrust and are therefore slower than those aircraft powered by jet engines (Img. 3).

One important item of note is that the job of the engine is to propel the aircraft, not to provide lift. It is primarily the wings that perform the task of lifting, not the engines.

Lift

Lift occurs when a moving flow of gas is turned by a solid object. The flow is turned in one direction, and the lift is generated in the opposite direction, according to Newton's Third Law of action and reaction. Because air is a gas and the molecules are free to move about, any solid surface can deflect a flow. For an aircraft wing, both the upper and lower surfaces contribute to the flow turning. Because the air moving over the top of a curved wing tends to go faster than the air under the wing, there is also less pressure at the top of curved wings, and more pressure below the wings. This principle of fast moving air having less pressure is known as Bernoulli's Principle, and also helps generate lift (Fig. 3).

To learn more about what causes lift, and three examples of incorrect theories of lift that people often believe, visit:

<http://www.grc.nasa.gov/WWW/k-12/airplane/lift1.html>



(Photo courtesy of NASA)

Img. 2 A NASA modified Cessna 190



(Photo courtesy of NASA)

Img. 3 A NASA modified Boeing 747



Fig. 3 Air approaching and passing over the surface.

Drag

Drag is produced any time a solid object tries to pass through a liquid or gas. In the case of an aircraft, drag is simply the resistance of the air against the aircraft. There are two types of drag, of which the first, Parasitic Drag, has three categories.

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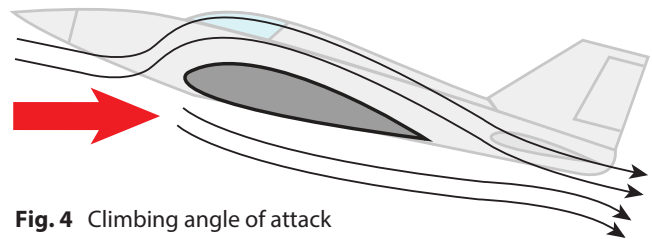


Fig. 4 Climbing angle of attack

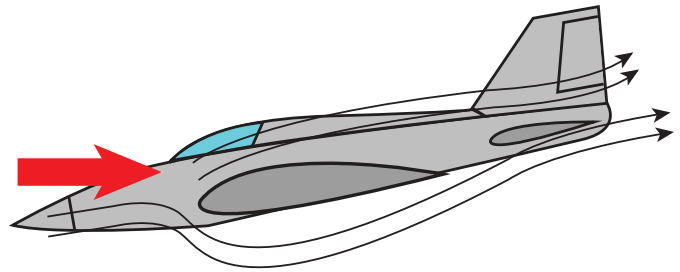


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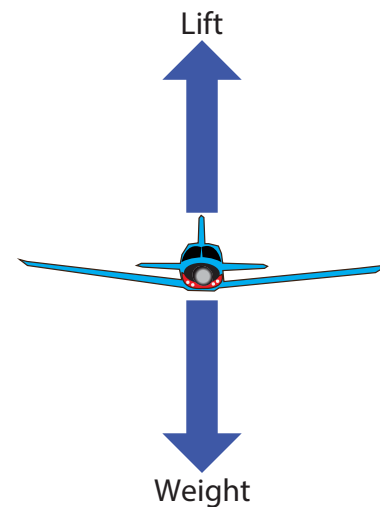


Fig. 6 Forces of straight and level flight

To reduce the amount of induced drag, some aircraft have an additional part to their wings, called winglets (Img 4). Winglets prevent the air from rotating around to the lower pressure area, thereby reducing the induced drag produced (Fig. 8).

NASA has performed many wingtip vortex studies in an attempt to reduce or eliminate the effects of induced drag on an aircraft. Typically these tests are performed by attaching smoke generators to the wing tips of aircraft and watching the resultant formations (Imgs. 5 & 6).

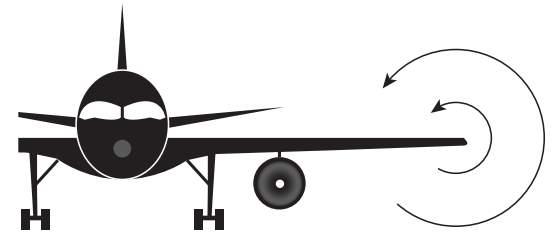


Fig. 7 Induced drag

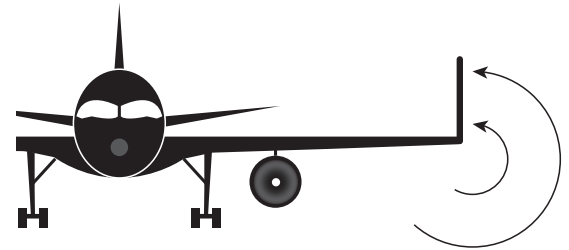


Fig. 8 Winglets' affect on drag



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Img. 5 A Boeing 727 vortex study



Img. 6 A wake vortex study at Wallops Island, VA

Weight

Weight is a force that is always directed toward the center of the earth due to gravity. The magnitude of the weight is the sum of all the airplane's parts, plus its payload, which is the sum of all the fuel, people and cargo. While the weight is distributed throughout the entire airplane, its effect is centered on a single point called the center of gravity. When an aircraft is loaded, it is vital that its center of gravity remain within certain limits. An aircraft that is too nose- or tail-heavy will either not fly, or be so difficult to control that it becomes too dangerous to try.

The goal of any aircraft design is to keep the weight to a minimum. The lighter an aircraft is, the less fuel it requires for flight, and the more payload it can carry.

The Forces in Flight

While each of the forces is completely independent of the others, in flight they work opposite each other to guide the aircraft as directed by the pilot. In straight and level, un-accelerated flight the total amount of thrust is equal to the total drag, while the total amount of lift is equal to the total weight (Fig. 9). For the aircraft to accelerate, the pilot must add additional thrust to overpower the drag and cause the aircraft to gain speed. If the need is to slow down however, the pilot will reduce the thrust to a value less than that of the drag, allowing the drag to slowly decelerate the aircraft.

The same is true for the weight and lift vectors, although once in flight, the weight of the aircraft remains mostly constant, becoming only slightly lighter as fuel is consumed. Once again, with the aircraft at cruise altitude, it has no need to climb or descend and therefore the total lift produced equals the total weight and is sufficient to do no more than support the weight of the aircraft. If the aircraft must climb, the pilot pitches the nose of the aircraft slightly upwards, increasing the difference in air pressure between the top and bottom surfaces of the wings and therefore producing more lift.

It is important to remember that changing one vector typically results in a change to the other three as well. For example, increasing thrust also increases the speed of the air over the wings, which in turn increases lift. If there was no need to climb, the pilot would have to also lower the nose, reducing the angle of attack of the wing and therefore the lift produced, restoring the balance between lift and weight. The opposite is true for a climb where an increase in lift would also increase the induced drag, requiring the pilot to add additional thrust not to accelerate, but to simply compensate for the increased drag component.

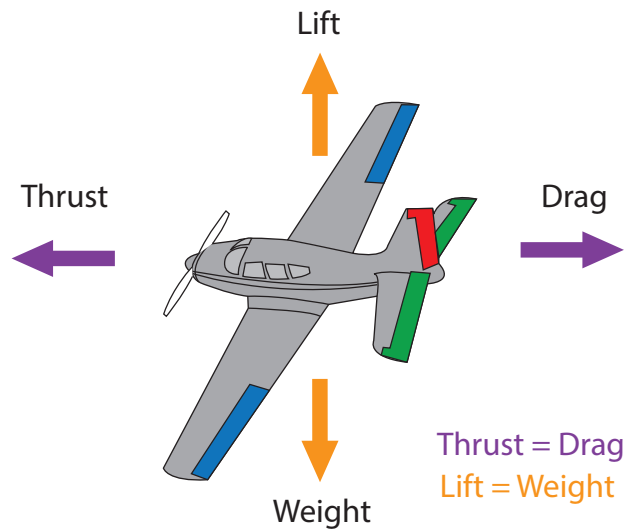


Fig. 9 The four forces of flight in balance

Activity 1

Understanding the Forces

GRADES**5-8****Time Requirements:** 1 hour 30 minutes**Materials:**In the Box

Balloons
 Stopwatch (2)
 2 balls of similar size but
 different weights
 Fan
 Umbrella
 Scale

Provided by User

Balloon pump (optional)
 Copy paper (8 sheets)

Worksheets

Table Toppers
 (Worksheet 1)
 Thrust & Time
 (Worksheet 2)

Reference Materials

None

Key Terms:

None

Objective:

Through experimentation, students will learn about energy transfer, as well as motions and forces, as they gain a basic understanding of the four forces of flight.

Activity Overview:

The work area will be divided into four stations, with one station specific to each force. Students will be divided into four teams and each team assigned to a station. After performing the listed tasks at that station, the groups will rotate to the next.

Note: This activity works best when four adults are available and can each be assigned to monitor a specific station. Depending on the size of the group and the number of adults available, you may find it more convenient to keep all of the students in a single group and rotate between stations together.

Activity:

1. **Prior to performing this activity, print Worksheet 1 onto thick card stock, then fold as indicated to make the table toppers required for each station.**
2. **Prepare the area by dividing the classroom into 4 stations.** Each station should be comprised of a table, its table topper from Worksheet 1 and the following items:
 - a. Station One: Thrust
 - Balloons (one per student)
 - Balloon pump (optional)
 - Stopwatch
 - Worksheet 2 (one per student)
 - b. Station Two: Drag
 - Umbrella
 - Stopwatch

c. Station Three: Weight

- 2 balls of similar size but different weights

Type of ball is irrelevant. The important part is the difference in weight.

Examples might include a tennis ball and an orange, or a marble and a grape.

- Sheets of blank copy paper
- Scale

d. Station Four: Lift

- A fan

3. **As a single group, discuss the **Background** information with the students.**
4. **If appropriate, divide the class into four approximately equal-sized groups and assign each group a station.** Have each group perform the activities described at each station.
As noted above, this can also be performed as a single group if class size or number of adults available to assist dictates as such.

Station One: Thrust

- Have each student inflate the balloon using either four breaths or four pumps of a balloon pump.
- Next, have the student let go of the balloon while another student times the length of the flight.
- Record the time the balloon spent airborne on the worksheet.
- Repeat the experiment multiple times with various levels of inflation, recording the number of breaths and the flight time for each trial.

Station Two: Drag

- Assign two points on opposite sides of the room between which the students can safely run.
- Have one student in the group run at a steady pace from one point to the other, while another student times the journey.
- Now have the same student run again at the same pace as before, but this time holding the open umbrella behind them. Again, time the journey.
- Have each student perform this activity noting the difference between the two times.

Station Three: Weight

- Pass the two balls around the group. Ensure the students note that the two balls are of different weights by weighing them on the scale.
- Have one student stand on the table or a chair for additional height. Next, have the same student hold the two balls at arm's length and at equal height.
- Ask the students which ball will hit the ground first, the lighter or the heavier.
- Have the student holding the balls drop them simultaneously while the other students watch.
- Repeat this with the other students taking turns dropping the balls until it is accepted that both balls hit the ground at approximately the same time.
- Next, take two sheets of copy paper and pass them around the group to confirm they are identical.
- Take one sheet of paper and scrunch it into a tight ball, leaving the other untouched.
- Remind the students that both sheets of paper weigh the same. Based on the previous demonstration, ask them to hypothesize as to which sheet of paper will hit the ground first.
- As before, have the students take turns dropping the two pieces of paper, noting which one landed first.

Station Four: Lift

- Using the fan, have each student hold one hand flat against the blowing stream of air. Now have them tilt the front of their hand slightly. They should feel it start to rise.

Discussion Points:

1. **What are the four forces that allow an airplane to fly**

Thrust, lift, drag and weight.

2. **What is thrust and how is it produced?**

Thrust is a force that moves an airplane forwards through the air. It is produced by the aircraft's engines, which accelerate the air around the aircraft.

3. **What correlation was there between the amount of air in the balloon and its flight time?**

It should have been discovered that as the amount of air in the balloon increased, the longer it stayed in flight.

4. **In what direction did the balloon move?**

The open end of the balloon always pointed away from the direction of travel. This proves Newton's Second Law of Motion because as the air escaped from the rear of the balloon, it pushed the balloon forwards, in an equal and opposite direction. The direction and speed the balloon moved is the balloon's thrust vector.

5. **What is lift?**

Lift is a force that allows an aircraft to climb or stay in the air, rather than fall to the ground.

6. **Why did your hand rise when you turned it upwards slightly?**

When we turned our hands, it caused the air passing over the top of the hand to move faster than the air below. As Bernoulli's principle states, this produced a lower air pressure on top, which meant the higher air pressure underneath could push the hand upwards.

7. **What is drag?**

Drag is a force that both opposes thrust and is a byproduct of lift. It is a type of friction, making objects harder to move.

8. **Why was it significantly harder to run with the open umbrella? Why were the sprinting times longer with the umbrella than without?**

Without the umbrella, the main drag component was the air resistance against your body as you ran. With the umbrella open, it provided a much larger surface area which also had to be pulled through the air. This created additional drag, which meant that you had to work harder, or provide more thrust, in order to complete the journey. As you had already given 100% of your available thrust on the first run, the additional drag slowed you down, creating a slower time.

9. **What is gravity?**

Gravity is a force that pulls objects towards the center of the Earth.

10. **What is weight?**

Weight is the effect of gravity on an object (mass). A 200lb man on Earth weighs almost nothing in space due to the much lower levels of gravity.

11. Why did both balls fall to the floor at approximately the same time even though one was heavier?

When it comes to gravity, the weight of an object is irrelevant. The speed at which an object falls due to gravity will always be the same. A stationary object accelerates by 9.8m/s for each second it falls (9.8m/s² or meters per second, per second). To put it another way, after one second a falling object will be moving at 9.8 meters per second. After 2 seconds it will be at 19.6 (9.8 + 9.8) meters per second, after 3 seconds its speed will be 29.4 (9.8 + 9.8 + 9.8) m/s, and so on. It doesn't matter whether that object is a grape or an elephant, they will both fall at the exact same speed. In actuality however, the elephant will hit the ground after the grape. This is due to the elephant being larger and therefore having more resistance against the air through which it is falling (drag).

12. If the speed of gravity is the same for all objects, why did the ball of paper drop much quicker than the sheet?

The ball of paper had very little resistance as it fell through the air, meaning it had very little drag. The sheet of paper on the other hand had a large, exposed surface area, which slowed down the rate of acceleration. This is precisely how a parachute works in slowing down a falling skydiver. It provides additional drag, allowing the skydiver to touch the ground at a much slower, safer speed.

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Properties and changes of properties in matter
- Transfer of energy

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology



Reference Materials

Fig. 1 Four forces of flight

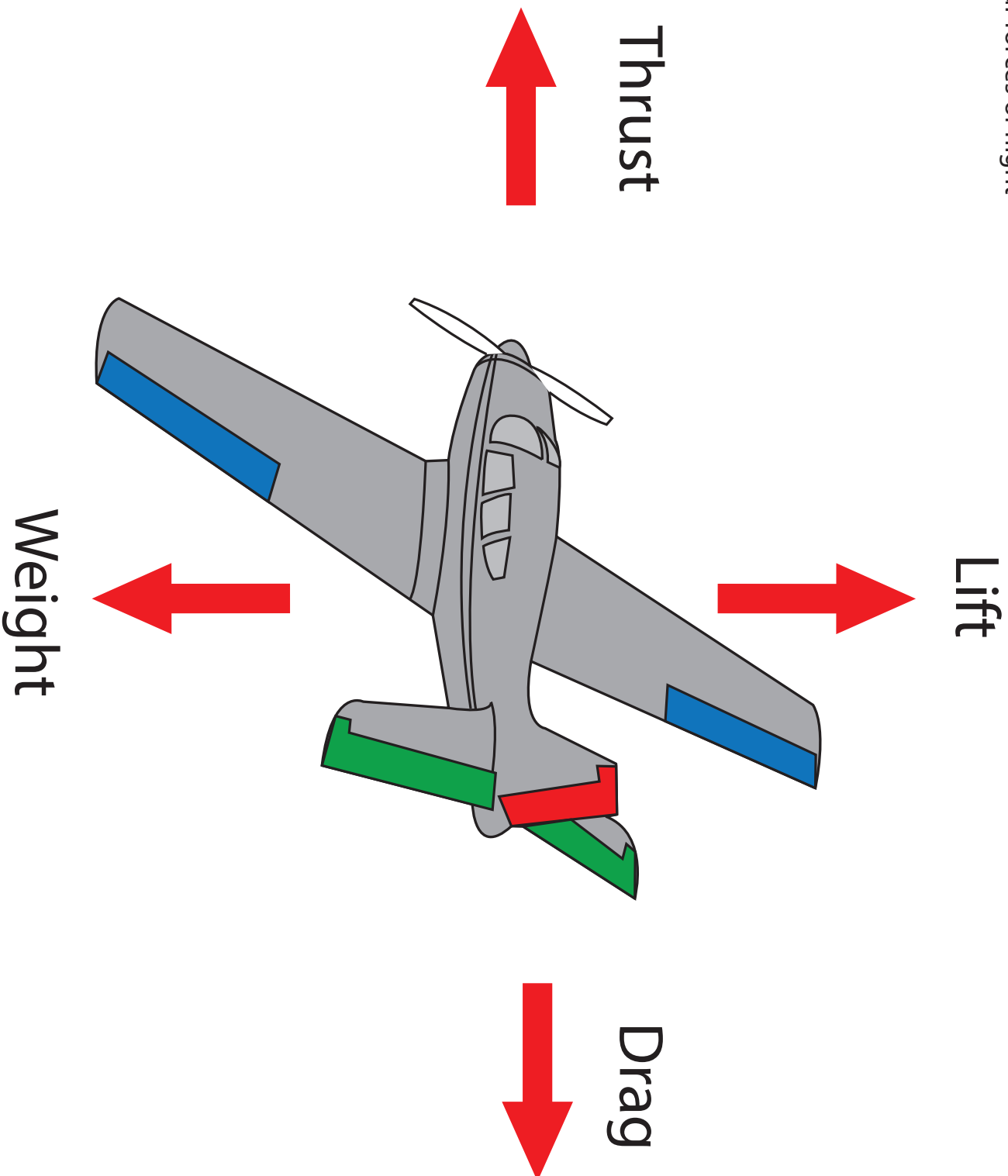
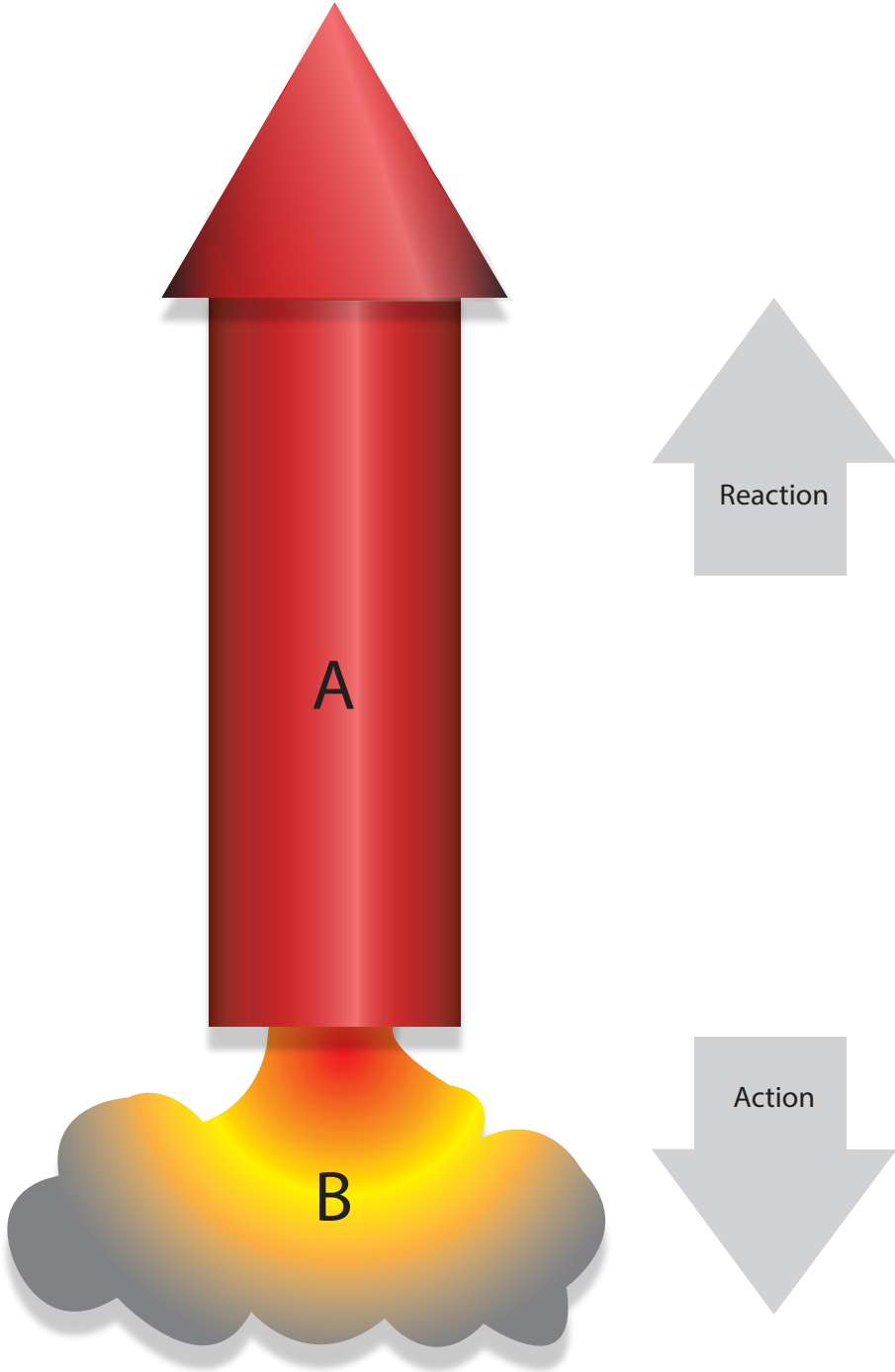


Fig. 2 Action & Reaction



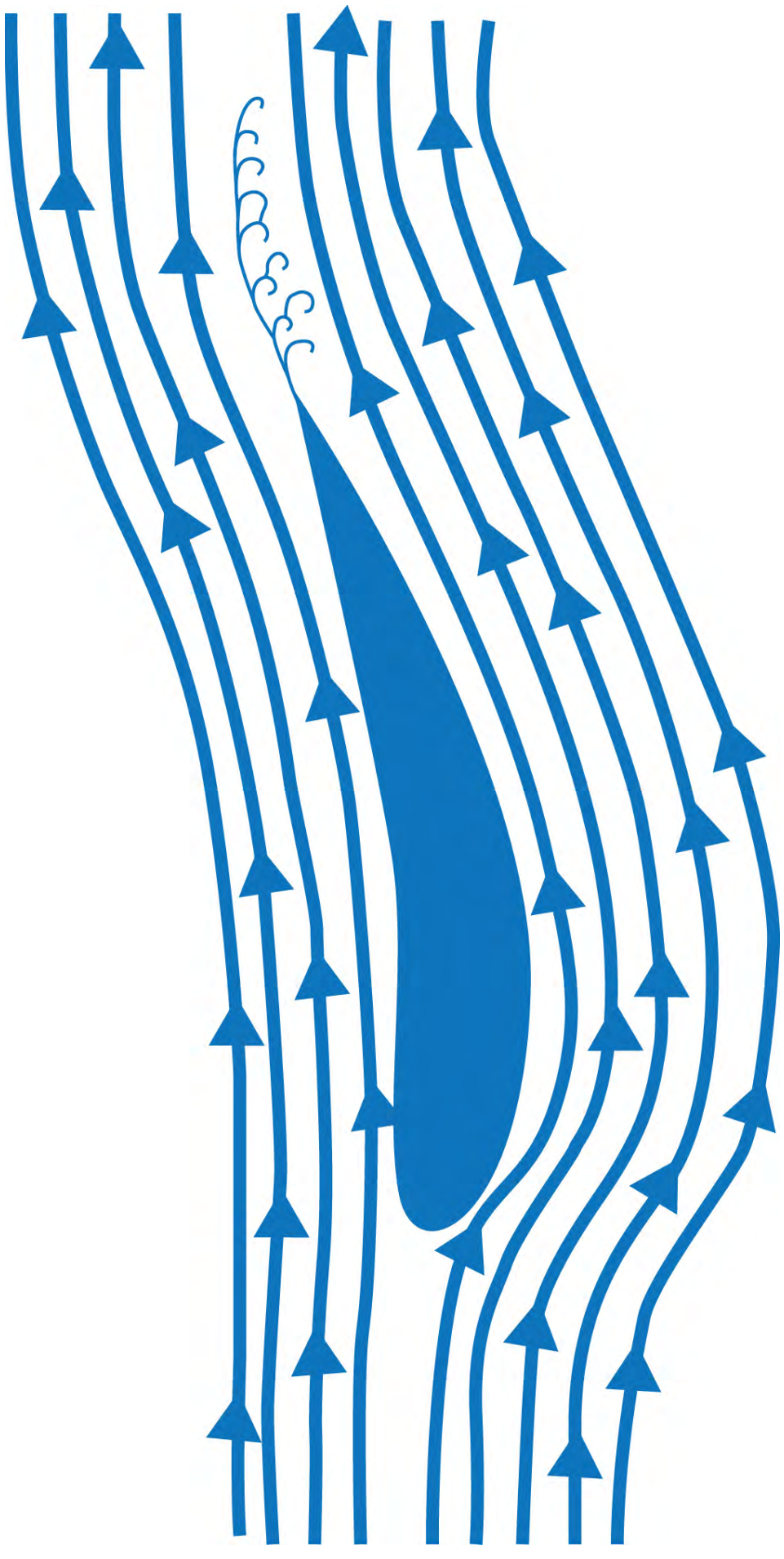


Fig. 3 Air approaching and passing over the surface.

Fig. 4 Climbing angle of attack

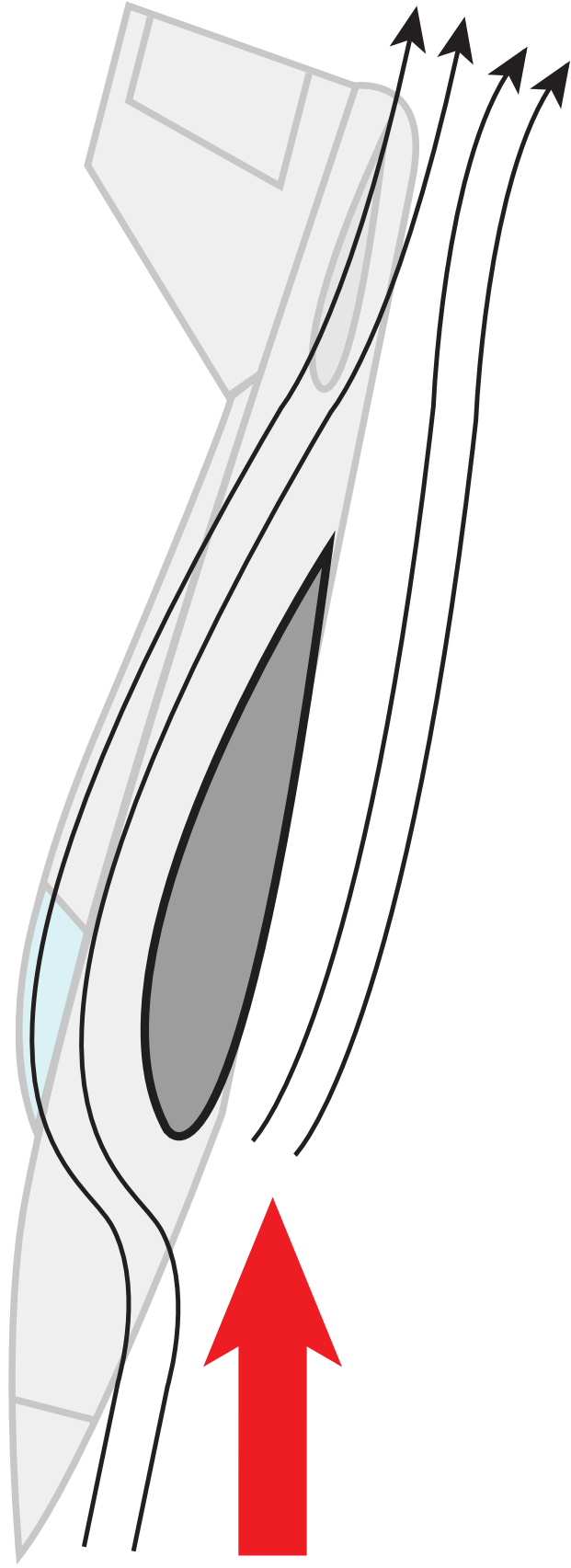


Fig. 5 Descending angle of attack

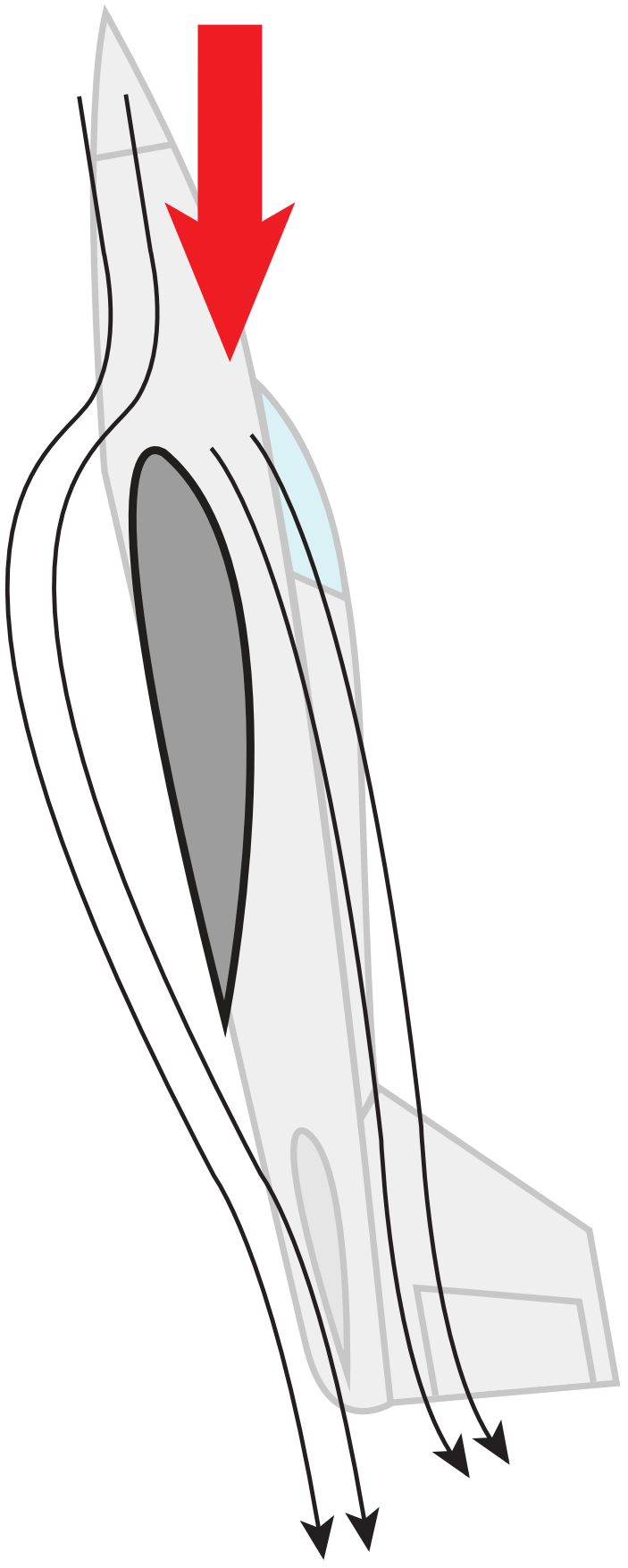


Fig. 6 Forces of straight and level flight

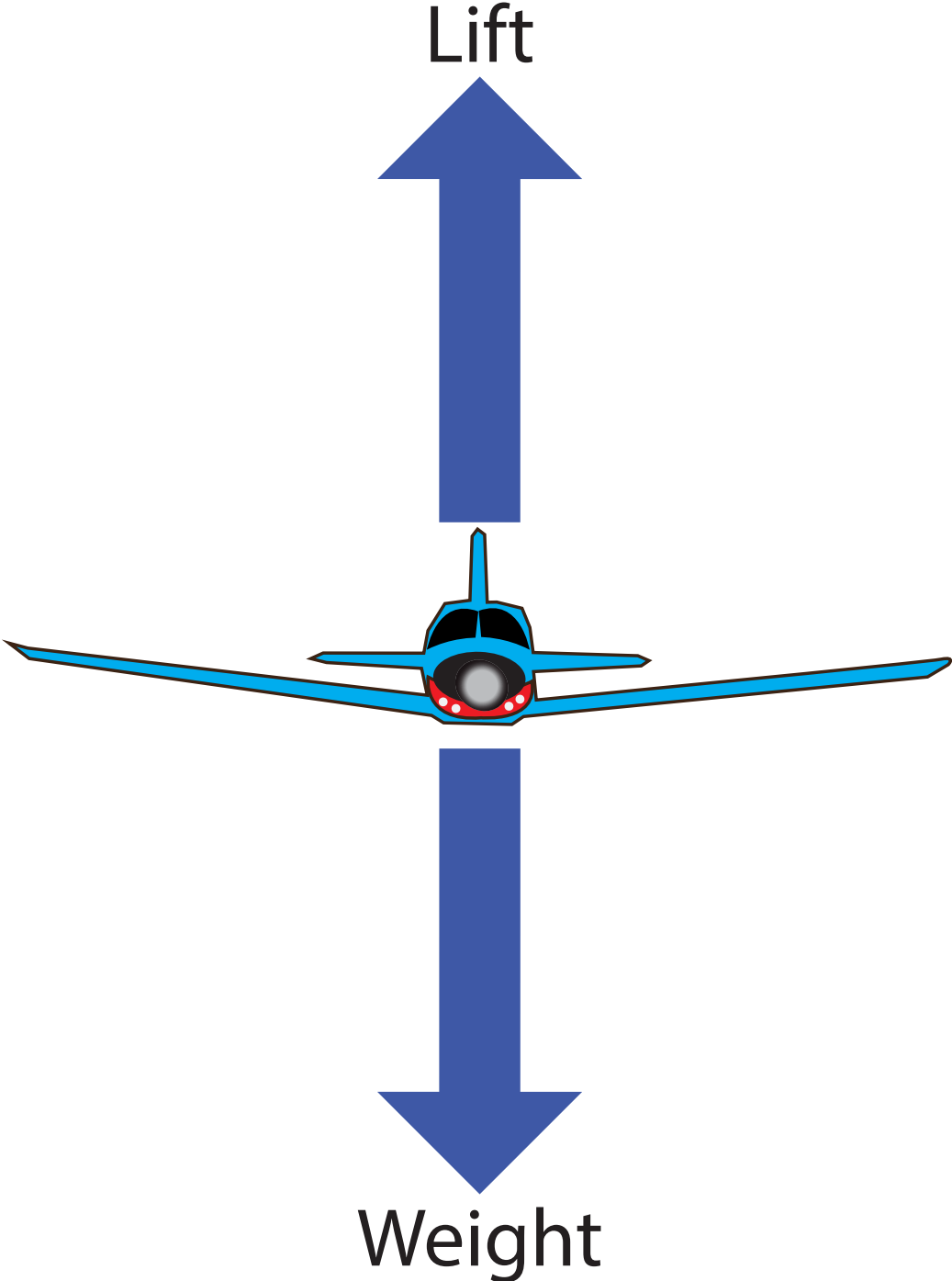


Fig. 7 Induced drag

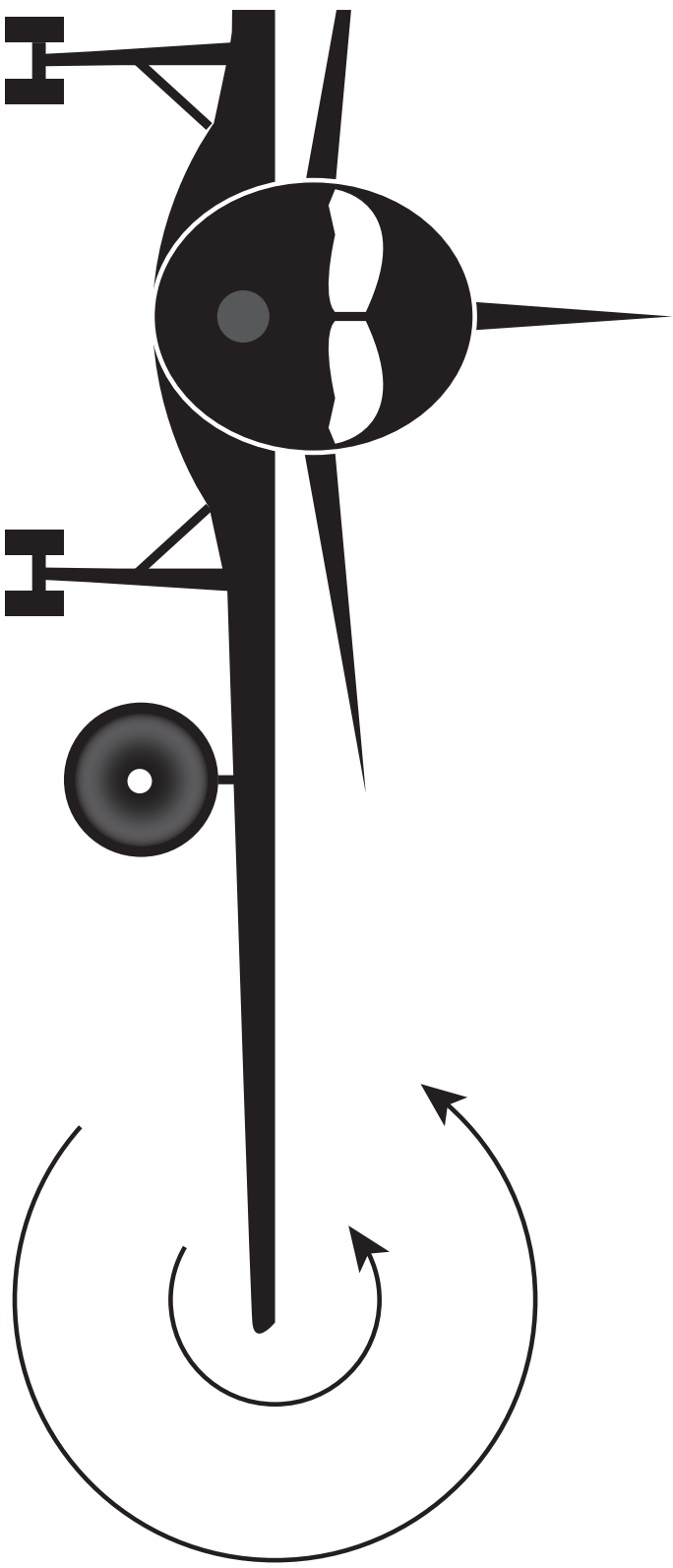


Fig. 8 Winglets effect on drag

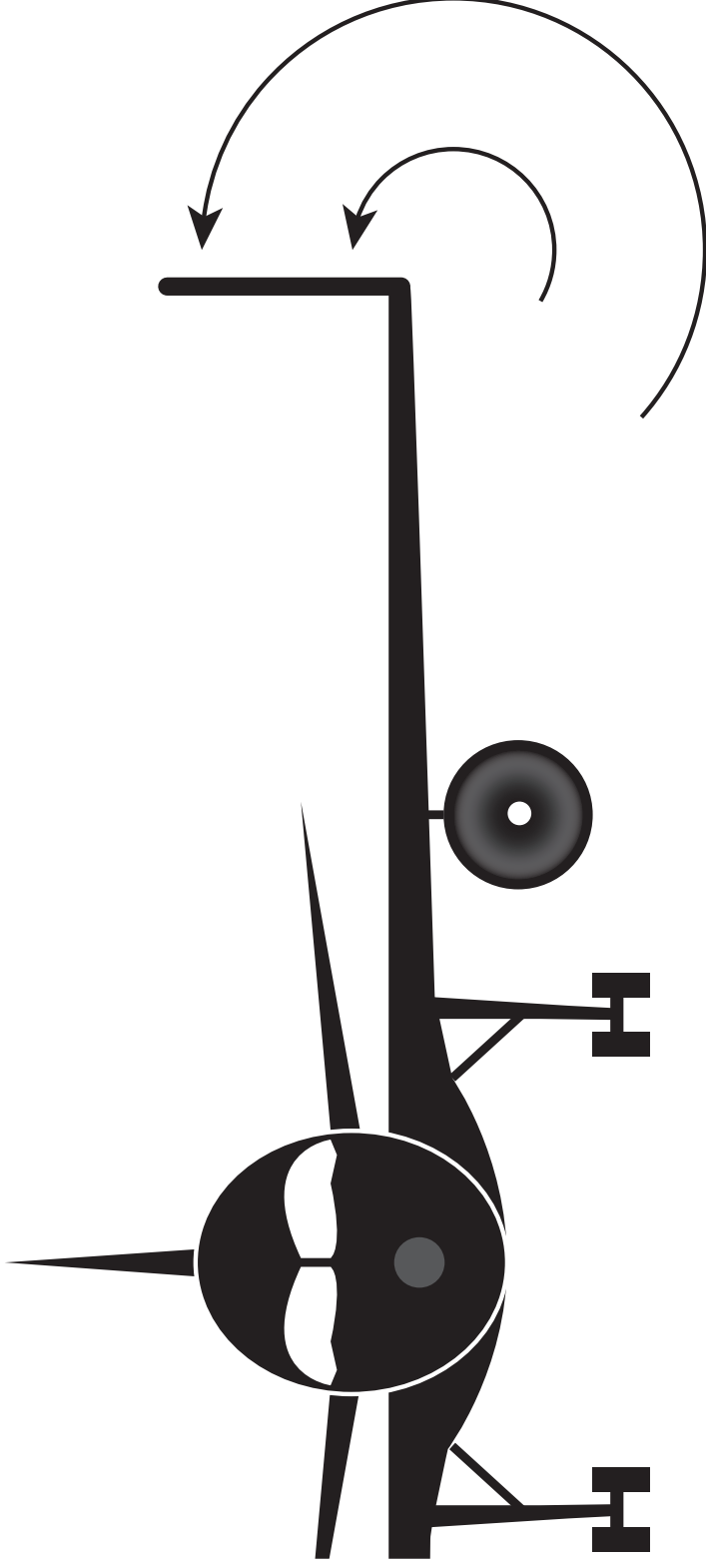
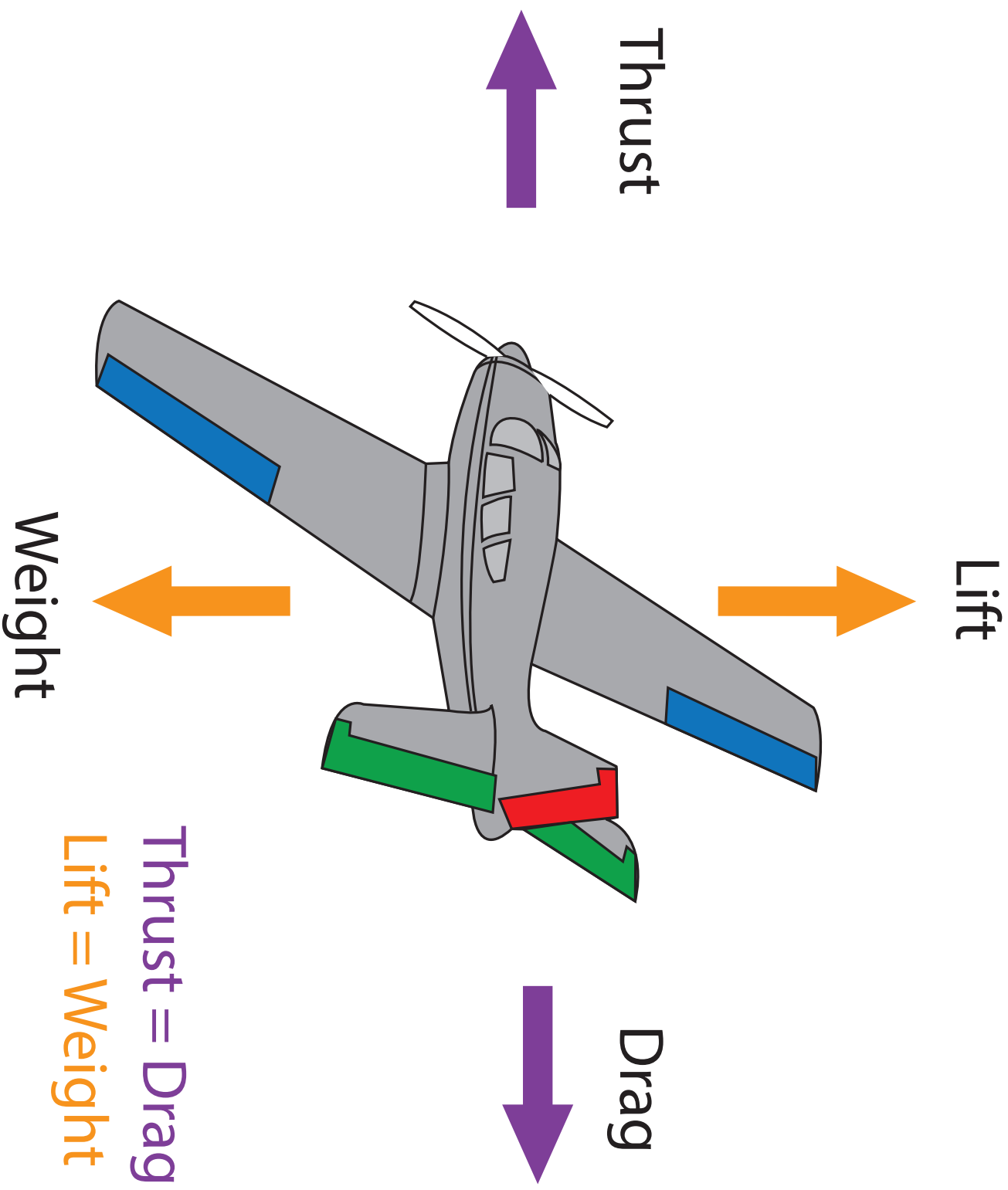


Fig. 9 The four forces of flight in balance





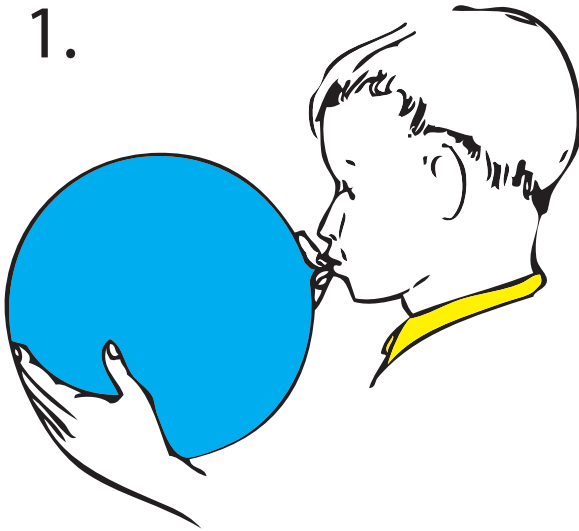
Worksheets

fold

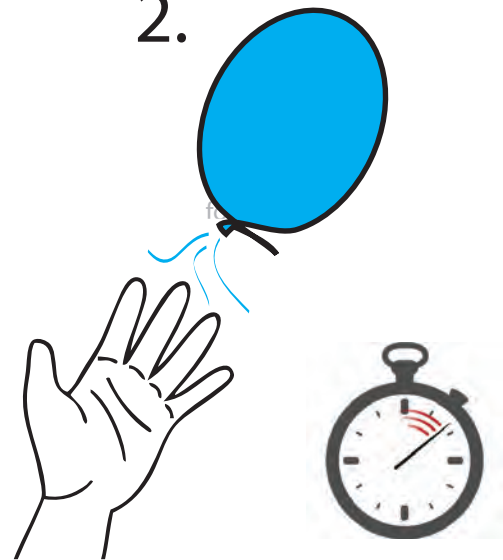
fold

Station One: Thrust

1.



2.



fold

fold

Station Two: Drag

1.



2.

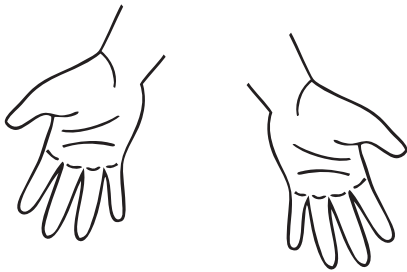


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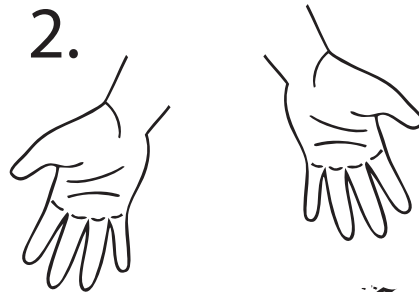
fold

Station Three: Weight

1.



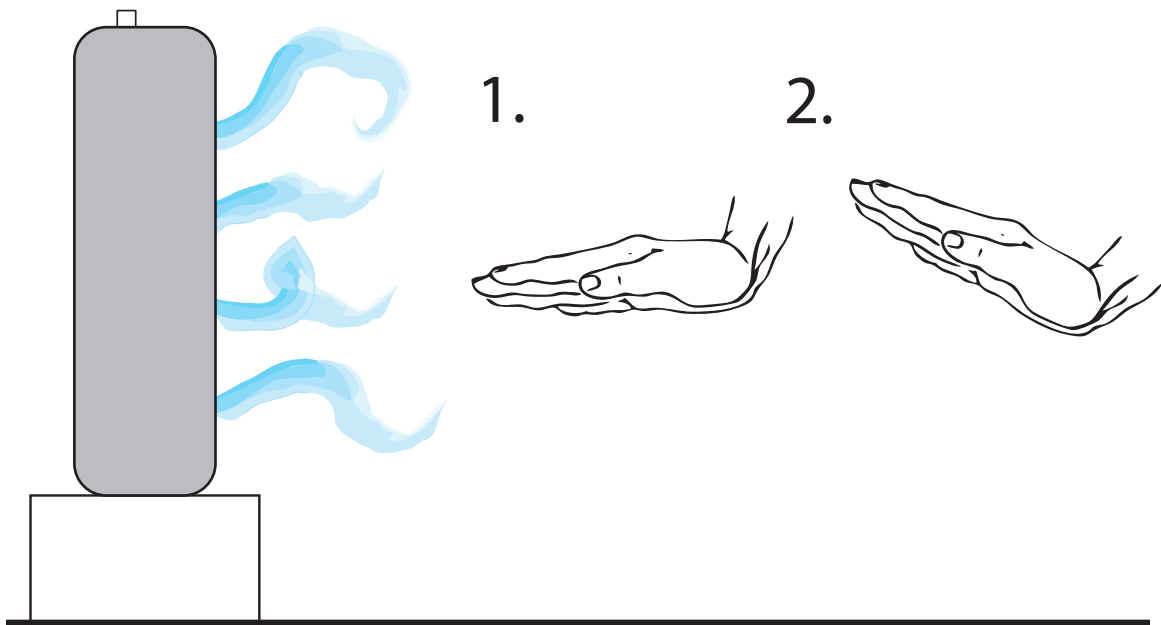
2.

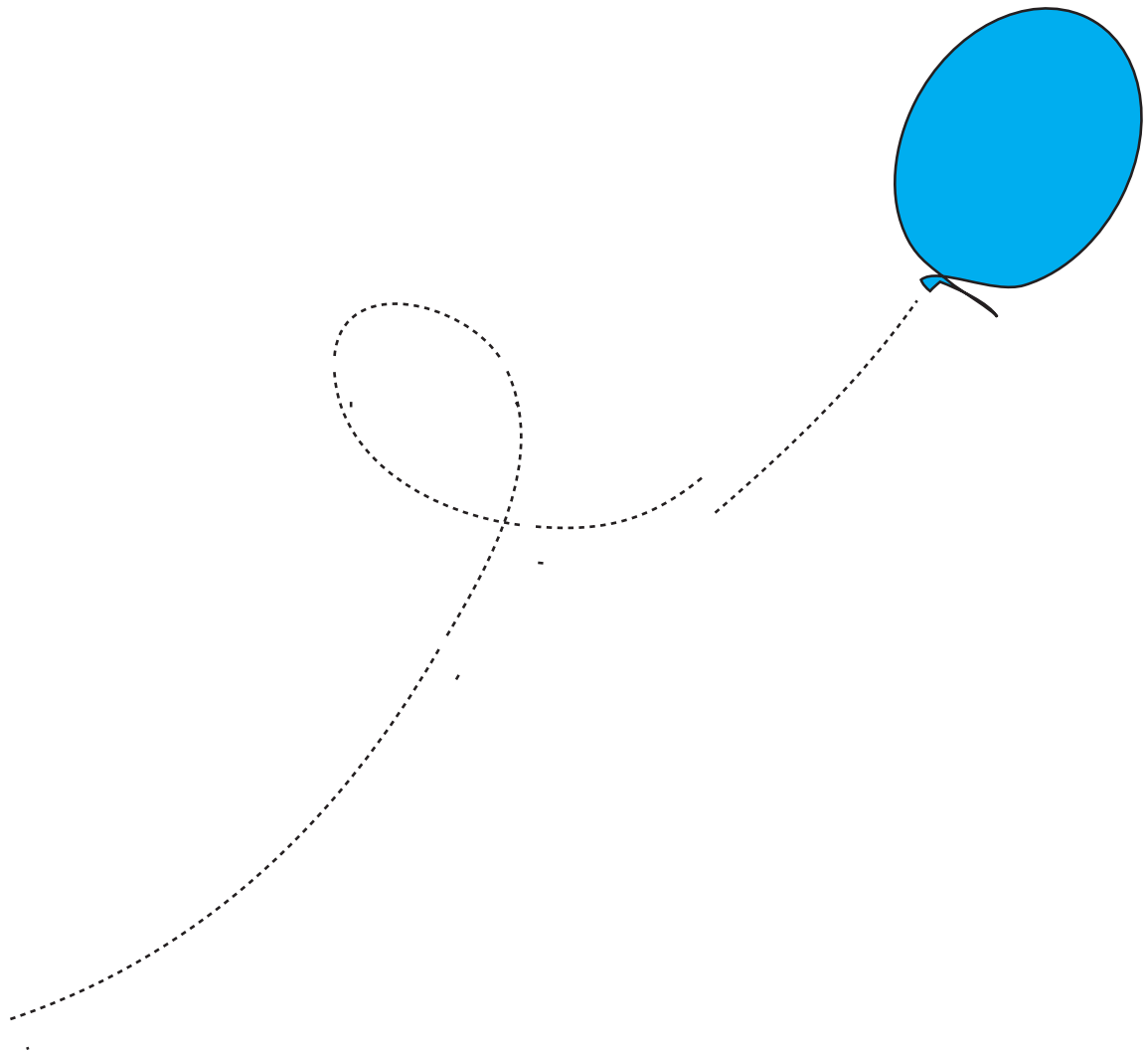


fold

fold

Station Four: Lift



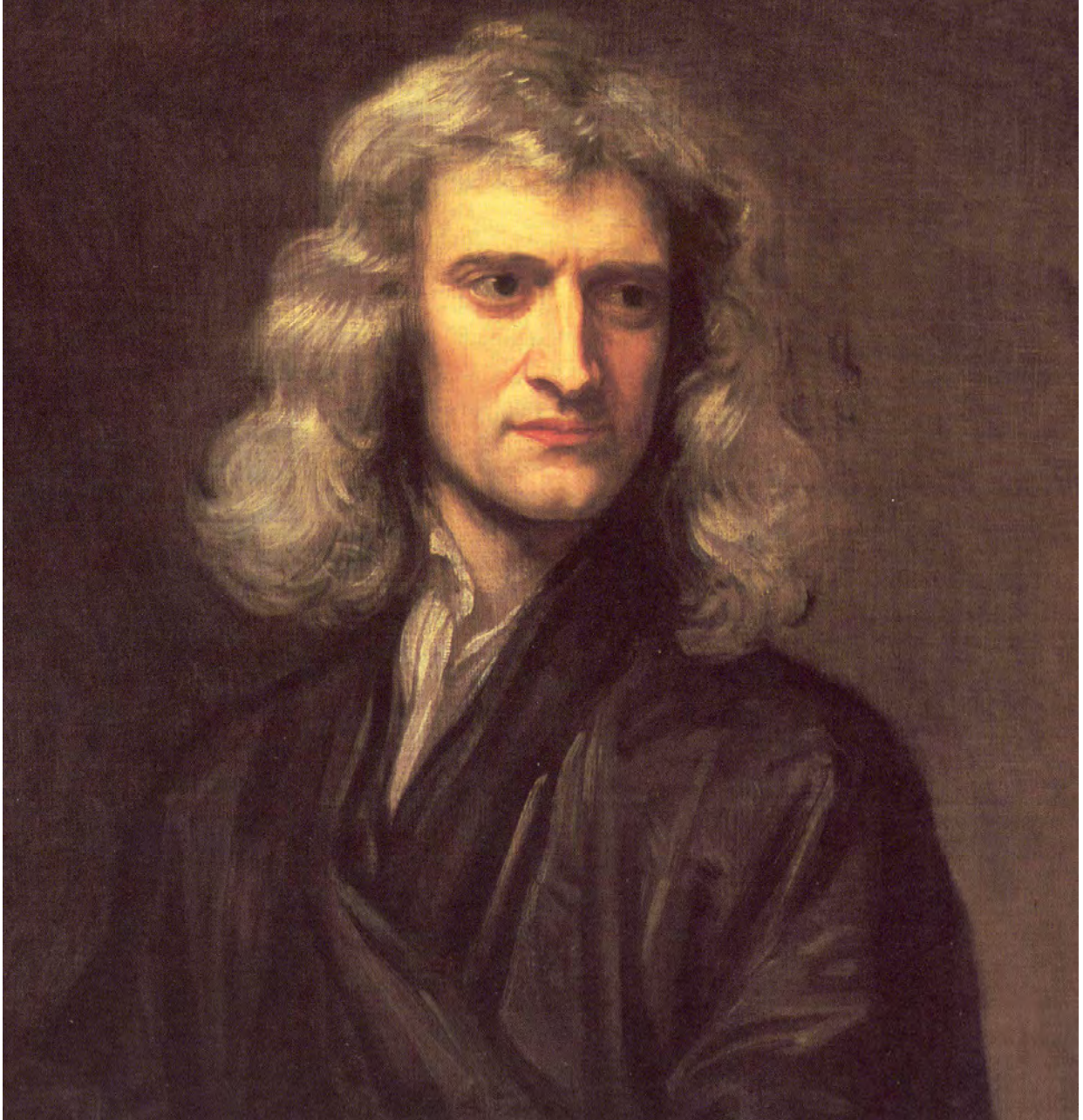


Number of Breaths	Flight Time



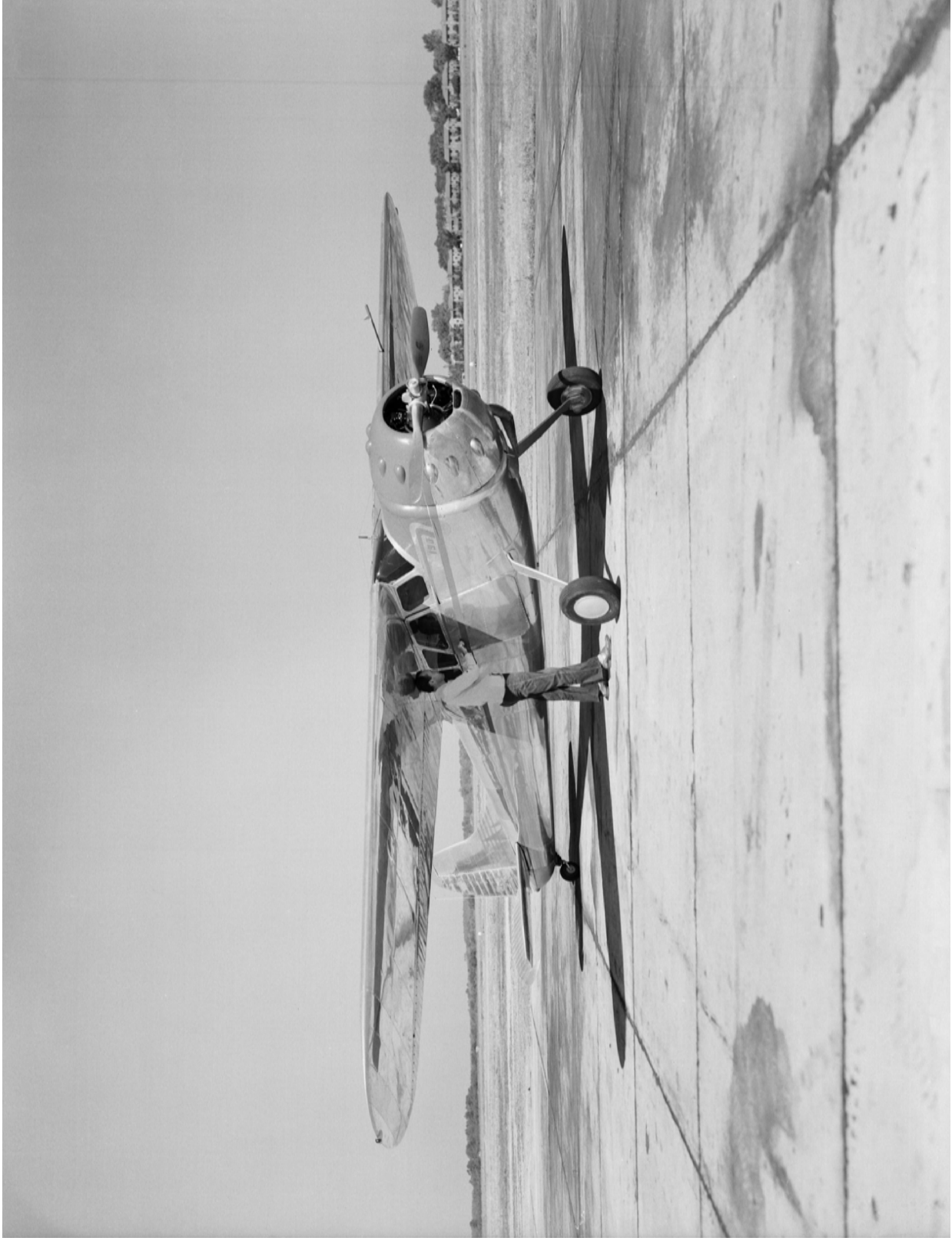
Images

Img. 1 Sir Isaac Newton (age 46)



(Painting by Sir Godfrey Kneller - 1689)

Img. 2 A NASA modified *essna 190*



(Photo courtesy of NASA)

Img. 3 A NASA modified Boeing 747



(Photo courtesy of NASA)

Img. 4 A NASA-modified C-135



(Photo courtesy of NASA)

Img. 5 A Boeing 727 vortex study



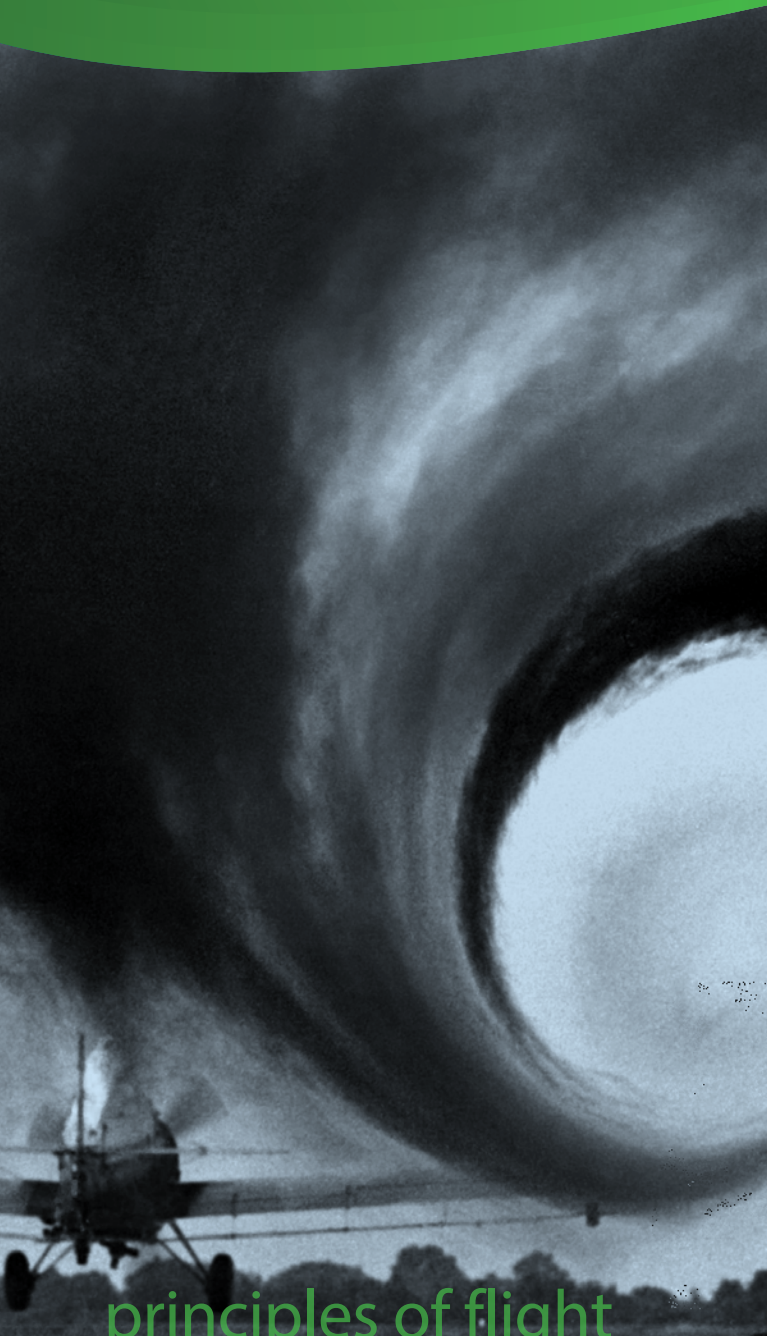
(Photo courtesy of NASA)

Img. 6 A wake vortex study at Wallops Island, VA

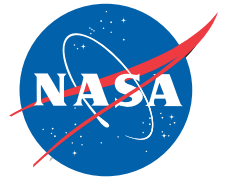


(Photo courtesy of NASA)

Aeronautics
Research
Mission
Directorate



principles of flight



GRADES

K-4

Bernoulli's Principle

principles of flight

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Bernoulli's Principle

Lesson Overview

In this lesson, students will learn about forces and motion as they see how the work of Daniel Bernoulli and Sir Isaac Newton help explain flight. Students will also learn how lift and gravity, two of the four forces of flight, act on an airplane while it is in the air. Additionally, students will experiment with the Bernoulli Principle. Students will relate the Bernoulli Principle to lift. Finally, students will relate the Bernoulli Principle to lift and apply the first and third laws of Sir Isaac Newton to flight.

Objectives

Students will:

1. Explore the Bernoulli Principle, which states that the speed of a fluid (air, in this case) determines the amount of pressure that a fluid can exert. Determine that though two items look identical, they may not have the same density.
2. Relate the Bernoulli Principle to the lift, one of the four forces of flight.
3. Explore, within the context of the Bernoulli Principle activities, how Newton's first and third laws of motion contribute to flight.

Materials:

In the Box

- Large paper grocery bag
- Scissors
- Tape or glue stick
- Ruler
- Variety of balloon shapes (optional)
- 2 large balloons
- 2 lengths of string 30cm each
- Straight straw (optional)
- 1 large trash bag
- 1 hair dryer or small fan with at least two speeds
- 1 ping-pong ball

Provided by User

- Paper
- Assortment of large felt tip markers (washable)

GRADES



Time Requirements: 3 hours

Background

How is it that today's airplanes, some of which have a maximum take off weight of a million pounds or more, are able to get off the ground in the first place, let alone fly between continents? Surprisingly, with today's technological advances, airplanes use the same principles of aerodynamics used by the Wright brothers in 1903. In order to gain an understanding of flight, it is important to understand the forces of flight (lift, weight, drag, and thrust), the Bernoulli Principle, and Newton's first and third laws of motion. Although the activities in this lesson primarily focus on the role the Bernoulli Principle plays in the ability of aircraft to achieve lift, the Bernoulli Principle is not the only reason for flight.

The Forces of Flight

At any given time, there are four forces acting upon an aircraft. These forces are lift, weight (or gravity), drag and thrust. Lift is the key aerodynamic force that keeps objects in the air. It is the force that opposes weight; thus, lift helps to keep an aircraft in the air. Weight is the force that works vertically by pulling all objects, including aircraft, toward the center of the Earth. In order to fly an aircraft, something (lift) needs to press it in the opposite direction of gravity. The weight of an object controls how strong the pressure (lift) will need to be. Lift is that pressure. Drag is a mechanical force generated by the interaction and contact of a solid body, such as an airplane, with a fluid (liquid or gas). Finally, the thrust is the force that is generated by the engines of an aircraft in order for the aircraft to move forward.

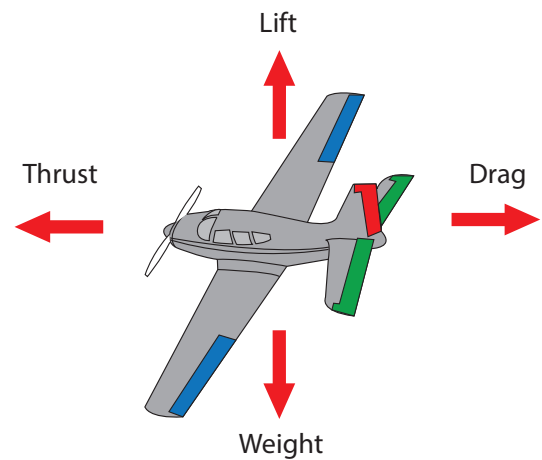
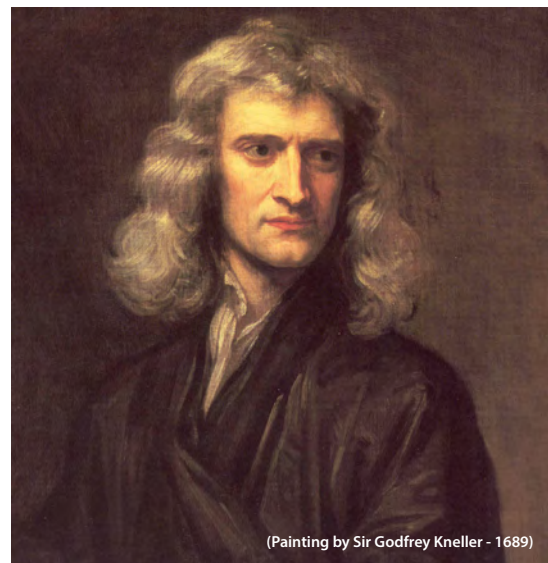


Fig. 1 Four forces of flight

Newton's Laws of Motion

Another essential that applies to understanding how airplanes fly are the laws of motion described by Sir Isaac Newton. Newton (1642 -1727) was an English physicist, mathematician, astronomer, alchemist, theologian and natural philosopher. He has long been considered one of the most influential men in human history. In 1687, Newton published the book "Philosophiæ Naturalis Principia Mathematica", commonly known as the "Principia". In "Principia", Newton explained the three laws of motion. Newton's first and third laws of motion are especially helpful in explaining the phenomenon of flight. The first law states that an object at rest remains at rest while an object in motion remains in motion, unless acted upon by an external force. Newton's second law states that force is equal to the change in momentum per change in time. For constant mass, force equals mass times acceleration or $F=m \cdot a$. Newton's third law states that for every action, there is an equal and opposite reaction.



Img. 1 Sir Isaac Newton (age 46)

The Bernoulli Principle

Daniel Bernoulli (1700 – 1782) was a Dutch-born scientist who studied in Italy and eventually settled in Switzerland. Born into a family of renowned mathematicians, his father, Johann Bernoulli, was one of the early developers of calculus and his uncle Jacob Bernoulli, was the first to discover the theory of probability. Although brilliant, Johann Bernoulli was both ambitious for his son Daniel and jealous of his son's success. Johann insisted that Daniel study business and later medicine, which Daniel did with distinction. It was mathematics, however, that really captured Daniel's interest and imagination. Despite Daniel's best efforts, Johann never acknowledged his son's brilliance and even tried to take credit for some of Daniel's most important ideas.



Img. 2 Daniel Bernoulli

After Daniel's studies, he moved to Venice where he worked on mathematics and practical medicine. In 1724, he published *Mathematical exercises*, and in 1725 he designed an hourglass that won him the prize of the Paris Academy, his first of ten. As a result of his growing fame as a mathematician, Daniel was invited to St. Petersburg to continue his research. Although Daniel was not happy in St. Petersburg, it was there that he wrote "*Hydrodynamica*", the work for which he is best known.

Bernoulli built his work off of that of Newton. In 1738, he published "*Hydrodynamica*", his study in fluid dynamics, or the study of how fluids

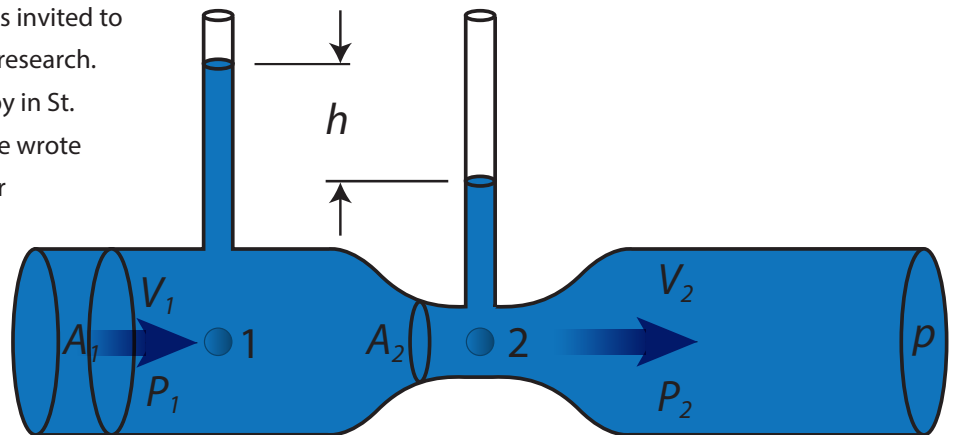


Fig. 2 Bernoulli fluid experiment

behave when they are in motion. Air, like water, is a fluid; however, unlike water, which is a liquid, air is a gaseous substance. Air is considered a fluid because it flows and can take on different shapes. Bernoulli asserted in "*Hydrodynamica*" that as a fluid moves faster, it produces less pressure, and conversely, slower moving fluids produce greater pressure.

We are able to explain how lift is generated for an airplane by gaining an understanding of the forces at work on an airplane and what principles guide those forces. First, it takes thrust to get the airplane moving - Newton's first law at work. This law states that an object at rest remains at rest while an object in motion remains in motion, unless acted upon by an external force.

Then because of the shape of an airplane's wing, called an airfoil, the air into which the airplane flies passes above and below the wing at different speeds. In general, the wing's upper surface is curved so that the air rushing over the top of the wing speeds up and stretches out, which decreases the air pressure above the wing. In contrast, the air flowing below the wing moves in a straighter line, thus its speed and pressure remain about the same. Since high pressure always moves toward low pressure, the air below the wing pushes upward toward the air above the wing. The wing, in the middle, is then "lifted" by the force of the air perpendicular to the wing. When the force of lift is greater than the force of gravity, the airplane is able to fly, and because of thrust, the airplane is able to move forward in flight. According to Newton's third law of motion, the action of the wings moving through the air creates lift.

In its simplest explanation, lift is a product of wing shape and the outcome of the total pressure on the bottom of the wing being greater than the total pressure on top of the wing. This difference in pressure results in a push force upwards. It is the difference in pressures that causes lift.

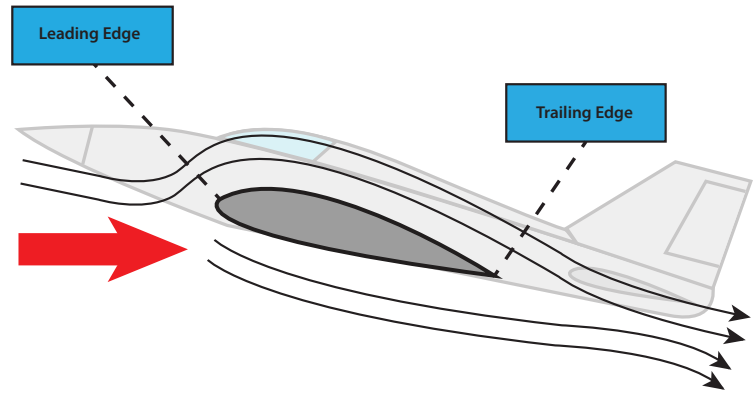


Fig. 3 Airfoil

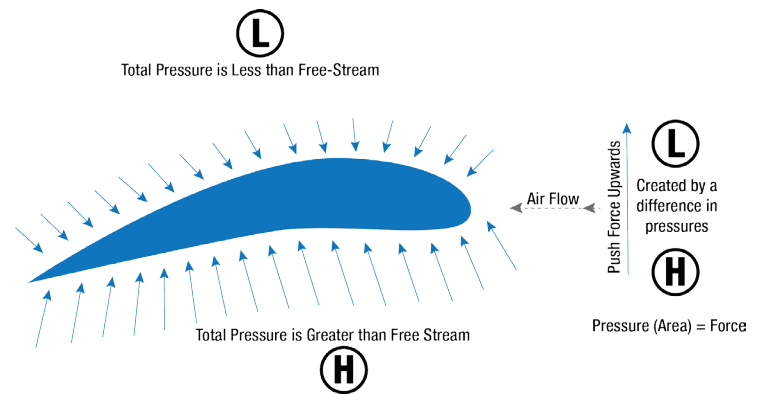


Fig. 4 Lift

Activity 1

Bernoulli and the Paper Bag Mask

GRADES

K-4

Time Requirements: 45 minutes

Materials:

Note to the Teacher: Decide if you are going to present this activity as a demonstration or as a hands-on learning experience for the whole class. For a demonstration, you will only need one of each item. For a hands-on class activity, you will need one set of the materials for every two students so that your students may work in pairs.

In the Box

Large paper grocery bag
Scissors
Tape or glue stick
Ruler
Variety of balloon shapes
(optional)

Provided by User

Paper
Assortment of large felt tip
markers (washable)

Worksheets

Bernoulli Experiment Log
(Worksheet 1)
Student Activity Directions
(Worksheet 2)

Reference Materials

None

Objective:

Students will learn about the position and motion of objects as they:

1. Create a paper bag mask to experiment with the Bernoulli Principle.
2. Explain how the Bernoulli Principle applies to the movement of the paper tongue attached to the paper bag mask.
3. Explain how the phenomenon they experienced in the paper bag mask activity relates to flight (lift).
4. Understand the effect of air flowing over a curved surface.

Activity Overview:

Students will make a paper bag mask with a protruding paper tongue, which they will use to experiment with the Bernoulli Principle. The students will be able to explain the Bernoulli Principle after they have observed it in action during the experiment.

Activity:

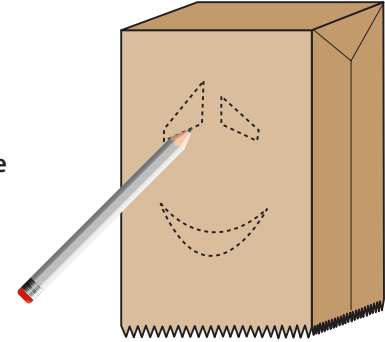
1. **If all of your students are going to participate in this activity, have the directions for the activity written on the board or make a copy of the direction sheet for each student or pair of students.**
2. **Ask the students this question: *How do airplanes, some of which weigh a million pounds, fly?***
Students' responses will vary but look for and encourage a response that includes weight or gravity. Tell the students that in order to fly, airplanes must overcome gravity, a force that wants to keep the airplane on the ground.
3. **Explain to the students that in order to overcome gravity, airplanes have to achieve lift, a force that opposes (or pushes against) gravity.** The greater the weight of the airplane, the greater the lift required.
4. **Explain to the students that today they will learn about a scientific principle that will help them understand lift.** Tell the students that the principle is called the Bernoulli Principle; it is named after the man who discovered it. (Here you can give the students some simple background information about Daniel Bernoulli. You may also show the students his picture.)

Key Terms:

Air pressure
 Air foil
 Bernoulli Principle
 Fluid
 Force
 Gravity
 Lift

5. Explain that the Bernoulli Principle states that slower moving fluids create greater pressure (force) than faster moving fluid. Tell the students that air is a fluid because it flows and can change its shape. Inflate balloons of different sizes and shapes to make this point. You may also need to clarify your students' understanding of the concept of "pressure" by comparing pressure to a push. A push may be light, or a push may be hard.

6. To begin, place a large paper grocery bag over the head of a student and have a second student use a felt tip marker to carefully draw small dots where the eyes, nose, and mouth of the student are located.



7. Remove the bag from the student's head and draw a face around the marks made in step 1.



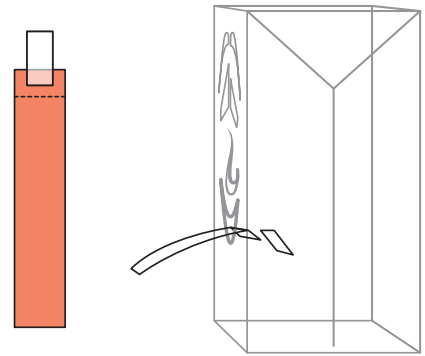
8. Cut out holes (approximately 1 inch in diameter) for each eye.



9. **Next, cut a mouth-shaped hole approximately 2 inches in height at the widest point, the middle, of the mouth.**
Have the students use safety scissors for this portion of the activity or have additional adults in the room to supervise.

10. **To make the tongue, cut a strip of printer/copier paper approximately 1½ inches wide and 8 inches long.**

11. **Fold down one end of the tongue to create a ¼ inch tab.** Tape or glue the tab to the inside of the bag along the lower middle edge of the mouth. The rest of the tongue should be hanging out of the mouth.



12. **Place the bag over a student's head and instruct the student to blow through the mouth hole with an even stream of air while the rest of the students observe the movement of the tongue.** (If this is being done in pairs, the partner who is not wearing the bag will do the observing.) Have the student wearing the bag vary the strength with which he or she blows. Remind students to keep a steady flow of air and to not just give a quick burst of air. Students will compare the effect of a gentle blow to the effect of a harder blow. If students are working in pairs, have them take turns wearing the bag and observing. (Students will notice that a gently blown stream of air will cause the tongue to rise, but a more forcefully blown stream of air will not lift the tongue at all.)



13. **Students record their observations on the Bernoulli Experiment Log.**

14. After the experiment, show a diagram of the cross-section of an airplane wing (also called an airfoil).

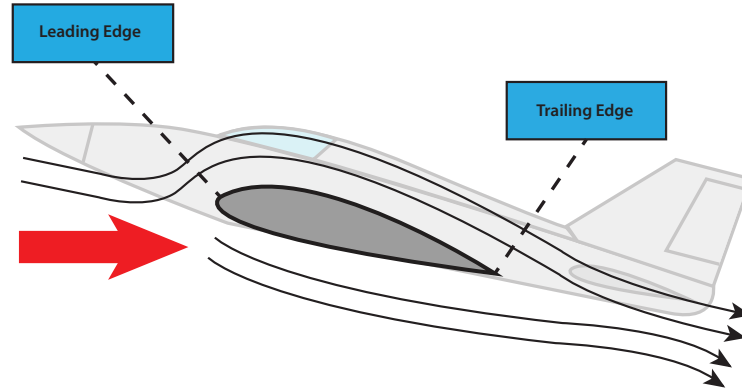


Fig. 3 Airfoil

15. Tell the students that the wing of an airplane is shaped in order to control the speed and pressure of the air flowing around it. Air moving over the curved upper surface of the wing will travel faster and thus produce less pressure than the slower air moving across the flatter underside of the wing. This difference in pressure creates lift which is a force of flight that is caused by the imbalance of high and low pressures.
16. Relate this information to the paper bag mask by saying this: Another example of Bernoulli's Principle was seen in our paper bag mask(s). When the air we blew over the curved surface of the paper tongue was faster than the air under the tongue, the unequal air pressure lifted the tongue in the same way an airplane wing produces lift.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Position and motion of objects

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

Activity 2

Balloon Magic

GRADES

K-4

Time Requirements: 60 minutes

Materials:

Note to the Teacher: Decide if you are going to present this activity as a demonstration or as a hands-on learning experience for the whole class. For a demonstration, you will only need one of each item. For a hands-on class activity, you will need one set of the materials for every two students so that your students may work in pairs.

In the Box

2 large balloons
2 lengths of string 30cm each
Straight straw (optional)
1 large trash bag

Provided by User

None

Worksheets

Bernoulli Experiment Log (Worksheet 1)
Student Activity Directions (Worksheet 2)

Reference Materials

None

Objective:

Students will learn about the position and motion of objects as they experiment with the Bernoulli Principle using a pair of inflated balloons that are suspended at the same height though several inches apart. By blowing air directly between the balloons, students will demonstrate the Bernoulli Principle and then explain the phenomenon to their classmates.

Activity Overview:

In this activity, students will experiment with the speed of the airflow between two suspended balloons, observing how fast moving air creates an area of low pressure and how high pressure moves toward low pressure.

Activity:

1. **Review what the students have learned so far about the Bernoulli Principle.**
Faster moving air equals less air pressure than slower moving air.

Also review what the students have learned so far about lift.

Lift is the force that opposes gravity and helps an airplane to fly. Lift is achieved in part by the design of an airplane's wing. Air moves more quickly over the curved upper surface of the wing than it does under the wing, which has a flatter surface. The faster moving air produces less pressure than the slower moving air, causing the wing to lift toward the area of low pressure.

2. **Now tell the students that they will explore the Bernoulli Principle again, but this time the activity will involve balloons.** If you are going to allow pairs of students (3rd and 4th grade) to construct their own experiment, caution the students about over-inflating the balloons.

Key Terms:

- Air flow
- High pressure
- Low pressure

3. Follow these directions below to conduct the experiment.
 - a. Inflate two balloons, tying off the end of each balloon
Teachers may wish to do this in advance. It is a good idea to keep the inflated balloons together by placing them in a large trash bag.
 - b. Cut two pieces of string each 30 cm in length.
Teachers may wish to have the strings cut in advance, too.
 - c. Tie the end of each string to one balloon so that when you are finished, you have each balloon tied to its own string (students may need help).



- d. Tape the loose end of each string to the underside of a table, to a window or doorframe, or to any other ledge that will allow the balloons to dangle in an open space about 5 cm apart.



- e. Use the straw to blow between the balloons, varying the amount and the speed of the airflow.



- f. Observe what happens.
Note: The balloons will come together when the students blow more forcefully.

- g. Record your results.

4. **After the experiment, have the students share their observations and any of their conclusions.**
5. **Explain that the balloons came together when the students blew through the straw with greater force because of the Bernoulli Principle, which states that faster moving air exerts lower pressure.** Tell them that when they blew air more forcefully between the two suspended balloons, they created an area of low pressure. Since the air pressure between the two balloons was not as great as the air pressure around the rest of each balloon, the balloons move toward each other because high pressure pushes toward low pressure.
6. **Relate this experiment to the paper bag mask. Ask: *How are the results of this experiment similar to those of the paper bag mask?***
Answers will vary but may include ideas such as faster moving air exerts lower pressure and slower moving air exerts higher pressure.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Position and motion of objects

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

Activity 3

The Floating Ball Demonstration

GRADES**K-4****Time Requirements:** 30 minutes**Materials:**In the Box

1 ping-pong ball
1 hair dryer or small fan
with at least two speed

Provided by User

None

Worksheets

Bernoulli Experiment Log
(Worksheet 1)

Reference Materials

Photo of Sir Isaac Newton
(Image 1)

Key Terms:

Airstream
Discrepant event
Gravity
Newton's Laws of Motion

Objective:

In this activity students will learn about position and motion of objects as they observe a discrepant event in which the Bernoulli Principle and Newton's First Law of Motion are demonstrated. Students will analyze what they learned from this activity and classify that information according to two criteria:

1. What previously learned information was reinforced from this activity?
2. What new information was learned from this activity?

Activity Overview:

In this activity students will observe a discrepant event in which the Bernoulli Principle and Newton's first Law of motion will be demonstrated. The discrepant event will involve placing a ping-pong ball into a stream of air generated by a hair dryer and exploring the conditions under which the ball "floats" in the air.

Activity:

Note: Prior to starting this activity, you may wish to practice balancing the ping pong ball in the air stream to ensure a seamless demonstration.

1. **Review the Bernoulli Principle with the class.** Write the explanation in the students' words on the board.
2. **Review the two vertical forces at work on an airplane in flight.** Students may need prompting, but get them to identify gravity and lift. Again, write the definitions or those two terms on the board using the students' words.
3. **Tell the students that the class will explore Bernoulli again, but this time the teacher will demonstrate the activity.**
4. **Show the students the materials for the activity, and explain that you are about to show them a trick that will almost look like magic, but what they are about to see can be explained by the science they have been learning.**
5. **Begin by asking the students if the hair dryer can make the ping-pong ball float?** Discuss students' responses, prompting them to elaborate and clarify by asking "why" and "how" when appropriate.

6. Turn the hair dryer on and aim it toward the ceiling, producing a vertical stream of air.
7. Place a ping-pong ball directly over the nozzle of the hair dryer and into the stream of air. The ball will appear to be floating in the air.



8. Ask the students to explain what the ball is floating on (air).
The air coming from the hair dryer.
9. Ask: Which air is moving faster, the air coming from the hair dryer or the air around the hair dryer?
The air coming from the hair dryer.
10. Ask: Which air is exerting a greater amount of pressure?
The air around the hair dryer.
11. Ask the students if they can explain why the ping-pong ball stayed in place while the hair dryer was on?
The slower moving air around the ball is holding the ball in place because the slower moving air exerts a greater amount of pressure than the faster moving air coming from the hair dryer.
12. Ask: What will happen if we turn off the hair dryer? What will happen if we turn the hair dryer down?
The ball will fall because there is no air flow there to hold it up.
13. After changing the direction of the hair dryer and turning it off and then on again, check to see if your students' predictions are correct. Remind the students that there is another force acting on the ball, a force that acts on all things – gravity. Ask students to define gravity. (Though their understanding will be limited, they may say that gravity is the force that causes things to fall.) Remind students that gravity is one of the four forces of flight they have been learning about (lift is another). Gravity wants to pull everything toward the center of the earth.
14. Explain that when the force of gravity becomes greater than the force of the air, the ball falls.



15. **Turn the hair dryer on again, “float” the ping-pong ball, and tilt the hair dryer slightly at first, then more severely.** The ball should move along with the hair dryer for a while, but when the hair dryer is tilted too far, the ball will fall to the ground. This will be the point at which gravity will have overtaken the lift produced by the faster moving air.
16. **Ask the students why the ping-pong ball eventually fell when the hair dryer was tilted too far toward the floor.** Answers will vary and it is likely that you will need to explain that gravity will have overtaken the lift produced by the faster moving air coming out of the hair dryer.
Explain that as long as there was equilibrium, or a correct balance between the forces acting on the ball, the ball stays floating in place, but when equilibrium is lost and one force becomes greater than another, the greater force takes over. When the force of gravity became greater than the force of the air around the ball, gravity took over, causing the ball to fall.
17. **Show the students a picture of Sir Isaac Newton.** Introduce him as the scientist who can offer an explanation for what we just observed in procedures 7 – 10 of the experiment. Tell the students that Newton wrote special laws called the Laws of Motion. Sir Isaac Newton’s laws of motion help us predict and explain the motion of objects and the forces that act on those objects, causing them to move.
18. **Ask the students how this particular law relates to our experiment.** Which part of our experiment might we identify as the object from Newton’s first law?
Students may identify the ping-pong ball as the object.

Which part of our experiment provided the force acting on the ball?
Students may identify the hair dryer as the source of the force.
19. **Ask the students if the ping-pong ball in our experiment acted according to the first part of the law.** In other words did it stay in motion?
Students will say yes.
20. **Ask the students to identify the point at which ball changed its motion.**
When we tilted the dryer, turned off the dryer or turned the force of the dryer down.
21. **Ask the students to identify the point in the experiment when the forces became unbalanced.**
This occurred when the force of gravity became greater than the air pressure from the hair dryer.
22. **Ask: What did you observe today that supported what you already knew from this lesson?**
Students may talk about the speed of air and air pressure.

- 23. Ask: What did you learn today that you didn't know before?
- 24. List students' answers to these two questions on the board on a T-chart:

What did I observe today that reinforced what I already knew?	What new information did I learn today?

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Position and motion of objects

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

Activity 4

A Letter to the Teacher

GRADES

K-4

Time Requirements: 45 minutes

Materials:

In the Box

None

Provided by User

Paper

Notes taken from the previous activities

Worksheets

Bernoulli Experiment Log (Worksheet 1)

Student Activity Directions (Worksheet 2)

Reference Materials

None

Key Terms:

None

Objective:

Students will write a paragraph about what they have learned in this lesson, incorporating new vocabulary and concepts.

Activity Overview:

In this activity students will recall all that they have learned from the previous activities about the forces of flight, the Bernoulli Principle and Newton's Laws of Motion.

Activity:

1. **To conclude the lesson, have the students write a brief paragraph (3 – 5 sentences) that answers the question asked at the beginning of the lesson: *How do airplanes fly?***
2. **In their paragraphs, students may include any of the ideas the teacher recorded on the board during activities or any ideas the students recorded on their Bernoulli Experiment Logs.**
3. **In order to help the students recall what they have learned, provide a word bank with the following words and terms:**

Air pressure	Airstream	Force	Lift
Airflow	Bernoulli Principle	Gravity	Low pressure
Airfoil	Fluid	High pressure	Newton's Laws of Motion

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology



Reference Materials

Glossary

Air pressure:

The amount of pressure air is able to exert on substances or objects; air pressure can be high or low, depending on the speed at which it travels

Air flow:

The air flowing past or through a moving object

Airfoil:

Any surface designed to help lift an aircraft with the use of air current

Airstream:

A current of air

Bernoulli Principle:

The principle that states that as the speed of a moving fluid (liquid or gas) increases, the pressure within the fluid decreases. Law that pressure in a fluid decreases

Discrepant event:

An event that goes against what is expected

Fluid:

A substance that can easily change its shape and is capable of flowing

Force:

A push or pull on an object

Gravity:

A pull between two objects based on their mass

High pressure:

Having a high barometric pressure

Lift:

Lift is the force that directly opposes the weight of an airplane and holds the airplane in the air. Although generated by every part of an airplane, wings generate the most lift. Lift is a mechanical aerodynamic force produced by the motion of the airplane moving through the air.

Low pressure:

Having a low barometric pressure

Newton's Laws of Motion:

Newton's laws of motion are three physical laws that describe the relationship between the forces acting on an object and the object's motion due to those forces. The laws can be summarized as follows:

First law: The velocity of a body remains constant unless the body is acted upon by an external force.

Second law: The acceleration of a body is parallel and directly proportional to the net force (F) and inversely proportional to the mass (m). Therefore $F = m \cdot a$.

Third law: The mutual forces of action and reaction between two bodies are equal and opposite.

Fig. 1 Four forces of flight

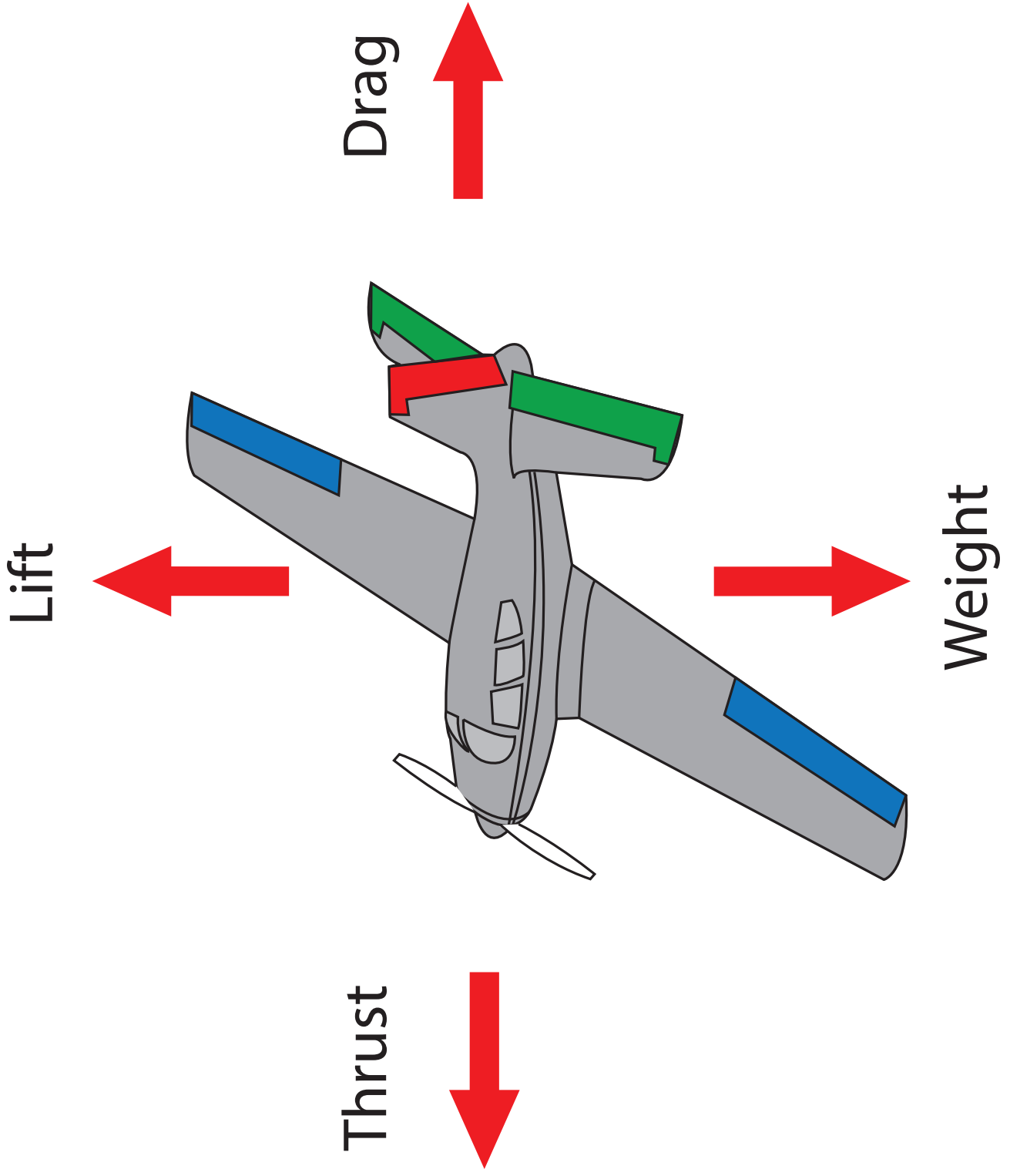


Fig. 2 Bernoulli fluid experiment

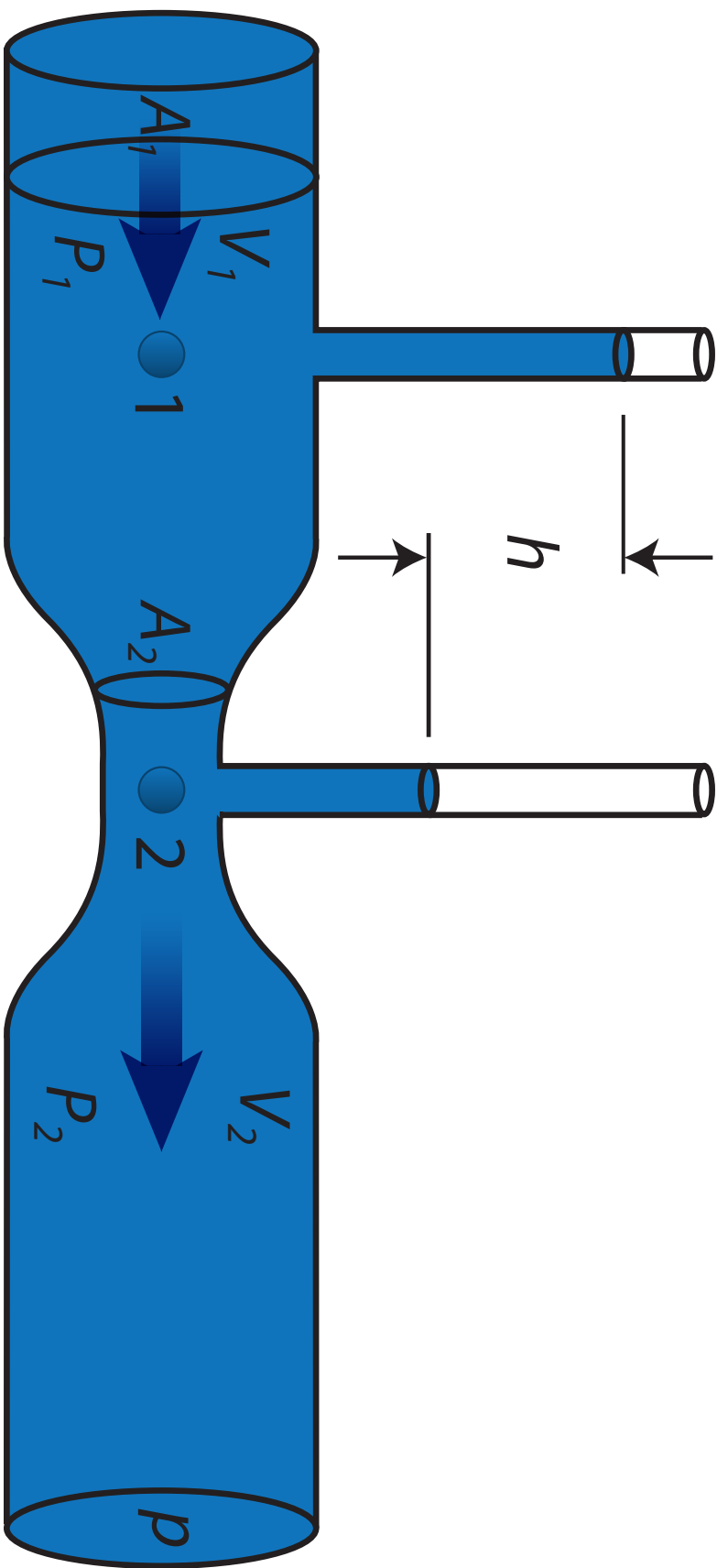


Fig. 3 Airfoil

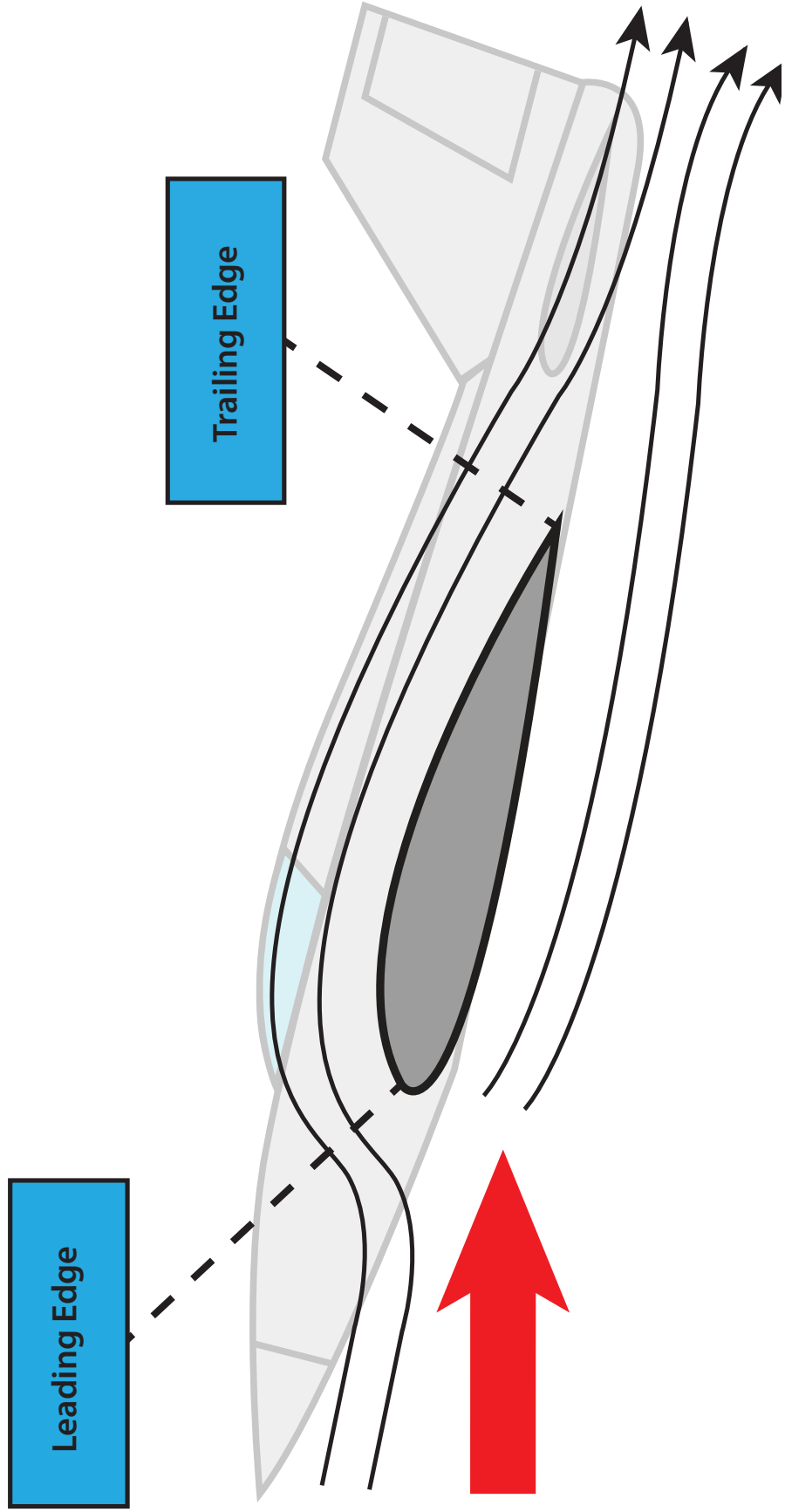
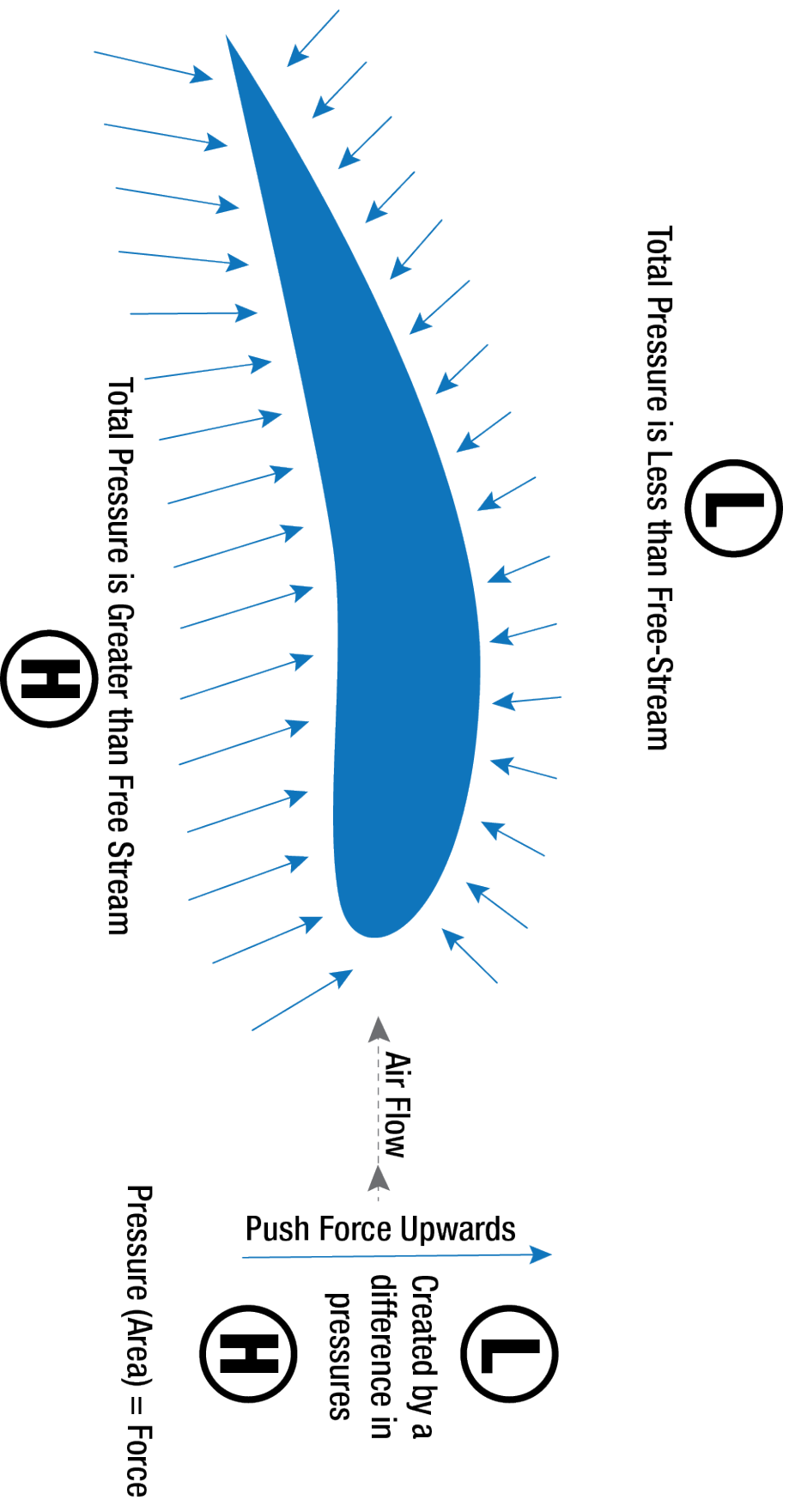


Fig. 4 Lift





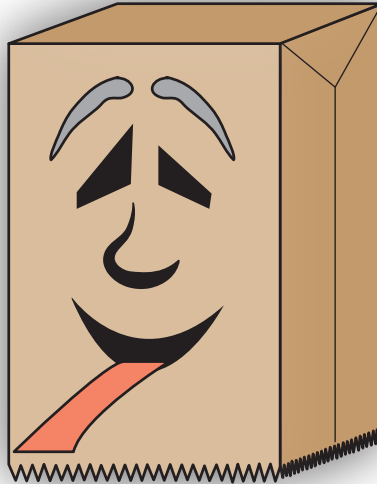
Worksheets

Worksheet 1

Bernoulli Experiment Log

After your teacher introduces the activity and you have read the Student Activity Instructions Page, predict what you think will happen in each activity. Then after you complete each activity, record what you observed during the activity. Finally, after you learn more about the Bernoulli Principle, give reasons for the outcome of each activity including how the outcome relates to the Bernoulli Principle. Write all of your responses in the boxes below.

<p>Activity</p>	<p>What do you think will happen?</p> <p><i><u>Predict</u></i></p>	<p>What happened?</p> <p><i><u>Observe</u></i></p>	<p>Why did it happen?</p> <p><i><u>Conclude</u></i></p>
<p>Paper Bag Mask</p>			
<p>Balloon Magic</p>			
<p>Floating Ball</p>			



Activity #1 Paper Bag Mask

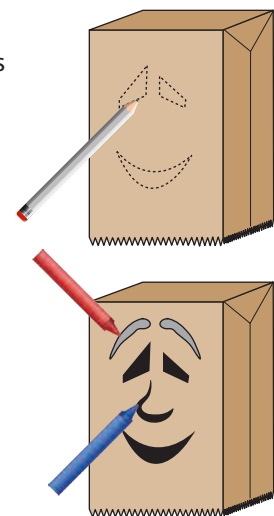
Materials:

One set per pair of students

- Large paper grocery bag
- Scissors
- Tape or glue stick
- Paper
- Ruler
- Assortment of large felt tip markers (washable)
- Variety of balloon shapes (optional)

Instructions for the Activity:

1. Place a bag over the head of one student and have a second student carefully draw small dots where the eyes, nose, and mouth are located.
2. Remove the bag from the head and draw a face around the marks made in step 1.



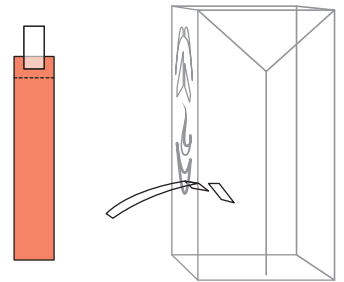
Worksheet 2 (cont.)

Student Activity Instructions

3. Cut out two holes (approximately 2 cm diameter) for the eyes.

4. Cut a hole (approximately 4 cm diameter) for the mouth.

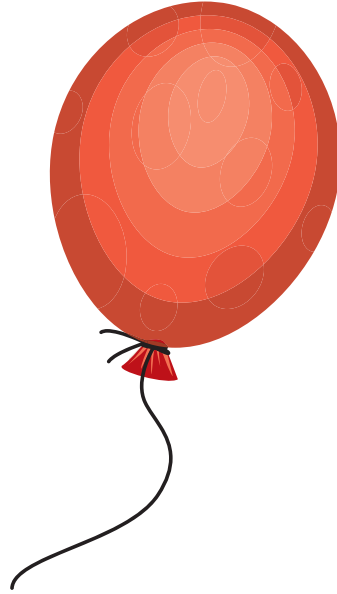
5. To make the tongue, cut a strip of paper, approximately 3 cm wide and 20 cm long.



6. Tape or glue one end of the tongue inside the bag at the bottom of the mask's mouth. Allow the tongue to droop through the mouth on the outside of the bag.

7. Place the bag over the head and blow through the mouth hole. Observe the movement of the tongue.





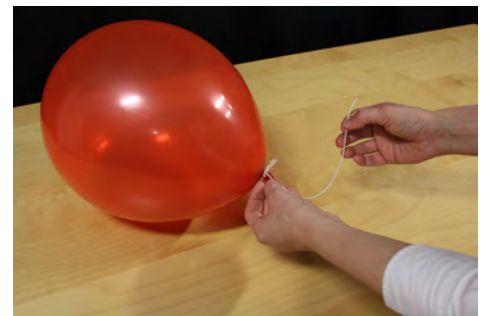
Activity #2 Balloon Magic

Materials:

- 1 hair dryer or small fan with at least two speeds
- 1 ping-pong ball

Instructions for the Experiment:

1. Inflate two balloons, tying off the end of each balloon
2. Cut two pieces of string each 30 cm in length.
3. Tie the end of each string to one balloon so that when you are finished you have each balloon tied to its own string.



4. Tape the loose end of each string to the underside of a table, to a window or doorframe, or to any other ledge that will allow the balloons to dangle in an open space about 5 cm apart.



5. Use the straw to blow between the balloons, varying the amount and the speed of the airflow.



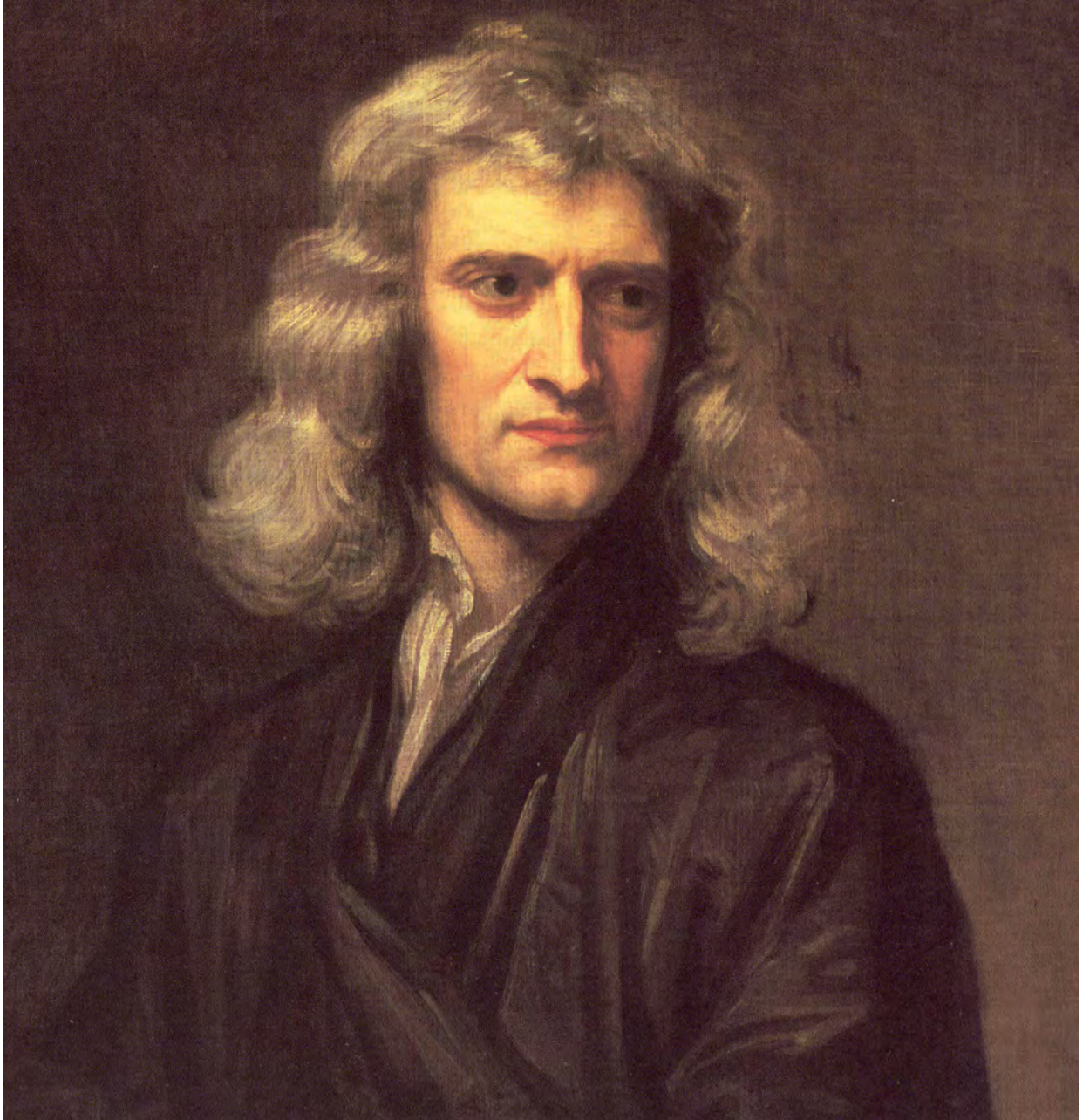
6. Observe what happens.

7. Record your results.



Images

Img. 1 Sir Isaac Newton (age 46)



(Painting by Sir Godfrey Kneller - 1689)

Img. 2 Daniel Bernoulli

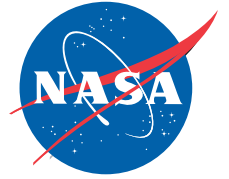


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principles of flight



GRADES

K-4

Bernoulli's Principle

principles of flight

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Bernoulli's Principle

Lesson Overview

In this inquiry-based lesson, students will learn about energy transfer as well as motions and forces as they engage in a series of five experiments, each of which will demonstrate the Bernoulli Principle. The students will discuss the role of the Bernoulli Principle in regards to flight only after they have completed their experiments, thus giving them a context for better understanding the Bernoulli Principle.

Objectives

Students will:

1. Explain that air is a fluid similar to water.
2. Demonstrate how the Bernoulli Principle helps create lift.
3. Use the scientific method to predict, observe and conclude.
4. Explain the relationship between the velocity of a fluid and the amount of lift created.

Materials:

In the Box

Drinking straws

Ruler

Scissors

1 clear plastic cup

Water

Food coloring (optional)

Medium-sized funnel (or the top of a 2-liter bottle)

1 ping-pong ball

Provided by User

Paper

2 empty soda cans

Several cheese balls

GRADES

5-8

Time Requirements: 2 hours

Background

How is it that today's airplanes, some of which have a maximum take off weight of a million pounds or more, are able to get off the ground in the first place, let alone fly between continents? Surprisingly, even with today's technological advances, we still use the same principles of aerodynamics used by the Wright brothers in 1903. In order to gain an understanding of flight, it is important to understand the forces of flight (lift, weight, drag, and thrust), the Bernoulli Principle, and Newton's first and third laws of motion. Although the activities in this lesson primarily focus on the role the Bernoulli Principle plays in the ability of aircraft to achieve lift, the Bernoulli Principle is not the only reason for flight.

The Forces of Flight

At any given time, there are four forces acting upon an aircraft. These forces are lift, weight, drag and thrust. Lift is the key aerodynamic force that keeps objects in the air. It is the force that opposes weight and thus, the force that helps keep an aircraft in the air. Weight is the force that works vertically by pulling all objects, including aircraft, toward the center of the Earth. In order to fly, an aircraft needs something to press it in the opposite direction of gravity, and the weight of an object controls how strong that pressure will need to be. Lift is that pressure. Drag is a mechanical force generated by the interaction and contact of a solid body, such as an airplane, with a fluid (liquid or gas). Finally there is thrust, or the force that is generated by the engines of an aircraft in order to move the aircraft forward in its path.

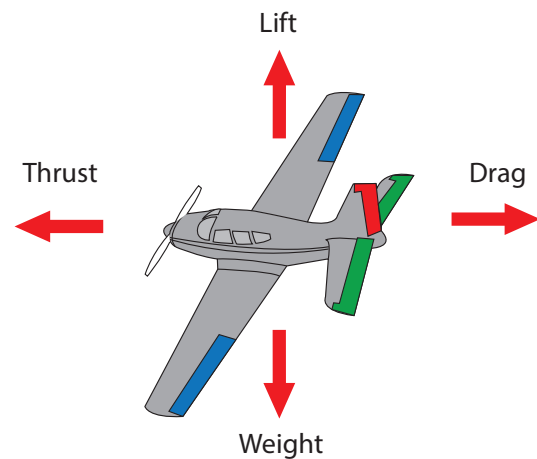
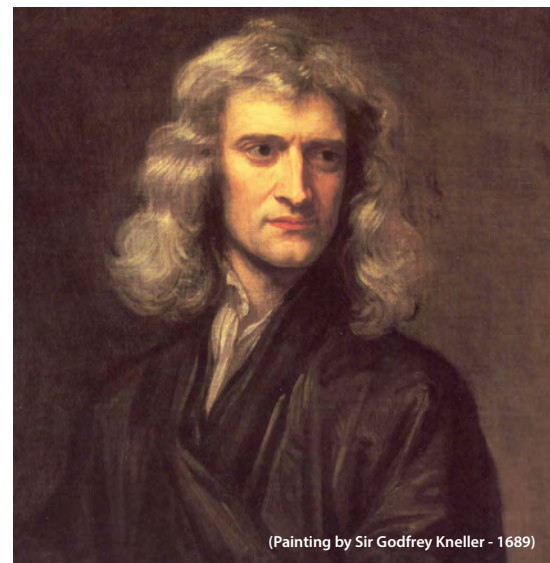


Fig. 1 Four forces of flight

Newton's Laws of Motion

Also, essential to an understanding of how airplanes fly, are the laws of motion first described by Sir Isaac Newton. Newton (1642 -1727) was an English physicist, mathematician, astronomer, alchemist, theologian and natural philosopher. He has long been considered one of the most influential men in human history. In 1687, Newton published the book "Philosophiæ Naturalis Principia Mathematica", commonly known as the "Principia". In "Principia", Newton explained the three laws of motion. Newton's first and third laws of motion are especially helpful in explaining the phenomenon of flight. The first law states that an object at rest remains at rest while an object in motion remains in motion, unless acted upon by an external force. Newton's second law states that force is equal to the change in momentum per change in time. For constant mass, force equals mass times acceleration or $F=m \cdot a$. Newton's third law states that for every action, there is an equal and opposite reaction.



Img. 1 Sir Isaac Newton (age 46)

The Bernoulli Principle

So, how does Daniel Bernoulli, who is known for the Bernoulli Principle, figure into all of this? Bernoulli built his work off of that of Newton.

Bernoulli (1700 – 1782) was a Dutch-born scientist who studied in Italy and eventually settled in Switzerland. Daniel Bernoulli was born into a family of renowned mathematicians. His father, Johann Bernoulli, was one of the early developers of calculus and his uncle Jacob Bernoulli, was the first to discover the theory of probability. Although brilliant, Johann Bernoulli was both ambitious for his son Daniel and jealous of his son's success. Johann insisted that Daniel study business and later medicine, which Daniel did with distinction. It was mathematics, however, that really captured Daniel's interest and imagination. Despite Daniel's best efforts, Johann never acknowledged his son's brilliance and even tried to take credit for some of Daniel's most important ideas.



Img. 2 Daniel Bernoulli

After Daniel's studies, he moved to Venice where he worked on mathematics and practical medicine. In 1724, he published *Mathematical exercises*, and in 1725 he designed an hourglass that won him the prize of the Paris Academy, his first of ten. As a result of his growing fame as a mathematician, Daniel was invited to St. Petersburg to continue his research. Although Daniel was not happy in St. Petersburg, it was there that he wrote "*Hydrodynamica*", the work for which he is best known.

In 1738, Bernoulli published "*Hydrodynamica*", his study in fluid dynamics, or the study of how fluids behave when they're in motion. Air, like water, is a fluid; however, unlike water, which is a liquid, air is a

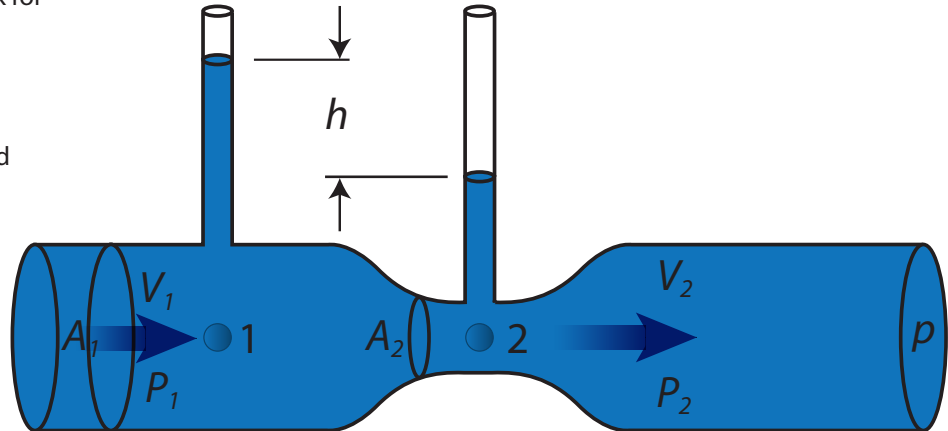


Fig. 2 Bernoulli fluid experiment

gaseous substance. Air is considered a fluid because it flows and can take on different shapes. Bernoulli asserted in "*Hydrodynamica*" that as a fluid moves faster, it produces less pressure, and conversely, slower moving fluids produce greater pressure.

By gaining an understanding of the forces at work on an airplane and what principles guide those forces, we are able to explain how lift is generated for an airplane. First, it takes a force, or thrust, to get the airplane moving. That's Newton's first law at work. This law states that an object at rest remains at rest while an object in motion remains in motion, unless acted upon by an external force.

Then because of the shape of an airplane's wing, called an airfoil, the air into which the airplane flies is split at the wing's leading edge, passing above and below the wing at different speeds so that the air will reach the same endpoint along the trailing edge of the wing at the same time. In general, the wing's upper surface is curved so that the air rushing over the top of the wing speeds up and stretches out, which decreases the air pressure above the wing. In contrast, the air flowing below the wing moves in a straighter line, thus its speed and pressure remain about the same. Since high pressure always moves toward low pressure, the air below the wing pushes upward toward the air above the wing. The wing, in the middle, is then "lifted" by the force of the air perpendicular to the wing. The faster an airplane moves, the more lift there is. When the force of lift is greater than the force of gravity, the airplane is able to fly, and because of thrust, the airplane is able to move forward in flight. According to Newton's third law of motion, the action of the wings moving through the air creates lift.

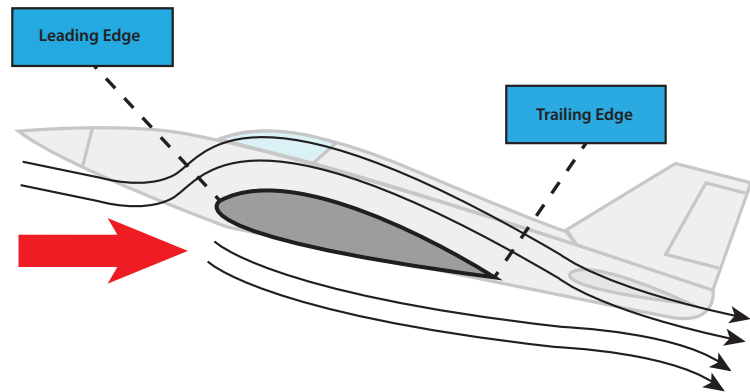


Fig. 3 Airfoil

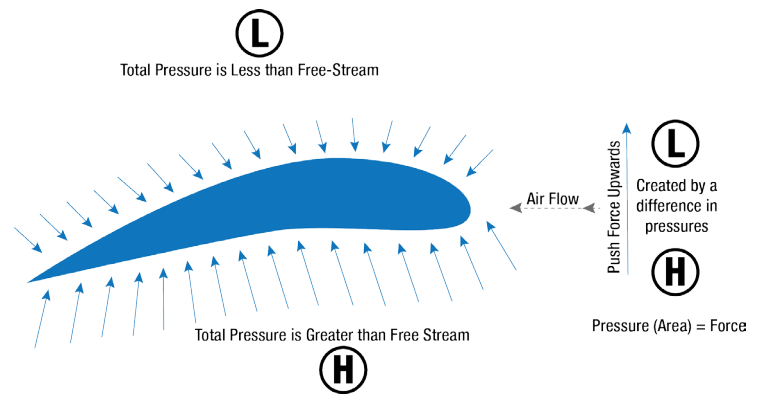


Fig. 4 Lift

Activity 1

Discovering the Bernoulli Principle

GRADES**5-8****Time Requirements:** 2 hours**Materials:**In the Box

Drinking straws
 Ruler
 Scissors
 1 clear plastic cup
 Water
 Medium-sized funnel (or
 the top of a 2-liter bottle)
 1 ping-pong ball

Provided by User

Paper
 2 empty soda cans
 Several cheese balls
 Alcohol swabs

Worksheets

Bernoulli Experiment Log
 (Worksheet 1)
 Student Activity Instructions
 (Worksheet 2)

Reference Materials

None

Objective:

Students will learn about motions and forces as they use the scientific method to predict, observe and conclude as they conduct a variety of experiments to discover how the velocity of air determines the amount of pressure the air is able to exert. Later, students will relate what they observed to the Bernoulli Principle.

Activity Overview:

Students will engage in a series of six experiments that relate to the Bernoulli Principle, first making predictions about the outcomes of their experiments. Students will record observations about each of the experiments, then participate in a discussion about Bernoulli's Principle. After the discussion, students will be able to directly relate the experiments to Bernoulli's Principle.

Activity:**PART ONE: INTRODUCING THE EXPERIMENTS**

1. Tell the students that they will be conducting a series of experiments in which they will explore the Bernoulli Principle.
2. Tell the students that they will learn more about the specifics of the Bernoulli Principle after they have conducted their experiments and recorded their observations in their Bernoulli Experiment Log.
3. Before the students begin their experiments, introduce each experiment by showing the students the materials they will be using and providing the students with a simple overview of how each of the experiments will be conducted.
4. Distribute the Student Activity Instructions Page. Explain that the specific steps for conducting each experiment are covered in the Student Activity Instructions Page.
5. Instruct students to carefully read the directions for each experiment and predict what they think will happen.

Key Terms:

Air pressure
Air foil
Bernoulli Principle
Conclude
Fluid
Fluid dynamics
Lift
Newton's Laws of Motion
Observe
Predict
Scientific method
Thrust
Velocity

6. Once the students' predictions are discussed and recorded, they may begin their experiments.
7. During the experimentation stage of the lesson, circulate throughout the classroom, facilitating discussion and guiding students through the experiments as needed. Students may want to know why the items in the experiment behave as they do, but resist the temptation to answer any "why" questions just yet. Instead, encourage the students to look for patterns in the outcomes of the experiments.

Note: This lesson plan has two sets of instructions. This section is for the teacher, and includes instructions, expected outcomes, scientific explanations, and tips for troubleshooting. The students will receive the Student Activity Instruction Page in the Worksheets Section, which does not include these extra explanations.

Also, many of the experiments call for each student to have their own straw. Give each student one straw and instruct them to keep that straw as they move from experiment to experiment. Students should rotate through the experiments in order, because the last experiment to use the straw calls for the straw to be cut in half.

PART TWO: STUDENTS ENGAGE IN THE EXPERIMENTS

Teacher Activity Instructions

EXPERIMENT #1 Paper Tent

Materials:

Per pair of students

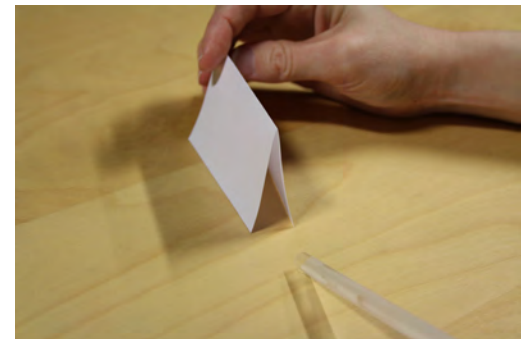
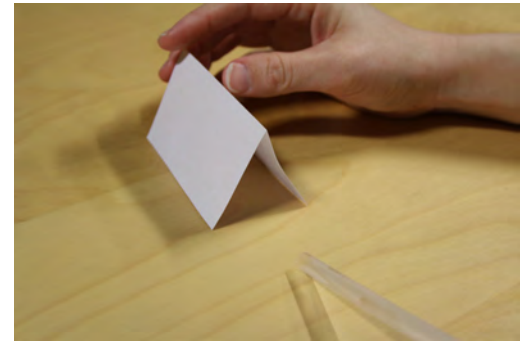
- One 3 ½" x 4" piece of paper

Per student

- Bernoulli Experiment Log
- One straight straw

Instructions for the experiment:

1. **Fold the paper in half to make a paper tent.**
2. **Place the paper tent on a flat surface such as a table or a desk.**
3. **Position the straw about 2 inches away from the paper tent so that you will be able to blow a steady stream of air across the surface of the table or desk and through the tent.**
4. **Observe what happens.**
5. **Now, blow harder and observe what happens.**
6. **Record your observations on your Bernoulli Experiment Log.**

**Expected outcome and reason why:**

When the experiment is performed correctly, the sides of the card will pull towards one another. The reason for this outcome is that the faster moving air under the card creates relatively lower pressure compared to the air over the card, and as a result, the card will bend toward the table or desk because, according to the Bernoulli Principle, higher pressure air pushes toward lower pressure air.

Troubleshooting:

If the experiment does not work as expected, students may have the end of their straw too close to or too far away from the paper tent or they may not be blowing hard enough.

EXPERIMENT #2 Magical Soda Cans

Teacher Activity Instructions

Materials:

Per pair of students

- Two empty soda cans (of the same size)
- Ruler

Per student

- Bernoulli Experiment Log
- One straight drinking straw

Instructions for the experiment:

1. Place the two soda cans parallel to one another and $\frac{3}{4}$ of an inch apart on a flat surface such as a table or desk.
2. Use a straw to blow between the two cans about $1\frac{1}{4}$ -inches above the surface of the table or desk. Be sure that the open end of the straw is placed in front of the cans and not between them.
3. Observe and record what happens.



Expected outcome and reason why:

When the experiment is performed correctly, the two cans will move together. The reason for this is that the air blowing through the straw will be faster moving than the air on any other side of the cans. Thus, according to the Bernoulli Principle, the faster moving air exerts lower pressure and the two cans are drawn toward each other.

Troubleshooting:

If the experiment does not work as expected, students may have the cans too far apart, the straw may be too close or too far away from the cans or the students are not blowing forcefully enough through the straw.

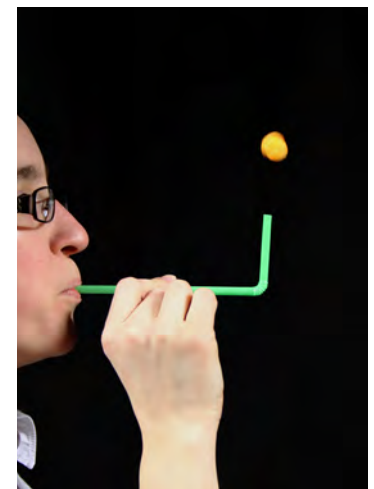
EXPERIMENT #5 Balancing Cheese Balls**Teacher Activity Instructions****Materials:**

Per student

- One flexible drinking straw
- One puffed cheese ball
- Bernoulli Experiment Log

Instructions for the experiment:

1. Bend your straw into an "L".
2. Place the long end of the straw in your mouth, with the short end pointing upwards.
3. Take a deep breath and blow steadily through the straw.
4. Try to balance the cheese ball in the stream of air coming out of the end of the straw.
5. Try to tilt your straw.
6. Observe and record what happens.

**Expected outcome and reason why:**

When the experiment is performed correctly, the cheese ball will balance itself in the steady stream of air coming from the short end of the straw. This happens because the air coming out of the straw is moving fast, so the faster moving air has less pressure than the slower moving or still air around the cheese ball. If the cheese ball starts to move away from the air stream, it experiences pressure from the still or slower moving air, which pushes the cheese ball back in place. If however, the straw is tilted, the force produced by the stream of air will no longer be sufficient to keep the cheese ball afloat because the force of gravity will then take over.

Troubleshooting:

If the experiment does not work as expected, students may not be blowing forcefully enough through the straw or they may be blowing with too much irregularity. A steady stream works best. Another possibility is that the short end of the straw may not be upright.

EXPERIMENT #4 Levitate a Sphere**Teacher Activity Instructions****Materials:**

Per pair of students

- Medium-sized funnel or the top of a 2-liter pop bottle cut to look like and act as a funnel
- One ping-pong ball or one small Styrofoam ball the size of a ping-pong ball

Per student

- Bernoulli Experiment Log
- Alcohol swab (to clean the funnel when shared between students)

Instructions for the experiment:

1. **Place the ball in the funnel.**
2. **Tilt your head back and point the wider end of the funnel upwards toward the ceiling or sky.**
Note: For health reasons only one student should blow into the funnel.
3. **Blow air forcefully through the narrow end of the funnel in an attempt to lift the ball out of the funnel.**
4. **Observe and record what happens.**
5. **Now, with ball in the funnel as before, hold the funnel in front of you and blow forcefully across the top of the wider end of the funnel.**

Expected outcome and reason why:

When the experiment is performed correctly, the air coming directly underneath the ping-pong ball will be moving more quickly than the air over the top of the ball. As Bernoulli's Principle states, this faster moving air results in a decrease in air pressure under the ball. This causes the ball to be pushed into, rather than out of the funnel, by the higher air pressure coming through the top of the funnel. The end result is the ball stays in the funnel.

By blowing over the top of the funnel, the speed of the air traveling over the top of the funnel is increased, which causes the air pressure in that area to decrease. Therefore, the ball rises because it is being pushed out of the funnel by the higher air pressure coming from underneath.

Troubleshooting:

If the experiment does not work as expected, students may be blowing too close to or too far away from the funnel, or they may be directing the air they are blowing into the funnel rather than across the top of the funnel.



EXPERIMENT #3 Cup of Water**Teacher Activity Instructions****Materials:**

Per pair of students

- Scissors
- One clear plastic cup (a 10-ounce cup works well)
- Water

Per student

- Bernoulli Experiment Log
- One straight drinking straw

Instructions for the experiment:

Note: the spray from the straws can get messy. You may wish to place a garbage bag or towel on the table to keep the area as clean as possible

1. **Fill a clear plastic cup, nearly to the rim, with water.**
2. **Cut the drinking straw in half.**
3. **Place one half of the straw in the water so that the bottom of the straw does not touch the bottom of the cup.**
4. **The top of the straw should be sticking out above the rim of the cup.**
5. **Position the second half of the straw so that it is perpendicular to, but not touching the straw in the cup of water.** You should be able to blow a stream of air over the hole of the straw sticking out of the water.
6. **Once the straw is in position, blow very hard through the straw.**
7. **Observe and record what happens.**

**Expected outcome and reason why:**

When the experiment is performed correctly, the water will rise through the straw in the cup, spraying away from the stream of air being blown across the straw.

The reason for this is that as the student blows through the straw, the faster moving air over the top of the straw creates an area of low pressure while the pressure on the surface of the water remains unchanged. Therefore, the water is drawn up the straw because of the area of low pressure.

Troubleshooting:

If the experiment does not work as expected, students may not be blowing through the straw with enough force or they may be blowing too close to or too far away from the top of the straw that is positioned in the water.

PART THREE: RELATING THE EXPERIMENTS TO THE BERNOULLI PRINCIPLE

1. **After the students have completed their experiments, ask them to explain what they have observed.** Teachers may wish to record and display students' observations on a chart similar to the student's Bernoulli Experiment Log.
2. **Ask the students if what they observed was what they predicted. If their predicted and actual outcomes differed, ask the students to hypothesize as to why.**
3. **Ask the students if they saw any patterns in the outcomes of the experiments. Record students' ideas.**
4. **Before presenting the Bernoulli Principle, ask the students how they would classify air.** In other words, ask them what kind of substance air is. Students will likely describe air as a gas. They may also say that air is a combination of gases, including water vapor, and other particles such as dust. If the students do not offer a description of air as a fluid, ask them if they would consider air a fluid.
5. **Tell the students that there is a test for determining if air is a fluid or no.** Tell them that you are going to give them this test. Begin by asking: Does air resist molding, shaping or being deformed? Can you move, bend, or twist air with relative ease? Try it. (Students will say that it is relatively easy to deform air) Next ask: What shape is air? Can the shape of air be changed? How? (Students will say that air can change shape depending on the container it's in.) Tell the students that because they answered yes to these questions, air has passed the test. Air is indeed a fluid because air, like other fluids, displays such properties as not resisting deformation, and it displays the ability to flow, which is also described as the ability to take on any shape. Make sure students understand that while all liquids are fluids, not all fluids are liquids.
6. **Introduce the Bernoulli Principle by saying:**

The Bernoulli's Principle is a physical phenomenon that was named after the Swiss scientist, Daniel Bernoulli, who lived during the eighteenth century. Bernoulli studied the relationship between the speed of a fluid and the pressure that fluid is able to exert. The principle states that "the pressure of a fluid [liquid or gas] decreases as the speed of the fluid increases." Within the same fluid, high-speed flow is associated with low pressure, and low-speed flow is associated with high pressure.

Note: At this point teachers may choose to show their students a picture of Daniel Bernoulli and his glass tube experiment or give more background about his life and studies.
7. **Now relate the Bernoulli Principle to the lift achieved by an aircraft.** Explain that lift is the force that helps an aircraft fly. Tell the students that lift occurs, in part, when the air traveling over the top of an airplane wing moves faster than the air traveling under the wing. Thus, the faster moving air creates an area of low pressure, while the slower moving air creates an area of high pressure.

8. **Show students a diagram of an airfoil (a cross-section of an airplane wing).** Explain, using arrows, how the faster moving air spreads out and speeds up over the upper surface of a wing to create low pressure, while the air traveling under the wing moves at a slower rate, thus creating high pressure. High pressure moves toward low pressure, thus generating lift.
9. **Direct the students' attention back to their experiments.** Ask the students how they saw the Bernoulli Principle at work. Prompt the students to recall what happened when they increased the speed of the air in their experiments. Students will recall that every time they changed the speed of the air in their experiment (by increasing it relative to the surrounding air), something moved in the direction of the faster moving air (the paper tent, the cans, the water, and the ping-pong ball). In the case of the "Balancing Cheese Ball", the slower moving air around the cheese ball kept the cheese ball positioned above the faster moving air being blown underneath it.
10. **Recreate a few of the experiments (or all if you prefer) as demonstrations.** Give the students time to explain what was actually happening in each, according to the Bernoulli Principle.
11. **Allow students to share their conclusions and use their own words to describe how the Bernoulli Principle relates to the experiments they conducted.**

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Motions and forces

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology



Reference Materials

Glossary

Air pressure:

The amount of pressure air is able to exert on substances or objects; air pressure can be high or low, depending on the speed at which it travels

Airfoil:

A surface or section of a surface that is designed to help lift an aircraft with the use of air current

Bernoulli Principle:

An increase in the velocity of any fluid is always accompanied by a decrease in pressure

Conclude:

To determine by reasoning

Fluid:

A substance that can easily change its shape and is capable of flowing

Fluid dynamics:

The subject of fluids in motion

Lift:

The upward force created by the wings moving through the air that helps to sustain the airplane in flight

Newton's Laws of Motion:

An explanation for the principles of motion and gravity

Law One: Every object persists in its state of rest or uniform motion in a straight line unless it is compelled to change that state by forces impressed on it.

Law Two: Force is equal to change in momentum per change in time. For a constant mass force equals mass times acceleration. $F = m \cdot a$

Law Three: For every action there is an equal and opposite reaction.

Observe:

To watch, or view, for a scientific purpose

Predict:

To indicate something in advance based on prior knowledge

Scientific method:

A method of research in which a problem is identified, relevant data are gathered, a hypothesis is formulated from these data, and the hypothesis is empirically tested

Thrust:

A force that pushes the air backward with the object of causing movement of the airplane in the forward direction

Velocity:

The rate of speed with which something happens

Fig.1 Four forces of flight

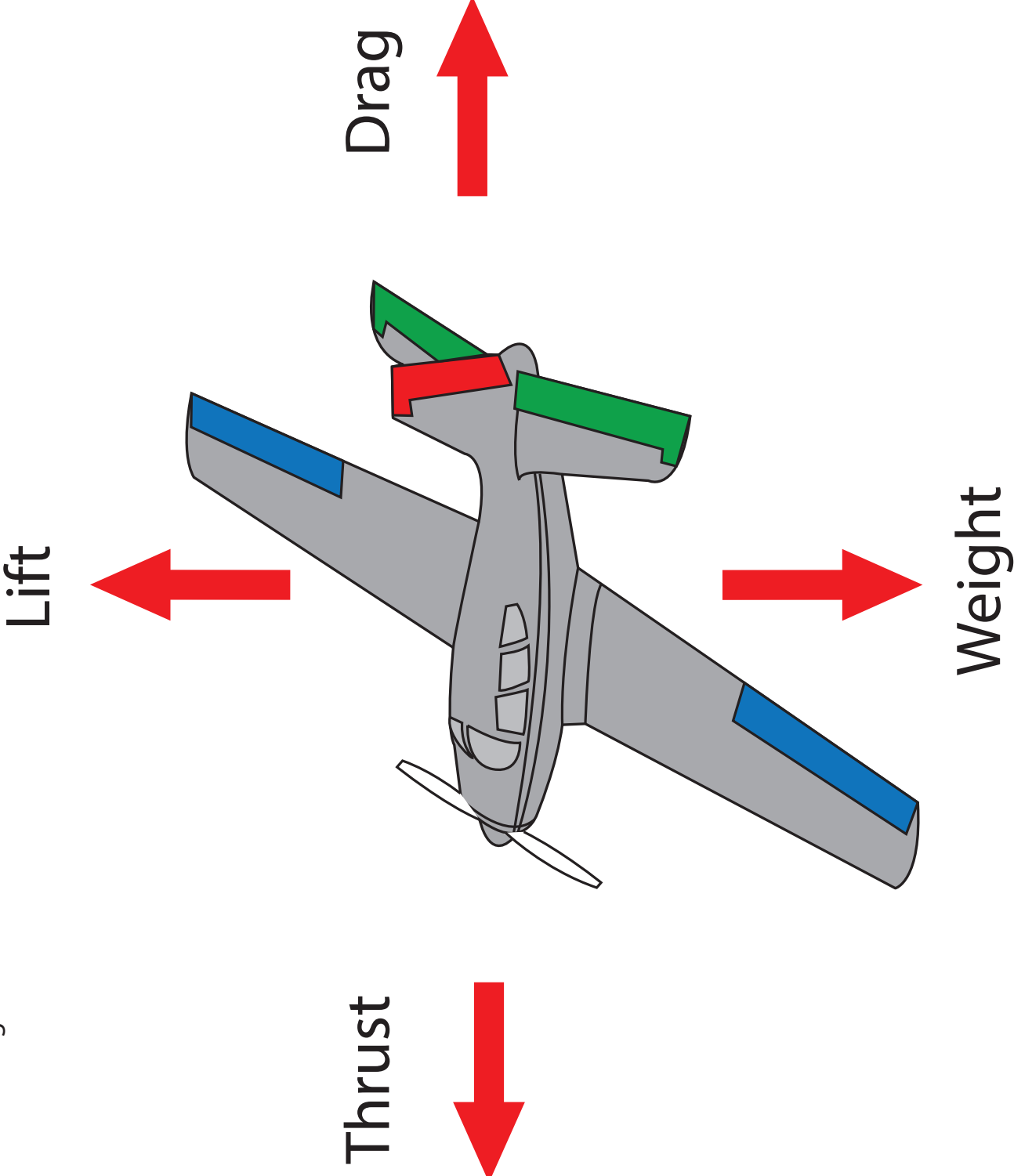


Fig. 2 Bernoulli fluid experiment

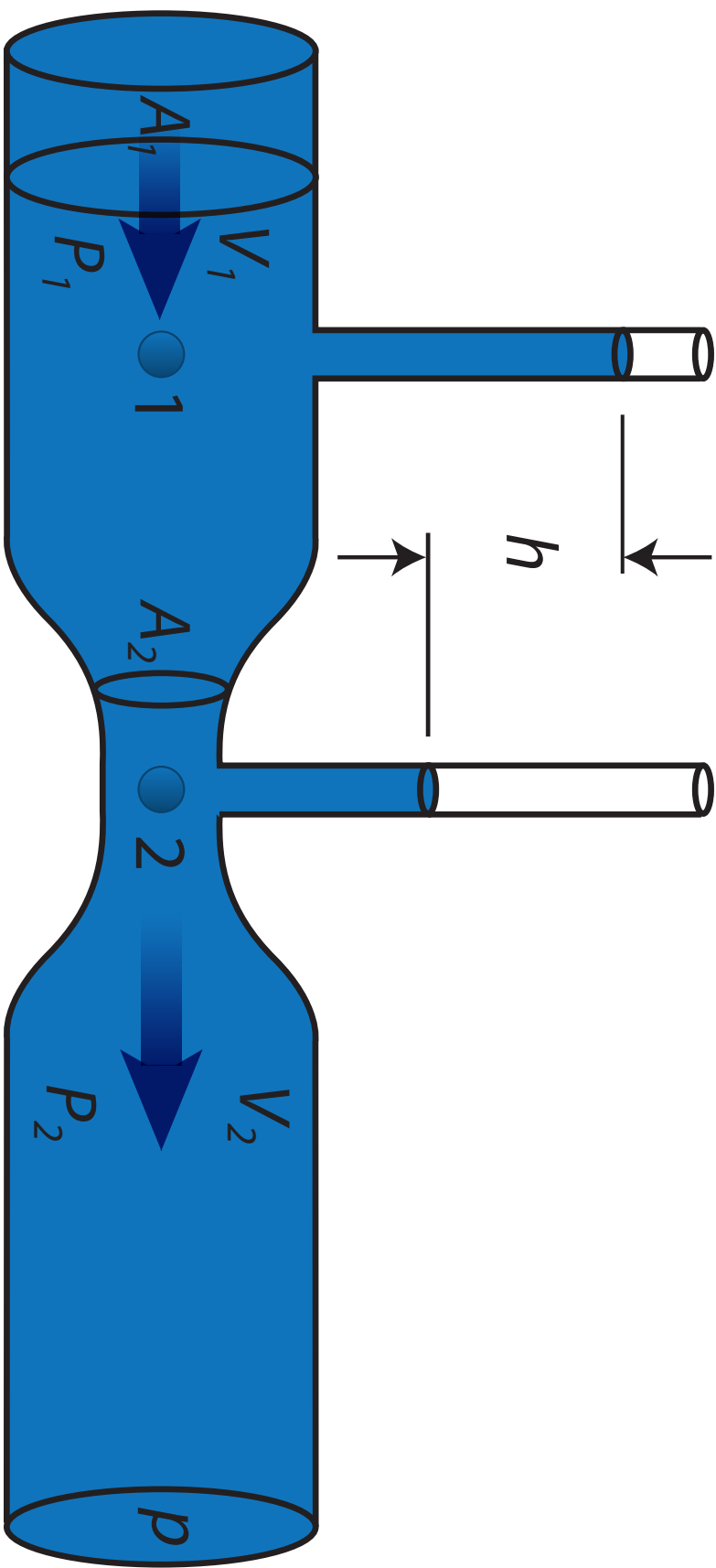


Fig. 3 Airfoil

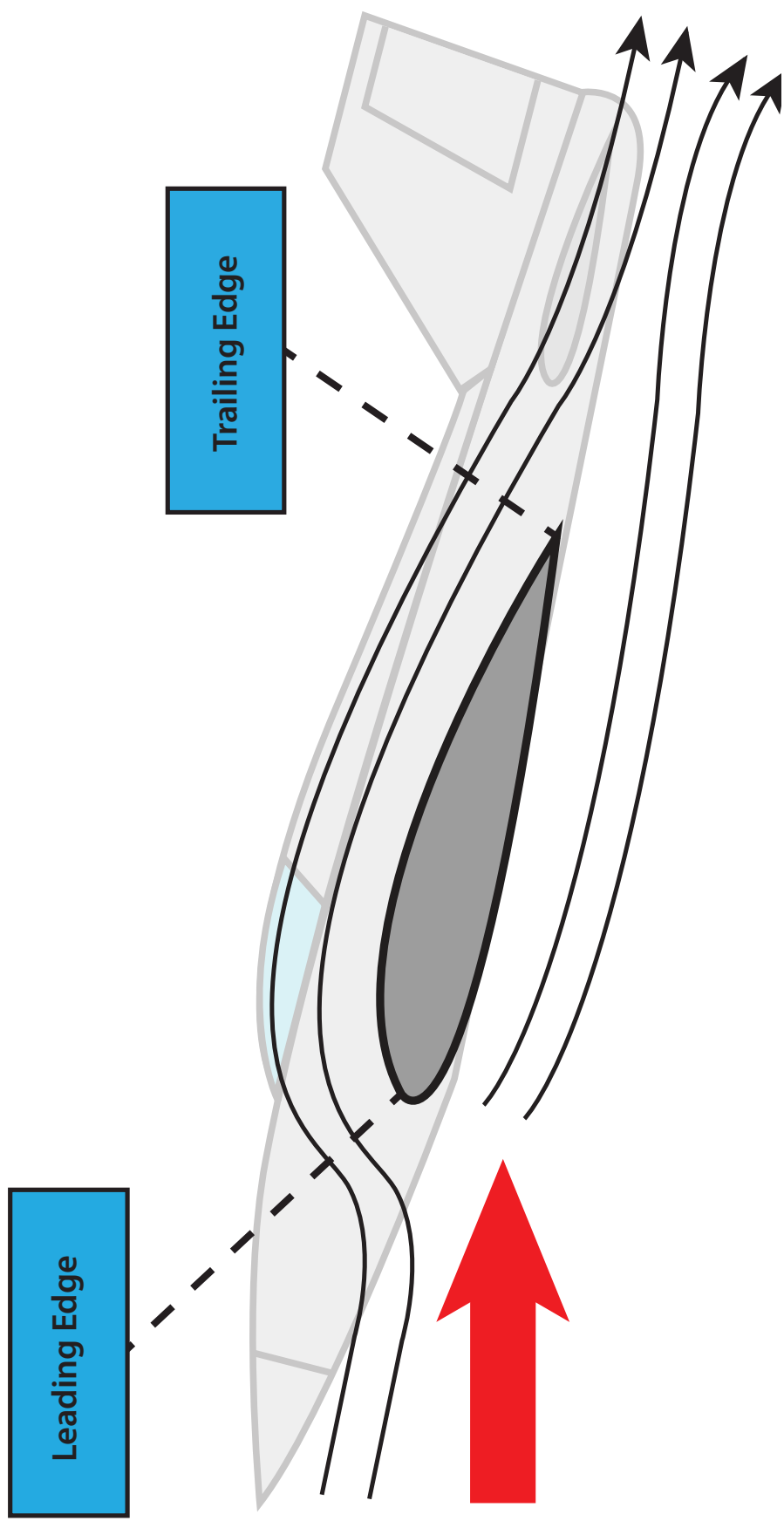
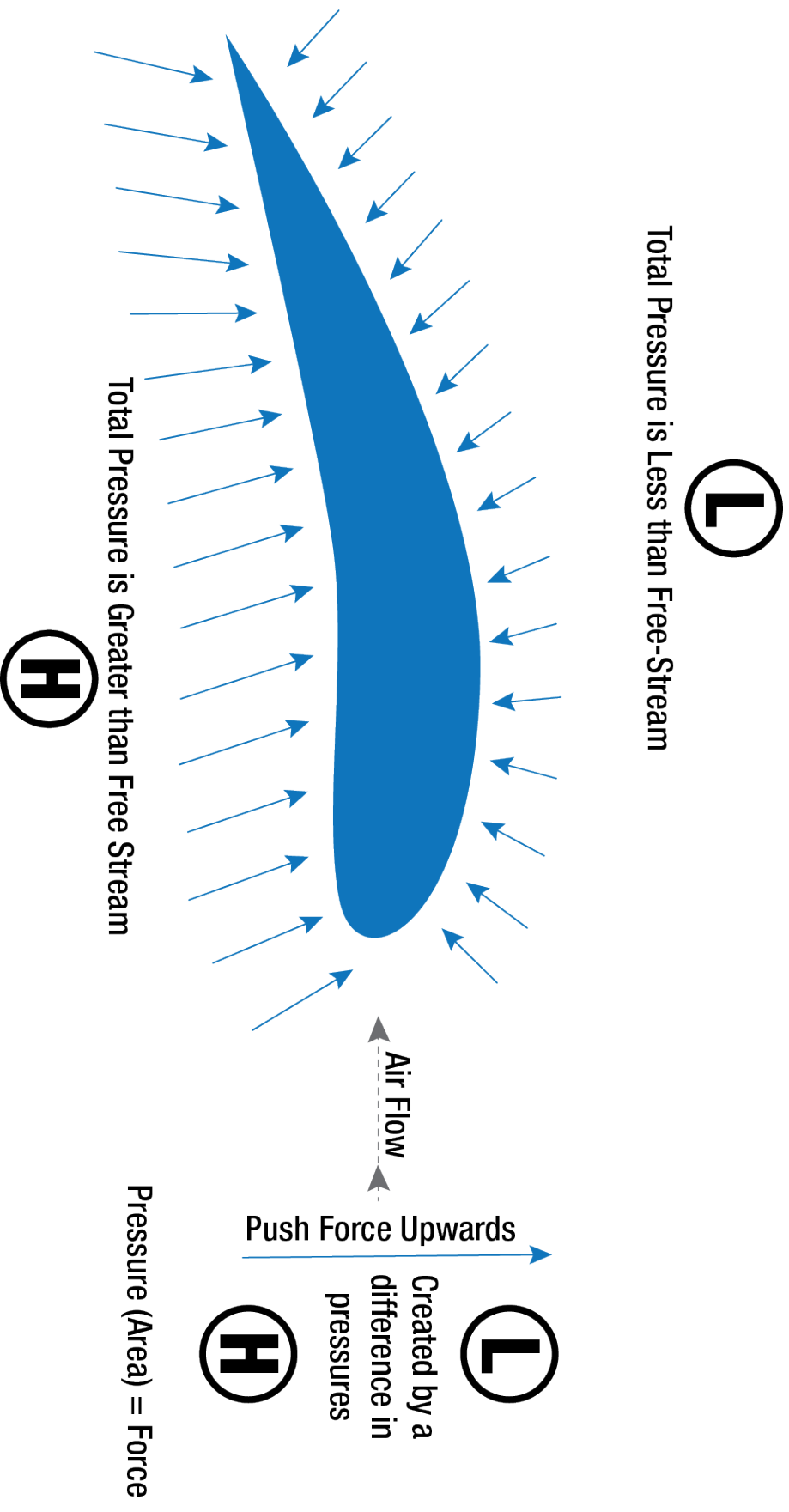


Fig. 4 Lift





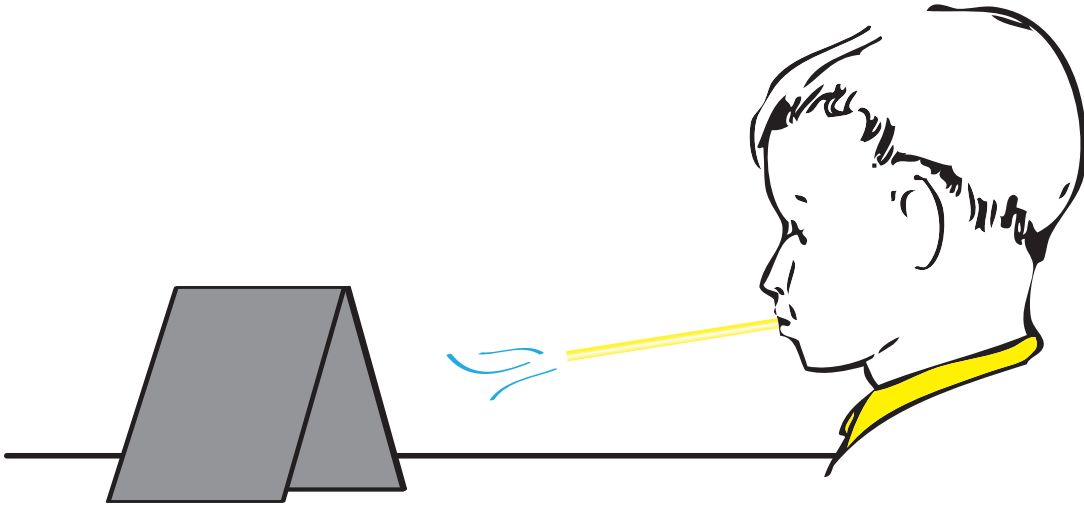
Worksheets

Worksheet 1

Bernoulli Experiment Log

After your teacher introduces the experiments and you have read the Student Activity Instructions Page, predict what you think will happen in each experiment before you begin. Then after you complete each experiment, record what you observed during the experiment. Finally, after you learn more about the Bernoulli Principle, give reasons for the outcome of each experiment including how the outcome relates to the Bernoulli Principle. Write all of your responses in the boxes below.

Experiment	What do you think will happen? <i>Predict</i>	What happened? <i>Observe</i>	Why did it happen? <i>Conclude</i>
Paper Tent: Normal Air-flow			
Paper Tent: Increased Airfl w			
Magical Soda Cans			
Cup of Water			
Levitate a Sphere			
Balancing Cheese Balls			

**EXPERIMENT #1 Paper Tent****Materials:**

Per pair of students

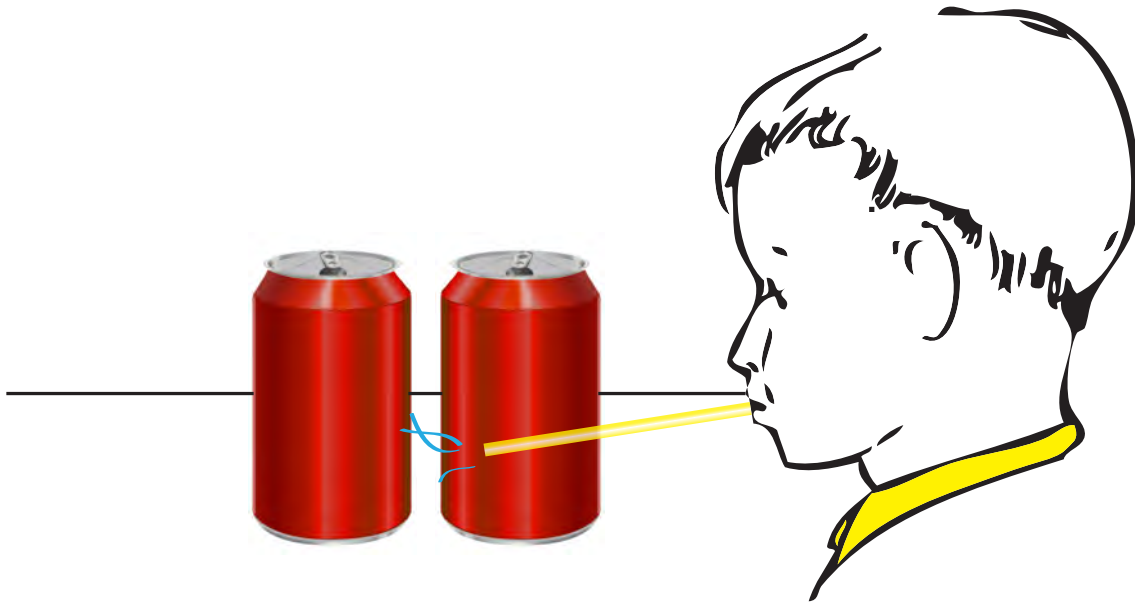
- One 3 ½" X 4" piece of paper

Per student

- Bernoulli Experiment Log
- One straight straw

Instructions for the Experiment:

1. Fold the paper in half to make a paper tent.
2. Place the paper tent on a flat surface such as a table or a desk.
3. Position the straw about 2 inches away from the paper tent so that you will be able to blow a steady stream of air across the surface of the table or desk and under the tent.
4. Observe what happens.
5. Now, blow harder and observe.
6. Record your observations on your Bernoulli Experiment Log.

**EXPERIMENT #2 Magical Soda Cans****Materials:**

One set per pair of students

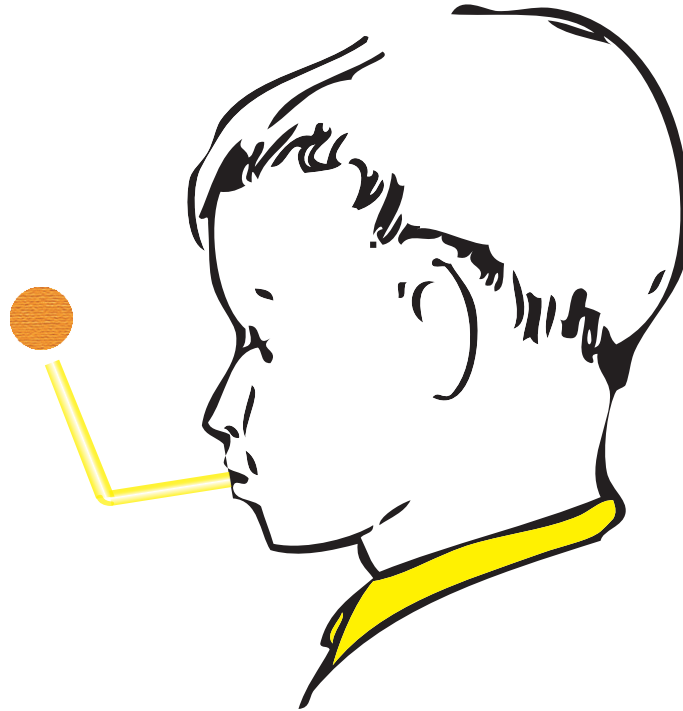
- Two empty soda cans (of the same size)
- Ruler

Per student

- Bernoulli Experiment Log
- One straight drinking straw

Instructions for the Experiment:

1. Place the two soda cans parallel to one another and $\frac{3}{4}$ of an inch apart on a flat surface such as a table or desk.
2. Use a straw to blow between the two cans about $1\frac{1}{4}$ -inches above the surface of the table or desk. Be sure that the open end of the straw is placed in front of the cans and not between them.
3. Observe and record what happens.

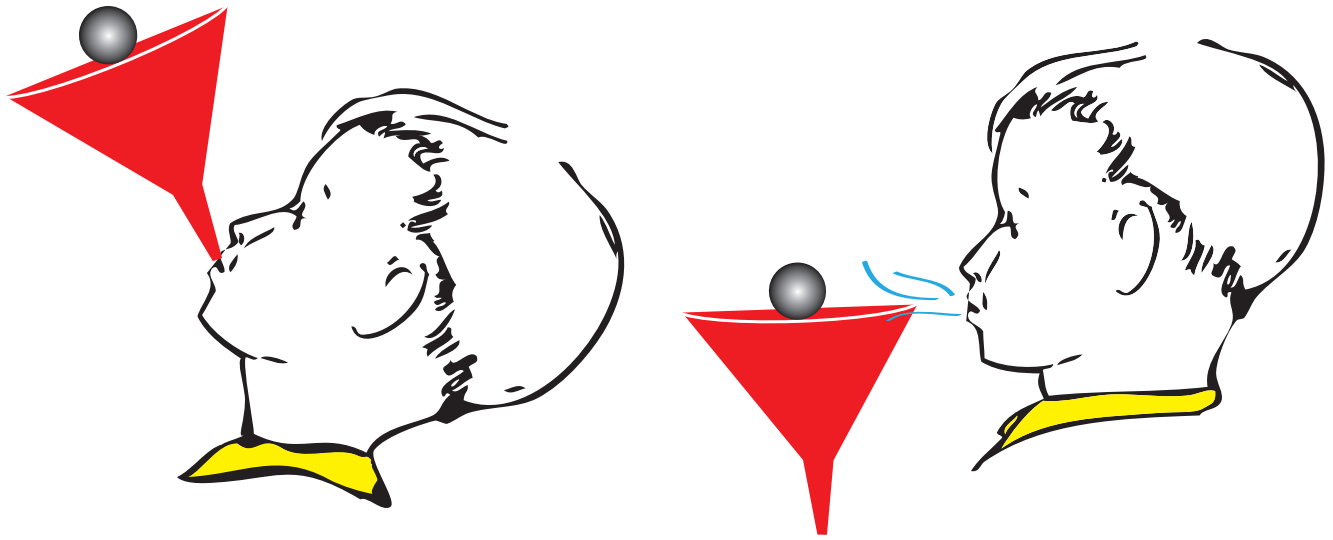
**EXPERIMENT #3 Balancing Cheese Balls****Materials:**

Per student

- One flexible drinking straw
- One puffed cheese ball
- Bernoulli Experiment Log

Instructions for the Experiment:

1. Bend your straw into an "L".
2. Place the long end of the straw in your mouth, with the short end pointing upwards.
3. Take a deep breath and blow steadily through the straw.
4. Try to balance the cheese ball in the stream of air coming out of the end of the straw.
5. Try to tilt your straw.
6. Observe and record what happens.

**EXPERIMENT #4 Levitate a Sphere****Materials:**

Per pair of students

- Medium-sized funnel or the top of a 2-liter pop bottle cut to look like and act as a funnel
- One ping-pong ball or one small Styrofoam ball the size of a ping-pong ball

Per student

- Bernoulli Experiment Log
- Alcohol swab

Instructions for the Experiment:

1. Place the ball in the funnel.
2. Tilt your head back and point the wider end of the funnel upwards toward the ceiling or sky.

Note: For health reasons only one student should blow into the funnel.

3. Blow air forcefully through the narrow end of the funnel in an attempt to lift the ball out of the funnel.
4. Observe and record what happens.
5. Now, with ball in the funnel as before, hold the funnel in front of you and blow forcefully across the top of the wider end of the funnel.

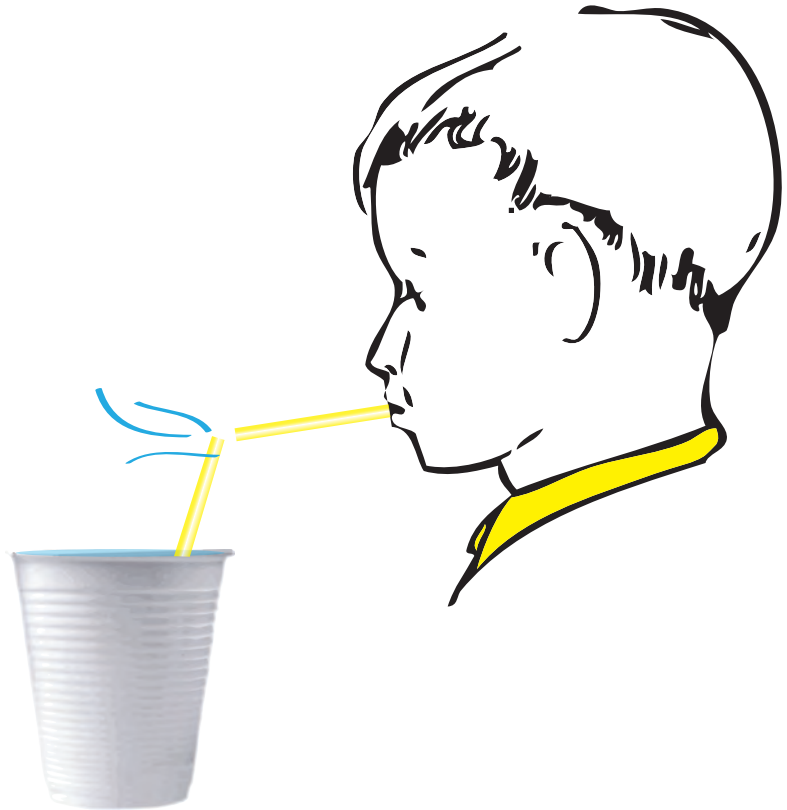
EXPERIMENT #5 Cup of Water**Materials:**

Per pair of students

- One clear plastic cup
- Water

Per student

- Bernoulli Experiment Log
- One straight drinking straw

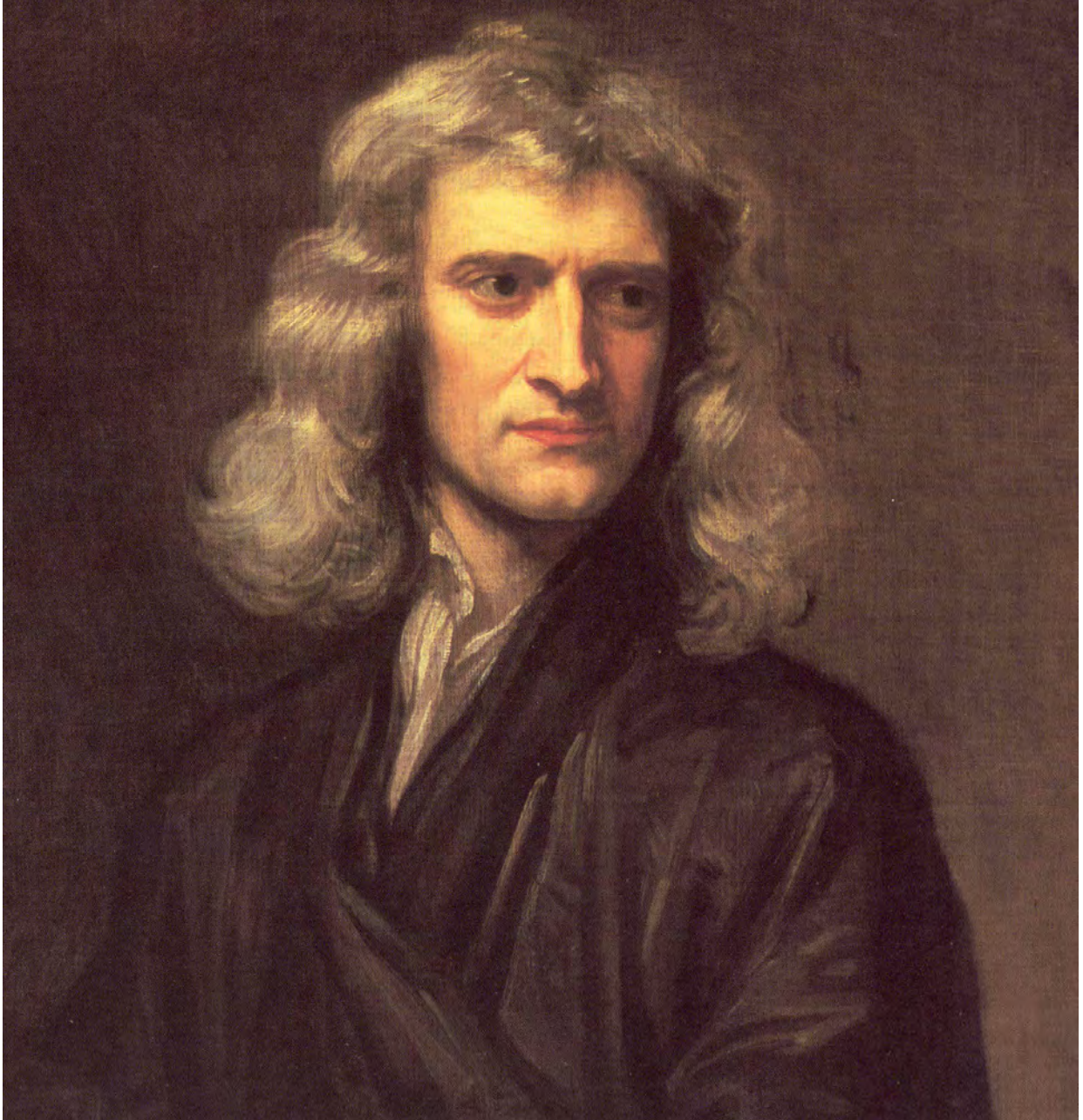
**Instructions for the Experimenter**

1. Fill a clear plastic cup, nearly to the rim, with water.
2. Cut the drinking straw in half.
3. Place one half of the straw in the water so that the bottom of the straw does not touch the bottom of the cup.
4. The top of the straw should be sticking out above the rim of the cup.
5. Position the second half of the straw so that it is perpendicular to, but not touching the straw in the cup of water. You should be able to blow a stream of air over the hole of the straw sticking out of the water.
6. Once the straw is in position, blow very hard through the straw.
7. Observe and record what happens.



Images

Img. 1 Sir Isaac Newton (age 46)



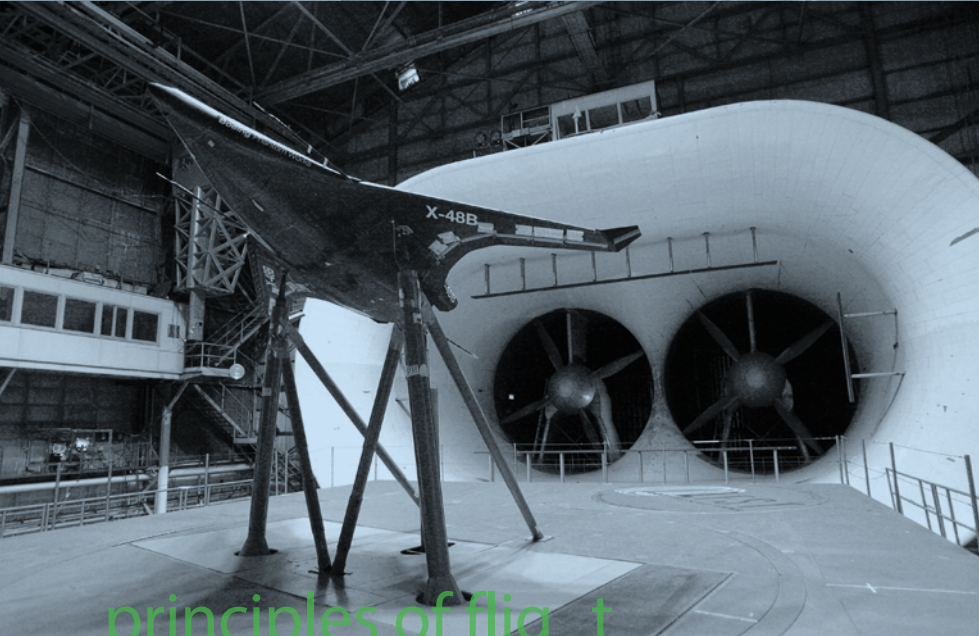
(Painting by Sir Godfrey Kneller - 1689)

Img. 2 Daniel Bernoulli

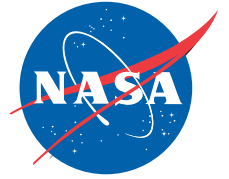


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Aeronautics
Research
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Directorate



principles of flight 1



GRADES

9-12

Principles of Flight in Action

principles of flight

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Principles of Flight in Action

Lesson Overview

During this lesson students will have the opportunity to use interactive computer simulations in order to gain a better understanding of some of the factors that affect flight through the atmosphere. Students will also be introduced to some of the aerospace pioneers that led the way to begin our understanding of the principles of flight. Aeronautical terms associated with principles of flight will be defined to provide for better understanding of the data the students collect while completing the two simulations.

Objectives

Students will:

1. Understand the importance of aeronautical research to design aircraft that can fly faster, farther, and higher.
2. By using AtmosModeler computer simulation software, students will demonstrate an understanding of density, pressure, and temperature in flight through the atmosphere
3. By using the FoilSim III computer simulation students will be able to understand the Lift/Drag ratio and its importance in designing aircraft with high lift ratios and low drag ratios and its implication in the design of aircraft.

Materials:

In the Box

CD with simulation applets necessary for lesson

Simulation applets can also be downloaded from the MIB website:

<http://www.aeronautics.nasa.gov/mib.htm>

Provided by User

Copies of worksheets in lessons

GRADES 9-12

Time Requirements: 2 hours 30 minutes

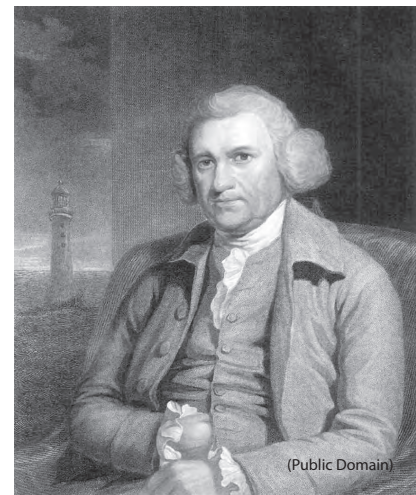
Background

Introduction to Aeronautical Research

For countless generations humankind dreamed of flying like the birds through the atmosphere. However, it would not be until the 18th century that the mystery of flight began to be understood. It takes a certain know-how to turn dreams into realities. The story of a heavier-than-air flight begins with a few individuals who began to study the properties of flight in new ways that enabled them to begin to identify the factors that influenced the behavior of the airplane. Space does not allow a detailed story of explaining the history of flight. For this brief introduction six individuals have been selected to start the story.

John Smeaton

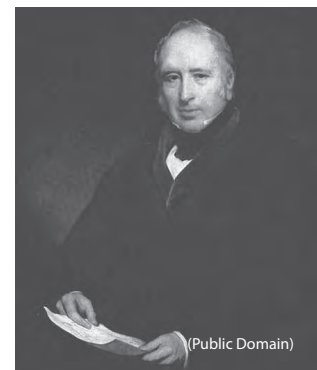
(1724-1792) In 1759, the British engineer John Smeaton published a paper that addressed the relationship between pressure and velocity for objects moving in water and air. Smeaton had used a whirling arm device to measure the drag exerted on a surface by moving air. From his work Smeaton created an equation to explain his observations. The equation is $D = (C_d) kSV^2$, where D is the drag, S is the surface area, V is the air velocity, and k is a pressure constant and C_d is a drag coefficient that depends on the shape, roughness, and inclination of the model to the flight direction. Smeaton's coefficient (k) is the drag of a 1 square foot flat plate moving at one mile per hour. The value of k was determined experimentally and, by 1900, the accepted value was .005. The modern accepted value is .00326. (Note that this form of the drag equation is no longer used today. The k factor has been replaced by the density of the air to account for variations with altitude and weather conditions.)



Img. 1 John Smeaton

George Cayley

(1773-1857), of Yorkshire, England is considered the "Father of Aviation". In 1799, he set forth for the first time in his theory, the concept of the modern airplane. Cayley understood the basic principles of flight and constructed working models. Cayley had identified two very important factors related to flight. One is that the drag vector is parallel to the flow and the lift vector is perpendicular to the flow. Cayley identified for the first time that lift is generated by a region of low pressure on the upper surface of the wing. In addition, he demonstrated that cambered wings (curved surfaces) generate lift more efficiently than a flat surface.



Img. 2 George Cayley

Otto Lilienthal

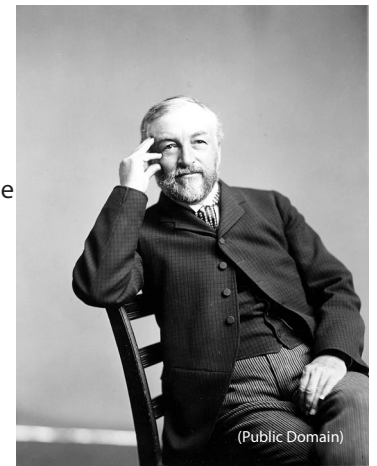
(1846-1896) Otto Lilienthal was a German engineer who became the first man to launch himself into the air, fly, and land safely. Lilienthal was an important source of inspiration and information for the Wright brothers. Unfortunately, on August 9, 1896, the glider he was piloting stalled and went into a nosedive. He died the next day of a broken spine. His last words were "Sacrifices must be made." Lilienthal had a great impact on aviation. His writings were translated and distributed worldwide. The many photographs that authenticated his flights visually proved that a human could launch himself into the air and stay aloft. He showed the significance of identifying the principles that governed an experiment before proceeding, and his painstaking records of his research provided guidance for those that came after him.



Img. 3 Otto Lilienthal

Samuel Pierpont Langley

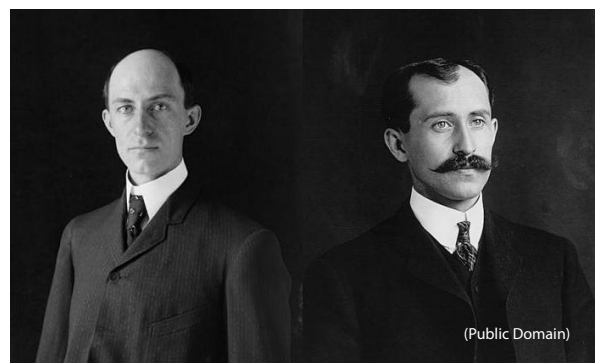
(1834-1906) Langley is remembered as one of the most unlucky trail blazers in flight history. Langley was highly-educated and served as Secretary of the Smithsonian Institution from 1887 to 1906. In 1896 one of his heavier-than-air machines, Aerodrome no. 6, became the first to achieve sustained unmanned flight. Aerodrome no. 6 flew 1280 meters (4,200 feet) at about 48 km/hr (30 mph) over the Potomac River in Washington, D.C. Langley received a government contract to build and fly a heavier-than-air machine with a pilot on board. However, his attempts to fly a manned aircraft were not so fortunate. The Great Aerodrome was built and was launched by catapult from a houseboat anchored in the Potomac River. The plane had to go from a dead stop to 96.5 km/hr (60 mph) in only 21.3 meters (70 feet). During the October 7, 1903, launch the catapult created more stress than the wood and fabric aircraft could stand and the front wing was badly damaged. Things went even worse during the second launch on December 9, 1903. The rear wing and tail completely collapsed during the launch. Charles Manley, the pilot, nearly drowned before he could be rescued from the wreckage in the ice-covered Potomac. After this near disaster, Langley did not attempt any further flights.



Img. 4 Samuel Pierpont Langley

Orville and Wilbur Wright

(Wilbur 1867-1912) (Orville 1871-1944) On December 17, 1903, the Wright Brothers changed the world forever. On that date at Kitty Hawk, North Carolina, the Wright Brothers flew the first powered, heavier-than-air machine to achieve controlled, sustained flight with a pilot aboard. There were several factors that led to the Wright Brothers' success. They invented a means for a pilot to steer the aircraft effectively to maintain three-axis control of roll, pitch, and yaw. They conducted flight experiments with kites and gliders for several years before the powered flight. By 1902, they were the most experienced glider pilots in the world. They built a wind tunnel and tested models of their aircraft in their bicycle shop in Dayton, Ohio. The data that they collected related to drag and lift were more accurate than any before.



Img. 5 The Wright Brothers

This enabled them to design and build wings and propellers that were more efficient than any other at that time. Following the first flights at Kitty Hawk, the brothers continued to perfect their design with two more years of powered flight experiments at Huffman Prairie in Dayton. By late 1905, they had an aircraft that could maneuver in the air at the pilot's command until it ran out of gas.

These pioneers in aeronautical research paved the way for future flight. The demand for aircraft to fly faster, farther, and higher led to the creation of aeronautical research centers in the United States. From March 1915 until October 1, 1958, the National Advisory Committee for Aeronautics (NACA) provided advice and carried out much of the cutting-edge research in aeronautics in the United States.

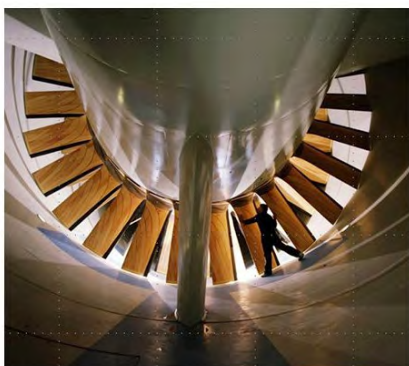


Img. 6 NASA's Aeronautical Research Centers

NACA created four aeronautical research centers that became a part of NASA on October 1, 1958. Note that some of the centers have been renamed since their beginning. The NASA aero centers are:

- Langley Research Center in Langley, Virginia
- Ames Research Center in Moffett Field, California
- Glenn Research Center in Cleveland, Ohio
- Dryden Flight Research Center at Edwards AFB, California

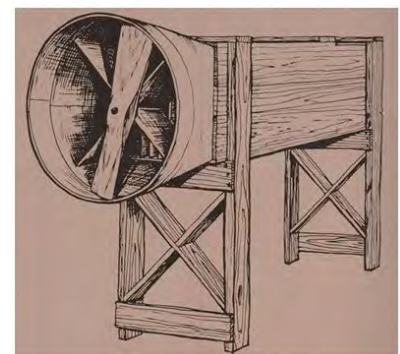
The research carried out at these four centers has greatly impacted flight. There is not an aircraft flying today that does not have some technology that was developed at one of these facilities. Aeronautical research does not stand still.



Img. 8 Big Fan in a Langley Research Center Tunnel

New test facilities are required to push the envelope in aeronautical research.

Wind tunnels have greatly increased research capabilities building on the model-testing techniques employed by the Wright Brothers. NASA has over 40 wind tunnels which enable researchers to 'fly' aircraft on the ground. Air speeds in NASA wind tunnels vary by wind tunnel.



Img. 7 Wright Brothers Wind Tunnel

Some tunnels accelerate air only to subsonic speeds which are slower than the speed of sound. Others reach transonic air speeds (slightly below, through and above the speed of sound), supersonic speeds (much faster than the speed of sound) and hypersonic speeds (more than five times the speed of sound).

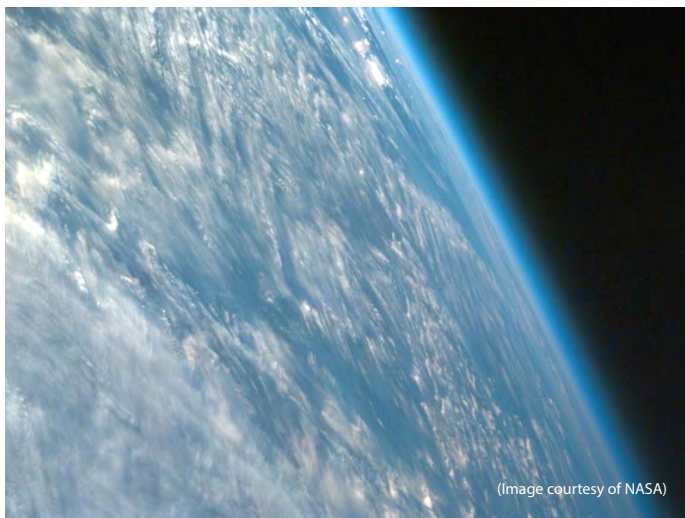
Though powerful wind tunnels continue to be used as a research tool, supercomputing is reducing NASA's dependence on wind tunnels to conduct aeronautical research. The Pleiades is a part of NASA's state-of-the-art technology for meeting NASA's supercomputing requirements, enabling its scientists and engineers to conduct modeling and simulation for aeronautics. Note in Images 9 and 10 how supercomputing is reducing the need for wind tunnels and assisting in the design of advanced aircraft.

So in a sense we are back where we began. Today's scientists and engineers are studying the same factors that impact the principles of flight that were identified by the pioneers in aeronautical research—lift, drag, gravity, and thrust. There is still plenty of research to be done.

Introduction to the Atmosphere

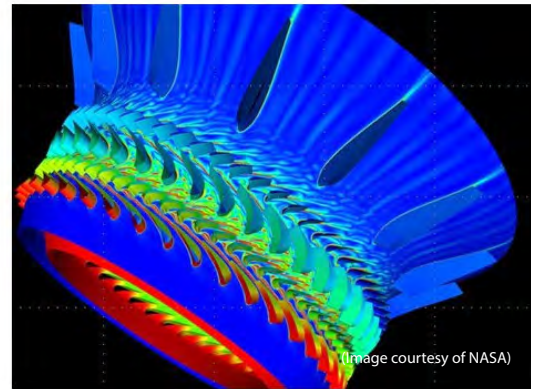
Since students will determine some of the effects of flying an aircraft at various altitudes in the atmosphere it is important that the students have some understanding of the atmosphere. From space one is able to view the atmosphere from a unique position. (See image 11)

As can be seen in this astronaut's photo of Earth, the atmosphere appears as a thin blue line stretching to the blackness of space. If an apple represented Earth, the red skin of the apple would approximate the thickness of the atmosphere.

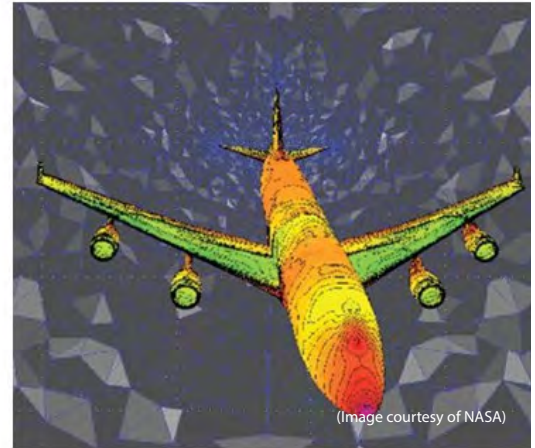


Img. 11 Earth from space showing our thin atmosphere

(cirrus, cirrostratus, and cirrocumulus) can be found in the lower regions of the stratosphere.



Img. 9 Super computer image of a fan



Img. 10 Super computer image of an airplane

Most aircraft flights occur in the lowest part of the atmosphere, which is called the troposphere. The troposphere extends from the Earth's surface to an altitude of about 17 kilometers (11 miles). The weather and clouds can be found in the troposphere.

Beyond the troposphere is the stratosphere. The stratosphere extends from the troposphere upwards to about 50 kilometers (31 miles). The ozone layer can be found in the stratosphere. The ozone layer protects living things on Earth from the biologically lethal ultraviolet rays. Only the highest clouds

At Earth's surface the pressure of air per square inch is about 100 kilo Pascals (14.7 pounds per square inch). However, as one gets to higher altitudes the air pressure is much less than 100 kilo Pascals. In addition, temperature's value also changes with a change in altitude. As a result of doing the activities in this lesson students will find that a change in temperature can affect the speed of sound.

Selected Definition Illustrations Included in the Activities

The Beginner's Guide to Aeronautics is an excellent resource to use to gain an overview of many aeronautics terms. The Beginner's Guide can be accessed at the following website: <http://www.grc.nasa.gov/WWW/K-12/airplane/index.html>. This website was created by Tom Benson at the NASA Glenn Research Center in Cleveland, Ohio. The following illustrations and information were taken from the Beginner's Guide.

The wing's geometry is a major factor affecting an aircraft's lift and drag.

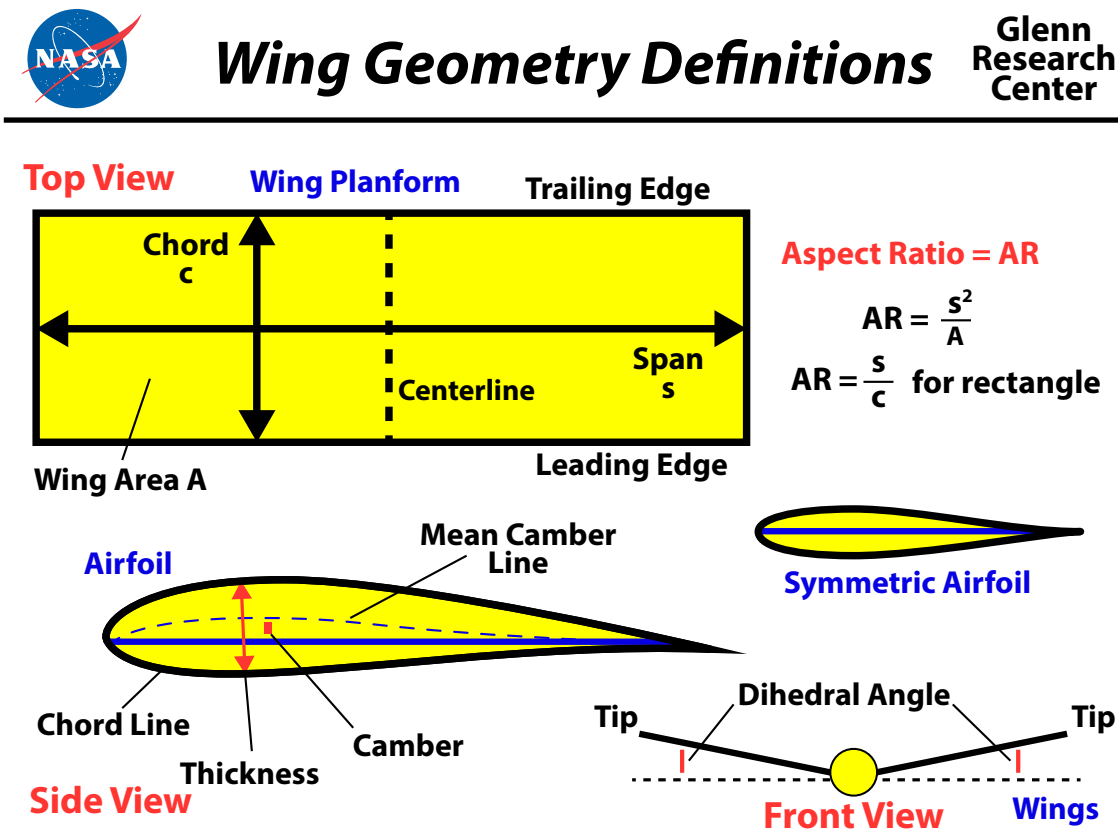


Fig. 1 Wing Geometry Definitions <http://www.grc.nasa.gov/WWW.k-12/airplane/geom.html>
Beginner's Guide to Aeronautics, NASA

The illustration in Figure 1 highlights the definitions for wing geometry. You may want to have students use the Wing Design Interactive on the MIB web page to get a better understanding of wing shapes. The Wing Design Interactive is shown on the next page.

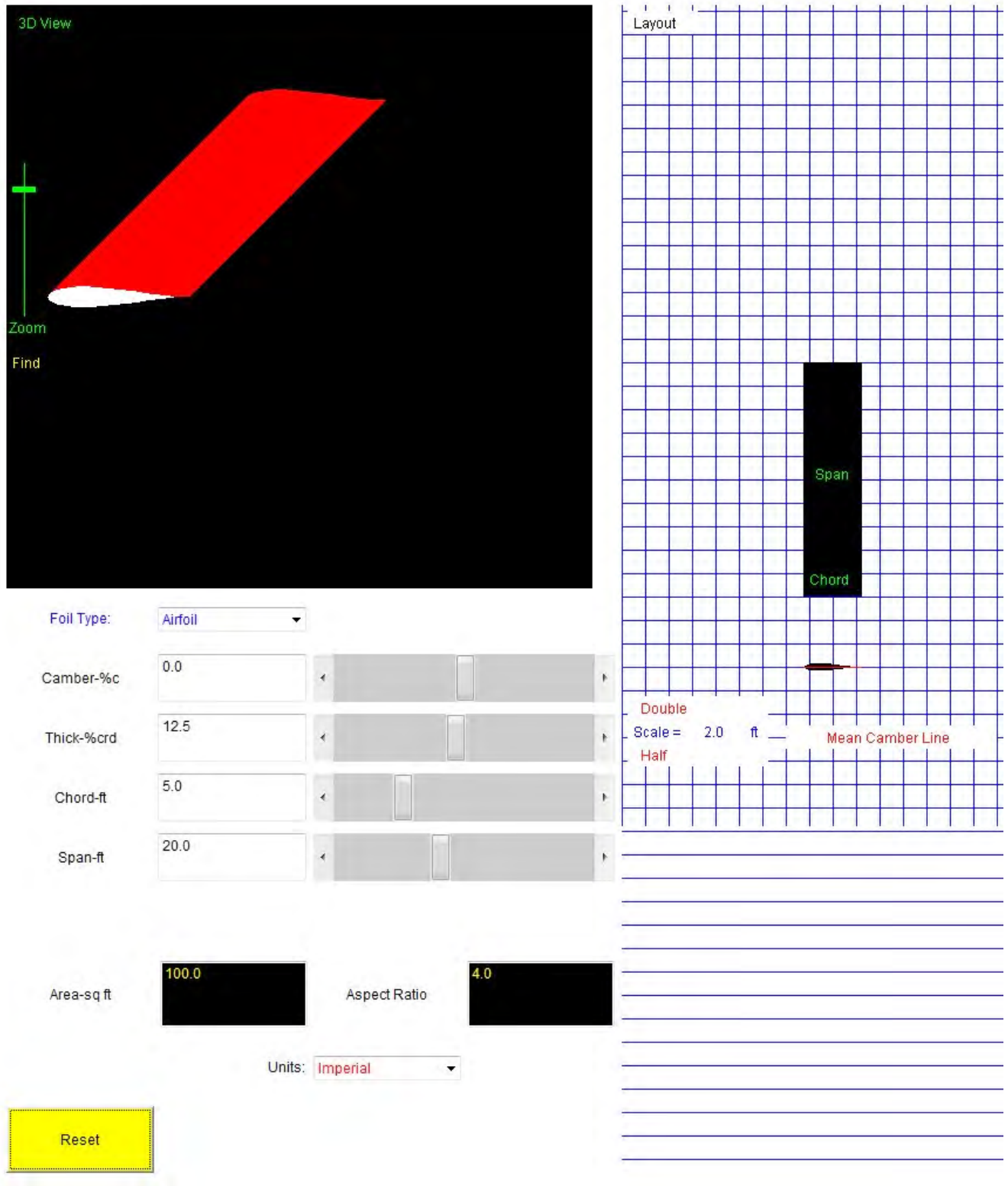


Fig. 2 Computer Wing Geometry Simulation (<http://www.grc.nasa.gov/WWW/k-12/airplane/geom.html>) Beginner's Guide to Aeronautics, NASA—Applet can be downloaded at MIB website: <http://www.aeronautics.nasa.gov/mib.htm>.

By moving the various sliders different wing configurations can be created.

Dynamic Pressure

In fluid mechanics, dynamic pressure depends on the density and velocity of the fluid. In flight, the fluid is air. The following equation is used to solve for dynamic pressure.

$$\text{Dynamic Pressure (q)} = \frac{\text{Density (velocity)}^2}{2}$$

Dynamic pressure is a pressure term associated with the velocity of the flow of air.

Assume an aircraft is flying at an altitude of 5000 meters and is traveling at a speed of 1029 km/hour. Determine the dynamic pressure. The density at 5,000 m is .74 kg/m³. Students will solve for density for the atmosphere in Activity 1. Use this number for the density in the Dynamic Pressure equation.

Sample Problem

An aircraft is traveling at a speed of 1029 km/hr. This number needs to be converted to meters/sec. Do the following:

1. Convert km/hr to meters/hr (1029 km/hr x 1000 m/km) = 1,029,000 meters/hr.
2. Next convert meters/hr to meters/sec. There are 3,600 seconds in one hour. To convert meters/hr to meters/sec divide the meters/hr by 3,600 secs

$$\text{Meters/sec} = \frac{1,029,000 \text{ m/hr}}{3,600 \text{ sec/hr}} = 285.8 \text{ m/sec}$$

Now the Dynamic Pressure can be calculated.

$$\text{Dynamic Pressure (q)} = \frac{\text{Density (velocity)}^2}{2}$$

$$q = \frac{.74 \text{ kg/m}^3 (285.8 \text{ m/sec})^2}{2} = 30.2 \text{ kilo Pascals}$$

Speed of Sound

The speed of sound through a gas is determined by the type of molecules in the gas and the temperature of the gas. Air is composed of 78% nitrogen, 21% oxygen, and traces of other molecules. There is a unique value of the gas constant that can be used when computing the speed of sound in air. When air heats up it has more kinetic energy and the molecules move faster and collide more often with other molecules. Since the molecules are moving faster at higher temperatures, sound waves travel more quickly.

The following equation can be used to find the speed of sound in air as follows:

$$\text{speed of sound} = a = \text{square root} [400.4 \text{ (m}^2/\text{s}^2 / \text{k)} \times T \text{ (k)}]$$

a = speed of sound

T is the absolute temperature of the air; the temperature relative to absolute 0.

In the metric system of units, T is expressed in kelvin. T kelvin = T Celsius + 273.15

One thing to keep in mind is that this equation finds the average speed of sound for any given temperature. The temperature is affected by several factors such as altitude and weather conditions. Assume that you are at an altitude of 2,000 meters, what is the speed of sound? The air temperature at 2,000 meters is 2° Celsius.

$$a = \text{square root} [400.4 \times T (k)]$$

$$a = \text{square root} [400.4 \times (273.15 + 2^\circ)]$$

$$a = \text{square root} [400.4 \times 275.15] = \text{square root} [110170.06]$$

$$V = 331.91 \text{ m/s}$$

To convert velocity in m/s to km/hr do the following:

1. Multiply the velocity in meters/sec x 3600 sec/hr. In the example 331.91 m/s x 3600sec/hr = 1,194,907 meters/hour
2. To convert to km/hr divide the number of meters by 1000 m/km. In the example, 1,194,907 meters/hour /1000 m/km = 1194.9 km/hr (the speed of sound at an altitude of 2,000 meters)

Why are engineers interested in the speed of sound? Near and above the speed of sound, the drag of the aircraft increases because of the formation of shock waves in the air around the aircraft. Shock waves are extremely small regions where the pressure and temperature increase by a large amount, while the velocity decreases by large amount. The change in pressure creates a sonic boom.

Static Temperature

The static temperature is the temperature of the gas if it had no ordered motion and was not flying. Temperature decreases to an altitude of about 20,000 meters. The sea level temperature is 15° C. By the time an aircraft climbs to 5000 meters the outside temperature is -17.5° C.

Static Pressure

The air pressure at different altitudes is referred to as static pressure. For an altitude of 2000 meters the static pressure is 80 kPa.

Mach Number

The Mach number is a ratio of the speed of the aircraft to the speed of sound. The following equation can be used to determine the Mach number. To be accurate the speed of sound for any given altitude should be used to determine the Mach number.

$$\text{Mach number} = \frac{\text{Speed of Aircraft}}{\text{Speed of Sound}}$$

An aircraft is traveling at a speed of 223 m/sec at a 2000 meter altitude, what is its Mach number? The speed of sound at 2000 meters is 332 m/sec.

$$\text{Mach number} = \frac{223 \text{ m/sec}}{332 \text{ m/sec}} = .67$$

Lift

Lift is a mechanical force. It is created when a solid object moves through a fluid. For an aircraft, lift is the force that directly opposes the weight of the aircraft and keeps the aircraft in the air. Most of the lift on an aircraft is produced by its wings. The amount of lift produced by a wing will vary depending on its shape and size. In addition, the

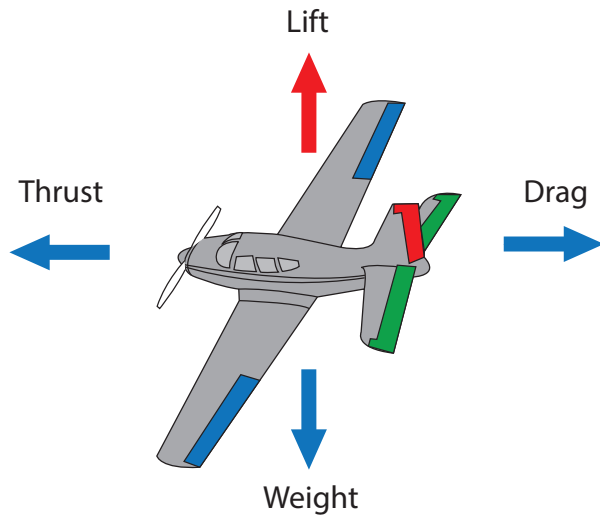


Fig. 3 Four forces of flight

fuselage of an aircraft can also produce lift if it is inclined to the airflow.

Notice the red arrow in Figure 3. The red arrow represents lift and is pointing straight up, while the blue arrow for weight is pointing straight down.

There are two requirements necessary to create lift. The first is that the aircraft must be in contact with a fluid and for an aircraft, the fluid is the air in our atmosphere. If there is no air, the aircraft will not fly. Lift also depends on the properties of air. For example, lift is affected by the density of the atmosphere. At a constant speed, lift decreases with an increase in altitude.

The second requirement deals with motion. There must be a motion between the aircraft and the air. With no motion there is no lift. Lift acts perpendicular to the flow of air. The amount of lift produced will depend on the speed of the aircraft and how it is inclined to the flow.

The most common explanation for lift provided to students is that lift is generated by a pressure difference across a wing. The air passing over the top of a lifting wing passes across the wing at a faster velocity than the air passing on the underside of the wing. Therefore, according to Bernoulli's principle the pressure on the top of the wing is less than the pressure below the wing. The difference in pressure produces the lift. Though this explanation is easy to understand, the real details for how an aircraft generates lift are complex. For additional background refer to NASA's Beginners Guide to Aeronautics.

The following equation can be used to solve for lift:

$$\text{Lift} = \frac{\text{coefficient of lift (C}_L\text{)} \times \text{density} \times \text{velocity squared} \times \text{wing area}}{2}$$

It should be noted that the Coefficient of Lift and the Coefficient of Drag include all of the complex dependencies on design parameters such as shape, surface roughness, sonic conditions, and angle of attack. The value of the coefficient changes with variations of the design parameters. The value of the coefficient is usually determined by wind tunnel experiments. For some simple designs, the value of the coefficient can be determined by numerical calculations. Here is a computer simulation program to allow students to study the effects of angle of attack on the lift of a wing.

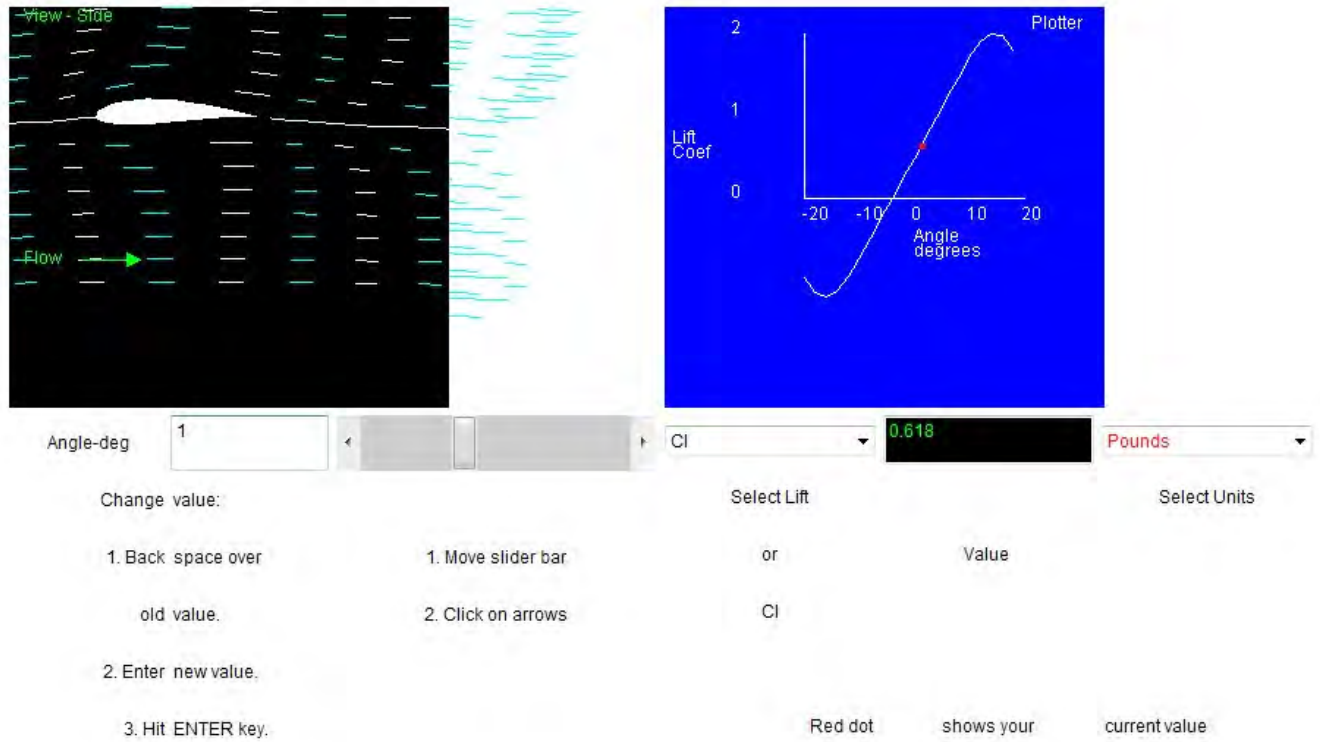


Fig. 4 Angle of Attack and Coefficient of Lift Interactive from the Beginner's Guide to Aeronautics, (<http://www.grc.nasa.gov/WWW/K-12/airplane/incline.html>) Beginners Guide to Aeronautics, NASA. Applet can be downloaded at MIB website <http://www.aeronautics.nasa.gov/mib.htm>.

Note in Figure 4 that an aircraft flying at a 1° angle of attack has a coefficient of lift of 0.618. You can use the slider or type in the angle of attack to determine the coefficient of lift at some other angle of attack.

Air Density is specified in kilogram/m³ or slug/ft³

Velocity measured in Meters/sec or ft/sec

Wing area measured in square meters or square feet.

Lift Sample Problem

A Boeing 747 is flying at an altitude of 12,192 meters and has a velocity of 265.5 m/s. The aircraft has a wing area of 510.97 m². The coefficient of lift is 0.52 and the density of air at 12,192 meters is approximately 0.30267 kg/m³. The weight of the 747 is 2,833,500 N (637,000 pounds). Solve for lift.

$$\text{Lift} = \frac{\text{coefficient of lift (C}_L\text{)} \times \text{density} \times \text{velocity squared} \times \text{wing area}}{2}$$

$$\text{Lift} = \frac{(0.52) \times 0.30267 \times (265.5\text{m/s})^2 \times 510.97 \text{ m}^2}{2}$$

$$\text{Lift} = 2,834,439 \text{ Newtons}$$

To convert Newtons to pounds divide the number of Newtons by 4.448. This is the number of Newtons in one pound.

$$\frac{2,834,439 \text{ Newtons}}{.448 \text{ Newtons/pound}} = 637,238 \text{ pounds of lift}$$

Notice the lift in Newtons and pounds matches within a few pounds the weight of the Boeing 747. The aircraft has enough lift to fly.

Angle of Attack

The angle of attack is the angle that the wing or airfoil is inclined into the airflow. A small angle of attack is adequate to achieve lift at a low speed. If the wing is moving at a constant speed, a larger angle of attack will generate more lift. However, if the angle of attack is too high, its ability to create lift is greatly reduced. This is called a “stall”. As the angle increases, it also causes more drag.

Drag

As an aircraft moves through air, it contends with a form of resistance called drag. Every part of an aircraft affects drag. The amount of drag produced depends on the aircraft’s size and shape. A large aircraft will produce more drag than a thin, streamlined one. Drag in flight is of two basic types: parasite drag and induced drag. The first is called parasite because it in no way functions to aid flight. For example, the shape of the aircraft or the smoothness of the skin of the aircraft impact parasite drag. The second type of drag is created as a result of the wing developing lift. Drag acts in a direction that is opposite the forward motion of the aircraft. Thrust from the engines is used to overcome drag. Drag reduces the efficiency of an aircraft in flight. Drag increases with the square of velocity and also increases with increasing air density.

Lift to Drag Ratio

For an aircraft, the lift-to-drag ratio, or L/D ratio is the amount of lift the wing generates, compared to the drag it creates by moving through the air. A higher L/D ratio is one of the major goals in wing design. A particular aircraft’s needed lift does not change. Producing that lift with lower drag leads directly to better fuel economy. The lift to drag ratio is used to describe the relationship between lift and drag. The L/D ratio is obtained by dividing the lift coefficient by the drag coefficient, C_L / C_D . The speed of an aircraft affects lift and drag. Both lift and drag increase with the square of the speed. If the speed of an aircraft is doubled, the drag or lift will be quadrupled. Remember in the equation for lift that the velocity is squared. In contrast the relationship between lift or drag and air density is a direct relationship. An increase or decrease in air density will cause an increase or decrease in both drag and lift.

A high lift to drag ratio can occur when an aircraft produces a large amount of lift or a small amount of drag. An aircraft with a large lift value can carry a larger payload. When the drag is low for an aircraft, it will not burn as much fuel during its flight and will be able to fly for longer distances.

L/D ratio

High Lift, High Drag—crop duster

Low Lift, Low Drag—jet fighter

Moderate Lift, Moderate Drag—light aircraft

Moderate Lift, Low Drag—aerobatic aircraft

Air Density

Air density is the mass per volume of Earth's atmosphere, and is a useful value in aeronautics. In the International System of Units air density is measured as the number of kilograms of air in a cubic meter. With a temperature of 20° C as sea level, a cubic meter of dry air has a mass of approximately 1.2 kg. At sea level and at 20° C dry air has a density of approximately 1.2 kg/m³.

Activity 1

Effect of Altitude on the Temperature, Density, Pressure, and Speed of Sound in Flight

GRADES**9-12****Time Requirements:** 60 minutes**Materials:**In the Box

CD with simulation applets necessary for lesson

Simulation applets can also be downloaded from the MIB website: <http://www.aeronautics.nasa.gov/mib.htm>.

Provided by User

None

Worksheets

How Does Altitude Relate to Temperature, Density, Pressure and the Speed of Sound Worksheet (worksheet 1)

Reference Materials

None

Key Terms:

Static Temperature

Static Pressure

Air Density

Speed of Sound

Mach Number

Dynamic Pressure

Objective:

Students will learn about motions and forces as they determine how a change in altitude affects temperature, pressure, density and the speed of sound through the use of the AtmosModeler Interactive Simulator. Students will also solve a problem related to dynamic pressure and the Mach number.

Activity Overview:

By completing this activity students will learn how the properties of the atmosphere change with altitude through the use of the AtmosModeler Simulator. Students will investigate changes in the atmosphere and its effects on aerodynamic variables. In this activity temperature, pressure, density, and speed of sound will be investigated. Students will create graphs to observe trends and draw conclusions on the effects of the atmosphere on the aerodynamics of flight. Students will also use data provided to solve for the dynamic pressure on an aircraft as well as the Mach number.

Activity:

1. **Introduce the lesson by reviewing some of the great research performed by the aeronautical pioneers included in the background.**
2. **Explain to the students that in this activity they will determine how changes in altitude affect the temperature, pressure, density, and the speed of sound of an aircraft flying at constant speed at the different altitudes using the AtmosModeler Simulator.** As the students change the height within the atmosphere, the software calculates the different outputs. For this activity, the students will be collecting data related to the static temperature, standard pressure, density, and the speed of sound.
3. **Have the students working as individuals, pairs or teams of 4.**

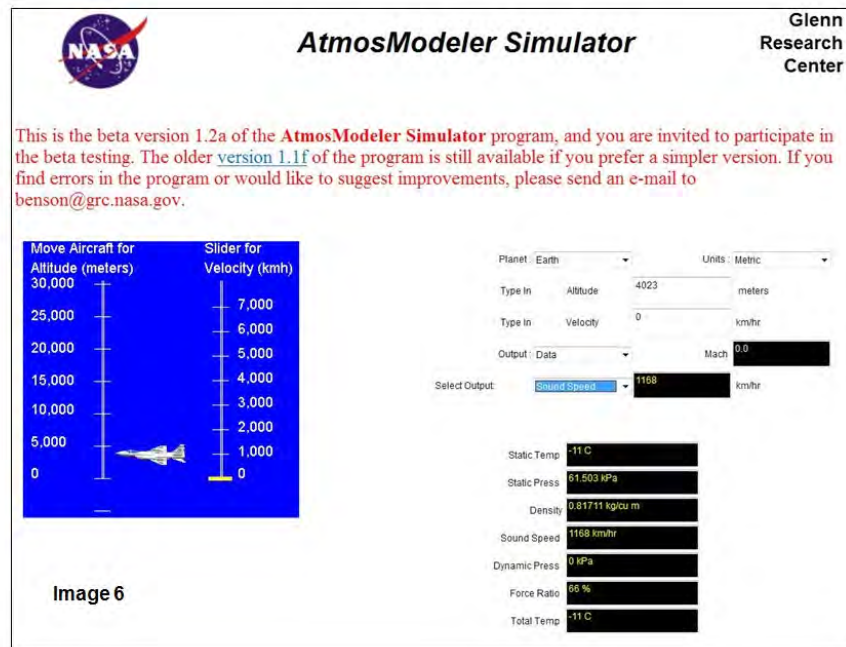


Image 6

Fig. 5 Beginner's Guide to Aeronautics, NASA
<http://www.grc.nasa.gov/WWW/K-12/airplane/atmosi.html>

4. **Show the students Figure 5.** Identify the various parts of the Atmospheric Simulator. Explain to them that in this activity they are to leave the aircraft speed at 0. Have the students use metric units. Show them on Figure 5 where the unit selection is located. Also remind them to select Earth as the planet. The students should also select to display their output in the data format as shown in Figure 5.
5. **Have the students open the AtmosModeler Simulator.**
6. **Allow the student a few minutes to familiarize themselves with the simulator.**
7. **Have the students set the aircraft speed to 0.** Explain to the students that by doing this they will be measuring the effect of only one variable, the altitude, on pressure, temperature, density and the speed of sound. It is important for this activity to have the students keep the speed of their aircraft at 0 for each measurement.
8. **Distribute the How Does Altitude Relate to Temperature, Density, Pressure and the Speed of Sound Worksheet.**
9. **Walk the students through the worksheet and highlight the instructions.** Remind the students that it is very important to follow the directions on the worksheet.
10. **Upon completion of the worksheet review the discussion points with the students.**

Discussion Points:

1. **How has aeronautical research changed over the years?**

Research has changed from when individuals or small groups of individuals studied flight. (Refer to Background Information) to today where we have research facilities that provide for many types of aeronautical research by teams of individuals including NASA centers, universities, or aerospace companies. In addition, today's aeronautical research centers have state of the art equipment. Modern super computers are enabling research that no longer requires the use of a wind tunnel to get accurate results.

2. **What is the effect of altitude on the speed of sound? What does your data tell you?**

The speed of sound decreases with increasing altitude. The speed of sound at sea level is approximately 341 m/s (1116 feet/sec). Expressed in kilometers per hour, the speed of sound is 1224 kilometers/hr. (761 mph) The speed of sound at 9.144 km (30,000 feet) is 300 m/s (994 feet/sec).

3. **What is the effect of altitude on static temperature? What does your data tell you?**

The atmospheric temperature decreases with increasing altitude. At sea level the standard temperature is 14.4° C (58° F). The temperature at 9.144 km (30,000 feet) is -43.8° C (-47° F).

4. **What is the effect of altitude on static pressure? What does your data tell you?**

The atmospheric pressure decreases with increasing altitude. At sea level the atmospheric pressure is 101.32 KPa (14.695 pounds/square inch - psi), while at 9.144 km (30,000 feet) the air pressure is reduced to 30.15 KPa (4.373 psi).

5. **What is the effect of altitude on atmospheric density? What does your data tell you?**

The density of the air through which an aircraft is flying is perhaps the most important factor affecting the performance of the aircraft in flight. For example, the flow of less dense air over a wing produces less lift for an aircraft flying at a constant speed. As evidenced through the use of the simulator, the density of air decreases with altitude. At sea level the density is 1.221 kilograms/cubic meter (.064 slugs/cu yard). At 9.144 km (30,000 feet) the density of air is .459 kilograms/cubic meter (.024 slugs/ cubic yard).

6. **How does the altitude affect the Mach number when flying at a constant speed?**

The Mach number increases with increasing altitude for an aircraft. An aircraft traveling at 500 mph would be traveling at Mach .736 while at 30,000 feet. With the same speed the aircraft would be traveling at Mach .656 at sea level. From question 1 above you can see that the speed of sound is lower at altitude than at sea level. Therefore traveling at a constant speed would increase the Mach number (dividing by a smaller number). This is an important result for airplane designers because the drag coefficient increases with Mach number as the aircraft approaches Mach 1. At altitude, one needs more thrust to overcome the increased drag to maintain the same speed as at sea level.

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES

- Science and technology in local, national, and global challenges

HISTORY AND NATURE OF SCIENCE

- Science as human endeavor
- Nature of scientific knowledge
- Historical perspectives

NATIONAL MATH STANDARDS 9-12

NUMBER AND OPERATIONS

- Understand numbers, ways of representing numbers, relationships among numbers, and number systems
- Understand meanings of operations and how they relate to one another
- Compute fluently and make reasonable estimates

ALGEBRA

- Represent and analyze mathematical situations and structures using algebraic symbols
- Use mathematical models to represent and understand quantitative relationships

MEASUREMENT

- Understand measurable attributes of objects and the units, systems, and processes of measurement
- Apply appropriate techniques, tools, and formulas to determine measurements.

DATA ANALYSIS AND PROBABILITY

- Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them

PROCESS

- Problem Solving
- Communication
- Connections
- Representation

Activity 2

Relationship of Lift and Drag in Flight

GRADES 9-12

Time Requirements: 90 minutes

Materials:

In the Box

CD with simulation applets necessary for lesson

Simulation applets can also be downloaded from the MIB website: <http://www.aeronautics.nasa.gov/mib.htm>.

Provided by User

None

Worksheets

Relationship of Lift and Drag in Flight (worksheet 2)

Reference Materials

Beginner's Guide to Aeronautics Website

Key Terms:

Lift
 Drag
 Lift to Drag Ratio
 Coefficient of Lift
 Coefficient of Drag
 Angle of Attack

Objective:

Through the use of the FoilSim III simulation students will learn how lift and drag are influenced by the angle of attack and how the Lift to Drag ratio can provide useful information about an aircraft such as whether it can lift a large payload or fly extended flights.

Activity Overview:

Through the first part of Activity 2 students will utilize the FoilSim III simulator to determine how the Coefficient of Lift and Drag are related by changing the angle of attack. During the second part of the activity students will change input for the size of the wing. All other inputs will remain the same. With the new input students will once again determine the Coefficient of Lift and Drag by changing the angle of attack. Results from the two simulations will enable the students to determine if the Coefficients of Drag and Lift are constant and if the lift and drag are also the same as they were during the first part of Activity 2. Students will analyze data from tables, graphs, and equations to gain a better understanding of the relationship of lift and drag and its effects on an aircraft's flight.

Activity:

1. **Introduce this activity by highlighting some of aeronautic concepts included in the lesson background such angle of attack, lift, drag and the lift to drag ratio.**
2. **Inform the students that in this activity they will be using the FoilSim III Student Version 1.4d software that was developed at the NASA Glenn Research Center.** Highlight for the students that this software will enable them to determine how changes in the angle of attack of an aircraft wing influence the lift and drag of the aircraft. For this activity students will collect data from the FoilSim III Student Version 1.4d interactive and record it on the data collection forms for them to analyze.



FoilSim III Student Version 1.4d

Glenn
Research
Center

This is a beta 1.4d student version of the FoilSim III program, and you are invited to participate in the beta testing. If you find errors in the program or would like to suggest improvements, please send an e-mail to Thomas.J.Benson@nasa.gov. FoilSim III is still available if you prefer the older version.

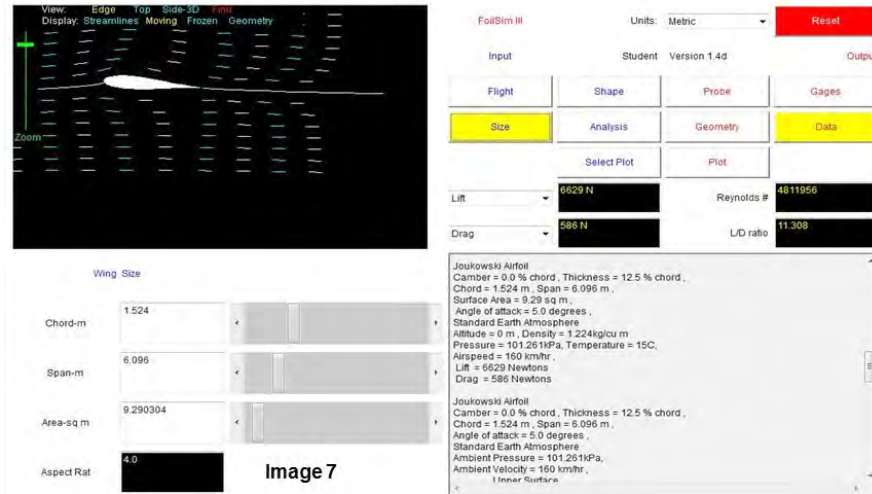


Fig. 6 Beginner's Guide to Aeronautics, NASA
<http://www.grc.nasa.gov/WWW/K-12/airplane/foil3.html>

3. Have the students working as individuals, pairs or teams of 4. Show the students Figure 6. Highlight the parts of the FoilSim III interactive.
4. Explain to them that in this activity they are to enter the data as called for in the Relationship of Lift and Drag in Flight Worksheet.
5. Have the students open the FoilSim III Student Version 1.4d software.
6. Allow the student a few minutes to familiarize themselves with the software.
7. Remind the students that they are to set the data for the simulation as required in the worksheet.
8. Distribute the Relationship of Lift and Drag in Flight Worksheet.
9. Walk through the students through the worksheet by highlighting the instructions.
10. Upon completion of the worksheet review the discussion points with the students.

Discussion Points:

1. **From your use of the FoilSim III simulator what factors influence how any aircraft will fly?**

Some possible answers include the speed of the aircraft, its altitude, the size of the wing, its shape, its span and thickness, the camber of the wing and the angle of attack.

2. **How does the angle of attack influence the Coefficient of Lift and Drag?**

From the coefficient of lift graph it can be noted that there is positive lift from an angle of attack greater than 0° and less than 15° . As angle of attack increases, the lift increases up to about 15° . An angle of attack greater than 15° will create a stall condition for the aircraft and the lift decreases. Drag also increases with angle of attack up to the stall angle.

3. **What angle of attack produced the maximum lift to drag?**

From the Lift to Drag graph an angle of attack between 2° and 6° produces the maximum lift to drag?

4. **During the activity you had to change the area on the wing leaving all of the other data the same? Were the coefficient of lift and drag the same in both flights?**

In the first flight with a wing area of 30 sq m the coefficient of lift was .0573 and the coefficient of drag was .054. The lift to drag ratio was 10.518. When the wing surface was increased to 54 sq m leaving all other variables the same the coefficient of lift was 0.578 and the coefficient of drag was .054. The lift to drag ratio was 10.625. The angle of attack for all measurements was 5° .

5. **How can the Lift to Drag ratio be used in the design of an aircraft?**

High Lift, High Drag aircraft often limited to flying slow and for short distances. A good example of a high lift, high drag aircraft is a crop duster.

Low lift, Low Drag aircraft are fast moving, like jets. Their thin shaped airfoil generates very little drag and little lift so the jet must fly very fast to generate enough lift to stay aloft.

Moderate Lift, Moderate Drag aircraft produce moderate lift and at the same time do not generate a lot of drag. Many small light planes like a Cessna 172 fall in this category.

Moderate Lift, Low Drag aircraft are used in aerobatics. The wing is symmetrical in aerobatic planes. That means that the curvature on the top of the wing is the same as the bottom of the wing.

6. **During the activity you were asked to design a wing that would generate a lift of 25,000 N. Share your results. Did all of the wings that were designed have the same measurements? So what can we say are ways to produce the 25,000 N of lift?**

There are many possible answers to this question—changing the angle of attack will impact lift; increasing the size of the wing will impact lift; changing the wing's camber will also impact lift. The lift to drag ratios will also be different.

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES

- Science and technology in local, national, and global challenges

HISTORY AND NATURE OF SCIENCE

- Science as human endeavor
- Nature of scientific knowledge
- Historical perspectives

NATIONAL MATH STANDARDS 9-12

NUMBER AND OPERATIONS

- Understand numbers, ways of representing numbers, relationships among numbers, and number systems
- Understand meanings of operations and how they relate to one another
- Compute fluently and make reasonable estimates

ALGEBRA

- Represent and analyze mathematical situations and structures using algebraic symbols
- Use mathematical models to represent and understand quantitative relationships

MEASUREMENT

- Understand measurable attributes of objects and the units, systems, and processes of measurement
- Apply appropriate techniques, tools, and formulas to determine measurements.

DATA ANALYSIS AND PROBABILITY

- Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them

PROCESS

- Problem Solving
- Communication
- Connections
- Representation



Reference Materials

Glossary

Air Density:

Is measured, in the International System of Units, as the number of kilograms of air in a cubic meter. With a temperature of 20° C as sea level, a cubic meter of dry air has a mass of approximately 1.2 kg.

Angle of Attack:

The angle that the wing is inclined into the air flow

Coefficient of Drag:

Determined experimentally and provides a value that is constant or predictable and is used in the calculation of drag

Coefficient of Lift:

Determined experimentally and provides a value that is constant or predictable and is used in the calculation of lift

Drag:

Acts in a direction that is opposite the forward motion (thrust) of the aircraft. Drag reduces the efficiency of an aircraft flight

Dynamic Pressure:

A pressure term associated with the velocity of the flow of air. The following equation is used to solve for dynamic pressure

$$\text{Dynamic Pressure (q)} = \frac{\text{Density (velocity)}^2}{2}$$

Hypersonic Speed:

The speed of an aircraft that is traveling at a speed of greater than Mach 5. At these speeds, the high energy and temperature of the flow cause the molecules of the air to rotate, vibrate, and finally to dissociate (break chemical bonds and strip off electrons)

Lift:

The force that directly opposes the weight of the aircraft and keeps the aircraft in the air

Lift to Drag Ratio:

The amount of lift the wing generates, compared to the drag it creates by moving through the air. A higher L/D ratio is one of the major goals in wing design

Mach Number:

The ratio of the speed of the aircraft to the speed of sound. An aircraft flying twice the speed of sound for that altitude has a Mach number of 2

Speed of Sound:

The velocity of sound in the atmosphere. Its speed varies with temperature and therefore by altitude. At sea level the speed of sound is 341 m/sec

Static Pressure:

Air pressure at different altitudes

Static Temperature:

The temperature of the gas if it had no ordered motion and was not flowing

Stall:

A condition in aerodynamics where the lift of a wing decreases as the angle of attack increases. Stall is caused by the separation of a thin layer of flow near the surface of the wing, called the boundary layer. The angle at which stall occurs is called the *critical angle of attack*

Subsonic Speed:

The speed of an aircraft that is traveling less than Mach 1

Supersonic Speed:

The speed of an aircraft that is traveling faster than Mach 1

Total Temperature:

The temperature of the airflow at the leading edge of the wing on an aircraft or about the nose of the aircraft

Transonic Speed:

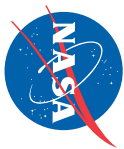
The speed of an aircraft that is traveling near Mach 1

WEBSITES TO VISIT:

Beginner's Guide to Aeronautics (Thomas J. Benson, Author, NASA Glenn Research Center)

<http://www.grc.nasa.gov/WWW/K-12/airplane/index.html>

Fig. 1 Wing Geometry Definitions



Wing Geometry Definitions

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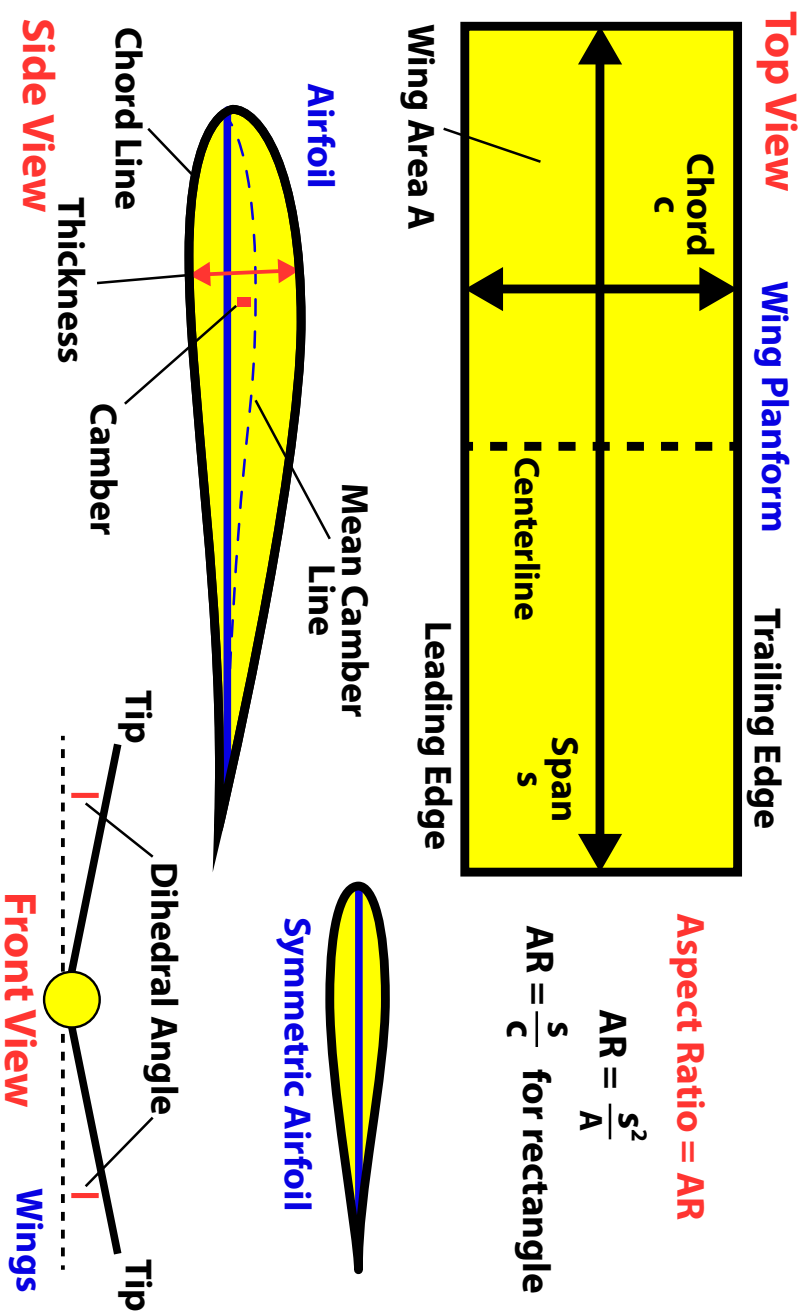
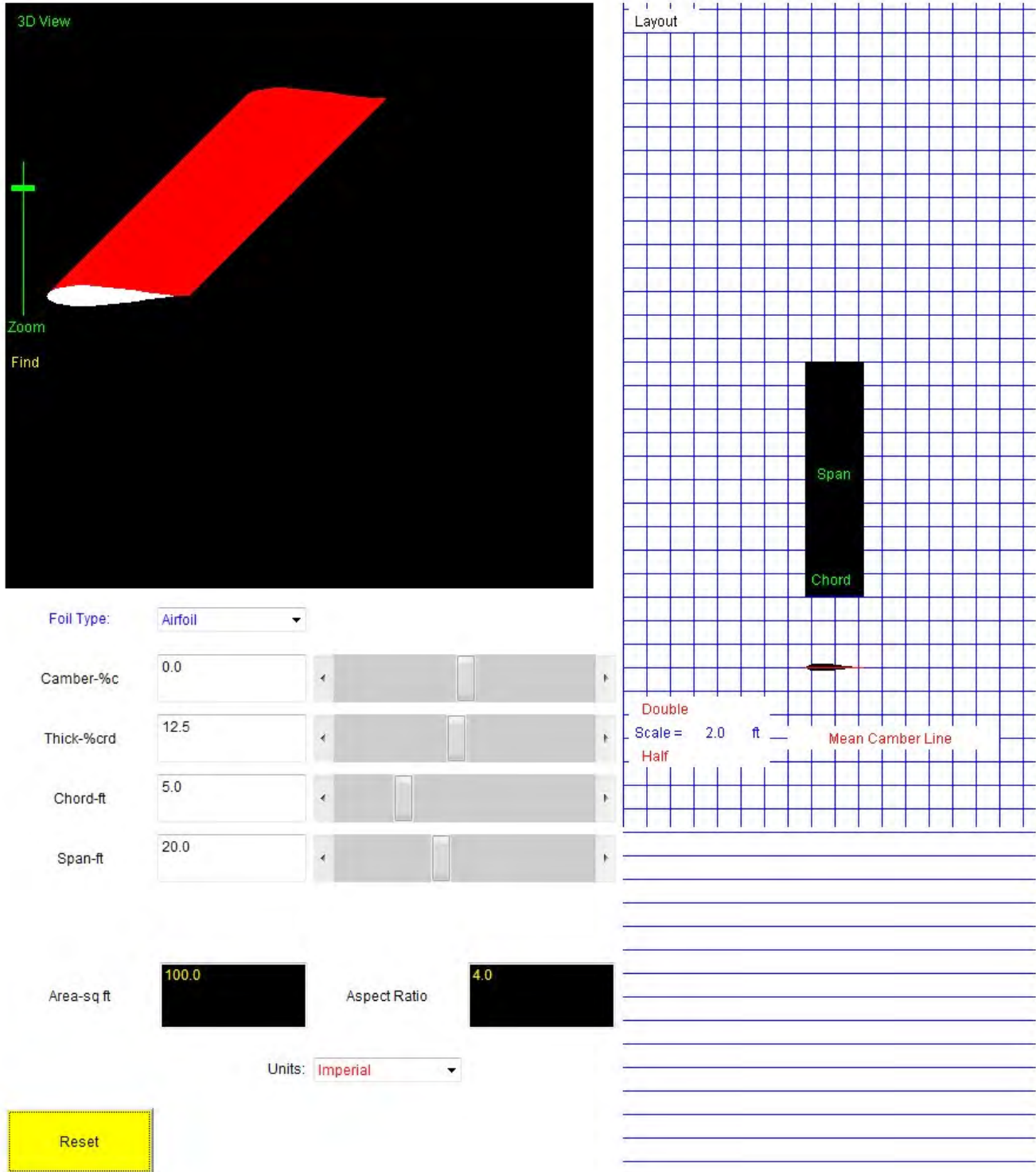


Fig. 2 Computer Wing Geometry Simulation



<http://www.grc.nasa.gov/WWW/k-12/airplane/geom.html> - Beginner's Guide to Aeronautics, NASA Applet can be downloaded at MIB website: <http://www.aeronautics.nasa.gov/mib.htm>.

Fig. 3 Four Forces of Flight

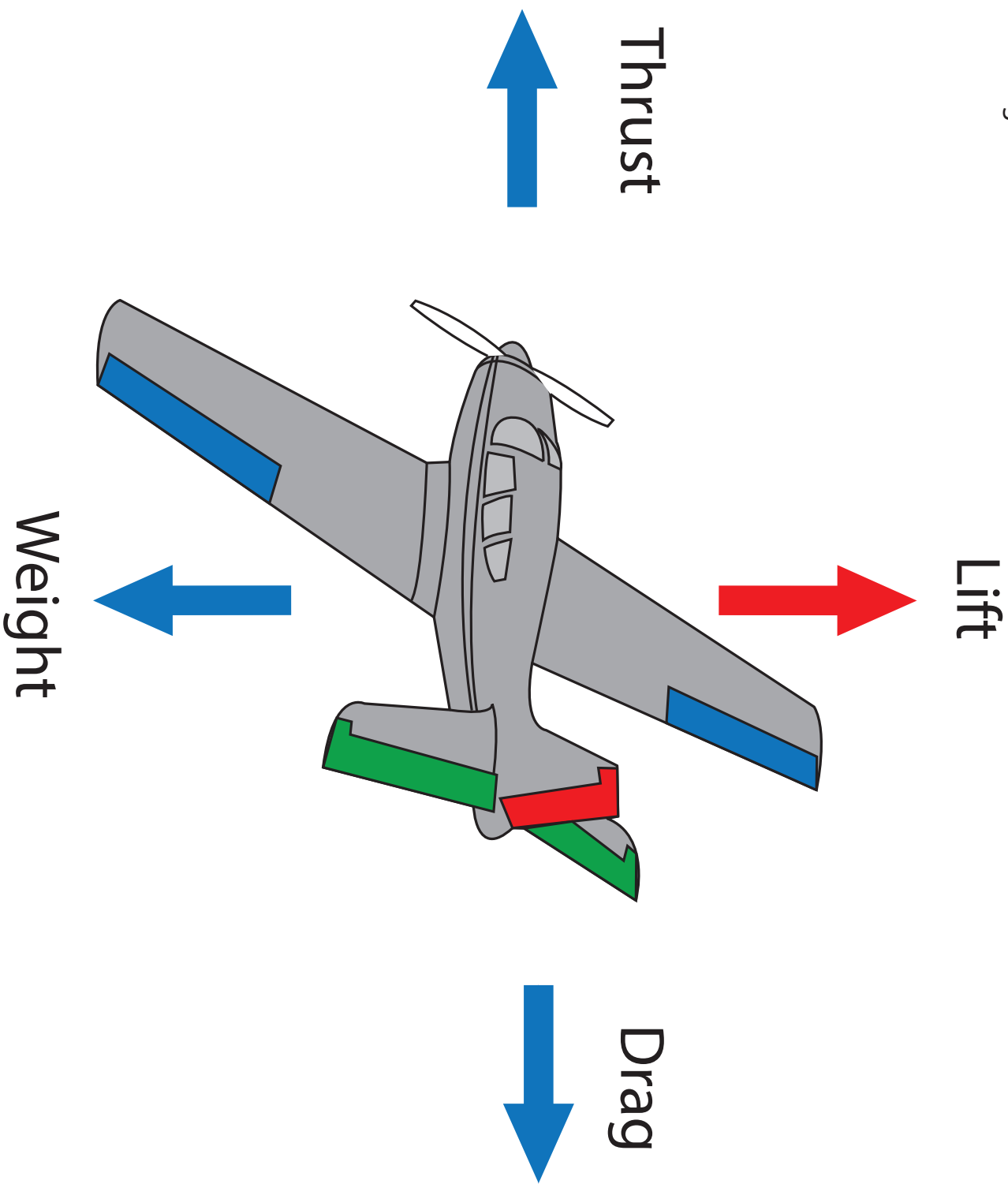
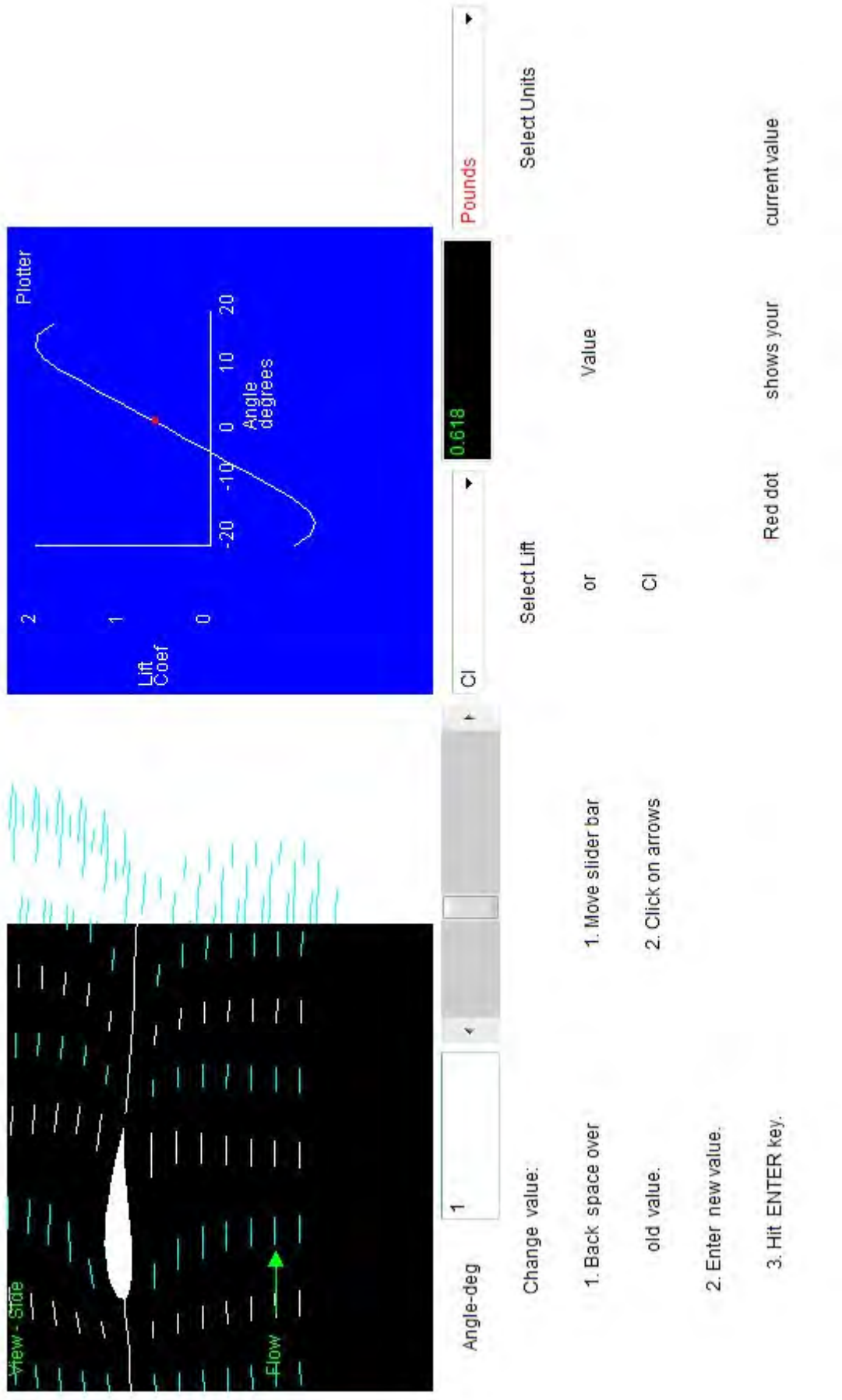


Fig. 4 Angle of Attack and Coefficient of Lift



Interactive from the Beginner's Guide to Aeronautics, (<http://www.grc.nasa.gov/WWW/K-12/airplane/incline.html>) Beginners Guide to Aeronautics, NASA. Applet can be downloaded at MIB website <http://www.aeronautics.nasa.gov/mib.htm>.



AtmosModeler Simulator

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This is the beta version 1.2a of the **AtmosModeler Simulator** program, and you are invited to participate in the beta testing. The older [version 1.1f](#) of the program is still available if you prefer a simpler version. If you find errors in the program or would like to suggest improvements, please send an e-mail to benson@grc.nasa.gov.

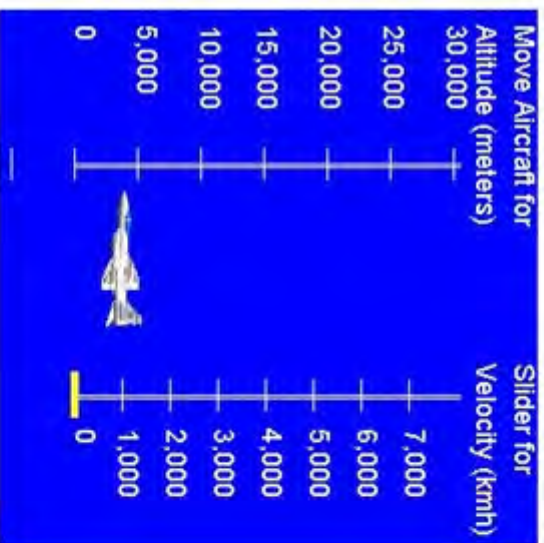


Image 6

Fig. 6 Beginner's Guide to Aeronautics, NASA



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Foilsim III Student Version 1.4d

This is a beta 1.4d student version of the **Foilsim III** program, and you are invited to participate in the beta testing. If you find errors in the program or would like to suggest improvements, please send an e-mail to Thomas.J.Benson@nasa.gov. [Foilsim III](http://www.nasa.gov/WWW/K-12/airplane/foil3.html) is still available if you prefer the older version.

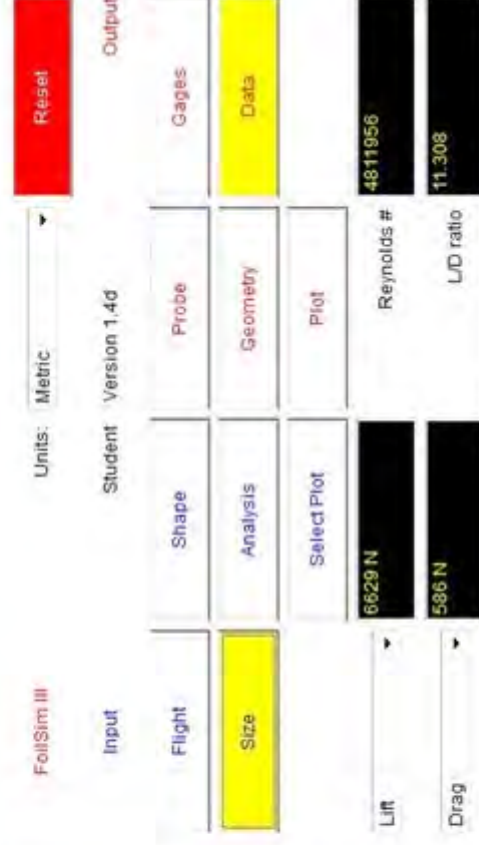
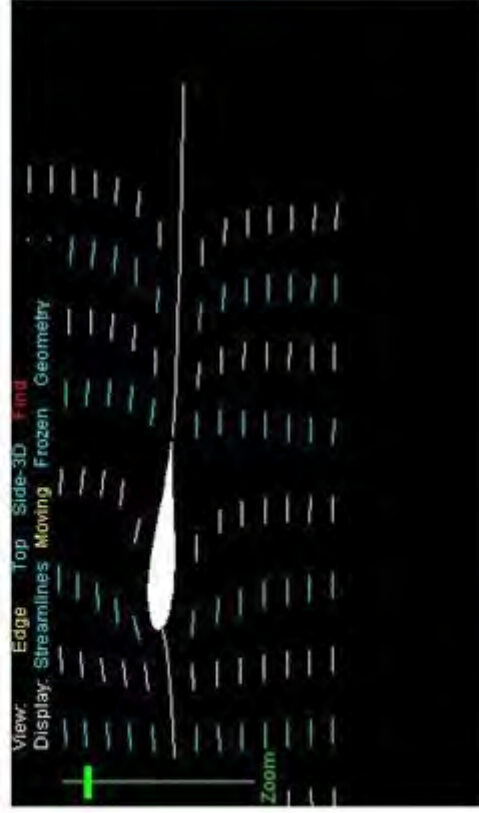


Image 7



Worksheets

Worksheet 1

How Does Altitude Relate to Temperature, Density, and Pressure

1. Open AtmosModeler Simulator
2. Familiarize yourself with the AtmosModeler Simulator
3. Make sure Planet Earth is selected, Units are in Metric and the Output is data.
4. On the simulator enter 0 for velocity and 0 meters, click enter and record the data.
5. Record the static temperature, static density, pressure, and speed of sound on the How Does Temperature, Density, and Pressure Vary with Altitude? form below.

How Does Temperature, Density, and Pressure Vary with Altitude?					
Altitude	Temperature C°	Density Kg/m ³	Pressure KPa	Speed of Sound km/h	Speed of Sound mph
0 - Sea Level					
5,000 meters					
10,000 meters					
15,000 meters					
20,000 meters					
25,000 meters					
30,000 meters					

Worksheet 1 (cont.) How Does Altitude Relate to Temperature, Density, and Pressure

How Does Temperature Vary with Altitude?								-60
								-50
								-40
								-30
								-20
								-10
								0
								10
								20
	Alt	30,000 m	25,000 m	20,000 m	15,000 m	10,000m	5,000 m	0 m	Temp in C°

Worksheet 1 (cont.) How Does Altitude Relate to Temperature, Density, and Pressure

Alt	How Does Density Vary with Altitude?																										
30,000 m																											
25,000 m																											
20,000 m																											
15,000 m																											
10,000 m																											
5,000 m																											
0 m																											
Density Kg/m ³	1.3	1.25	1.2	1.15	1.1	1.05	1.0	0.95	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50	0.45	0.40	0.35	0.30	0.25	0.20	0.15	0.10	0.05	0.00

Worksheet 1 (cont.) How Does Altitude Relate to Temperature, Density, and Pressure

How Does Pressure Vary with Altitude?								0
								10
								20
								30
								40
								50
								60
								70
								80
								90
								100
								110
Alt	30,000 m	25,000 m	20,000 m	15,000 m	10,000 m	5,000 m	0 m	Pressure KPa

Worksheet 1 (cont.) How Does Altitude Relate to Temperature, Density, and Pressure

Alt	How Does Speed of Sound Vary with Altitude?						
30,000 m							
25,000 m							
20,000 m							
15,000 m							
10,000 m							
5,000 m							
0 m							
Speed of Sound in m/sec	350	340	330	320	310	300	290

Worksheet 1 (cont.) How Does Altitude Relate to Temperature, Density, and Pressure

Dynamic Pressure

Next solve for the dynamic pressure for an aircraft traveling at 1,500 km/hr at 8,000 meters.

The formula for the dynamic pressure on the aircraft =

$$\text{Dynamic Pressure (q)} = \frac{\text{Density (velocity)}^2}{2}$$

Use the AtmosModeler Simulator to determine the density of the atmosphere at 8,000 meters.

Density of atmosphere at 8,000 meters = _____

The aircraft is traveling at 1,500 km/hr

Next convert speed in km/hr to m/sec.

To do this:

1. Convert km/hr to m/s
 - a. Multiply km/hr x 1000 m/km (1,500,000 m/hr)
2. Convert m/hr to m/sec
 - a. Divide m/hr by 3,600 sec/hr $\frac{(1,500,000 \text{ m/hr})}{3,600 \text{ sec/hr}} = \text{_____ m/sec}$
3. Now solve for Dynamic Pressure

$$\text{Dynamic Pressure (q)} = \frac{\text{Density (velocity)}^2}{2}$$

Dynamic Pressure = _____ Pascals

To convert Pascals to Kilo Pascals divide the number of Pascals found for the Dynamic Pressure by 1,000 Pascal/kilo Pascal.

Dynamic Pressure = _____ Kilo Pascals

Worksheet 1 (cont.) How Does Altitude Relate to Temperature, Density, and Pressure

Mach Number

For the aircraft traveling at 1,500 km/hr, determine its Mach number. Use the speed in m/sec that was solved for in the Dynamic Pressure question as the speed of the aircraft. From the graph you created for the Speed of Sound estimate the speed of sound at 8,000 meters.

From the graph it appears that the speed of sound at 8,000 m is approximately _____ m/sec. Use this speed in solving for the Mach number.

$$\text{Mach number} = \frac{\text{Speed of Aircraft}}{\text{Speed of Sound}}$$

Mach Number = _____

Solve for Temperature

For an altitude < 11,000 meters (troposphere) atmospheric temperature in Celsius can be estimated using the formula:

$$T = 15.04 - .00649h \text{ (altitude in meters)}$$

Solve for the temperature at an altitude of 9,000 meters.

The formula to use to solve for temperature in the troposphere is

$$T = 15.04 - .00649^\circ/\text{m} \text{ (altitude)}$$

Answer: _____

Solve for Pressure

Solve for the air pressure at 9,000 meters.

To determine pressure in the troposphere use the formula:

$$P = 101.29 \times \left[\frac{T + 273.1^\circ}{288.08} \right]^{5.256}$$

-273.16° is the temperature of absolute zero

Use the temperature calculated in the Solve for Temperature problem.

The pressure will be in kilo Pascals (KPa)

Answer _____ kilo Pascals

1. Open FoilSim III Student Version 1.4d
2. Familiarize yourself with the FoilSim III interactive.
3. Select metric units
4. Enter the following data for Flight, Size, and Shape

A. Data for FoilSim III to Determine Lift, Drag, C_L , C_D and L/D ratio	
Flight	
Speed - km/h	300 km/h
Altitude - m	2000m
Size	
Chord - m	3 m
Span - m	10 m
Area - sq m	30 sq m
Shape	
Angle - deg	To be entered for each attack angle
Camber - %c	0.0
Thick - %crd	12.5

5. Once the inputs have been completed, reopen the Size Tab. Now enter, one at a time, the angle of attack for each of the angles in the left column of the Form. For each angle record the data in the proper column on the Form. As an example, the data for an angle of attack -3° is listed.

Worksheet 2 (cont.) Relationship of Lift and Drag in Flight

A. Effect of Angle of Attack on Lift and Drag Recording Form					
Angle of Attack	Lift	Drag	C_L	C_D	L/D ratio
-3°	-37340 N	2750 N	-0.354	0.026	-13.577
-2°					
-1°					
0					
1°					
2°					
3°					
4°					
5°					
6°					
7°					
8°					
9°					
10°					
11°					
12°					
13°					
14°					
15°					
16°					
17°					
18°					
19°					

6. Using the same procedure as above collect the required data for the parameters given in B. Entry Data for FoilSim III to Determine Lift, Drag, C_L , C_D , and L/D ratio.

B. Entry Data for FoilSim III to Determine Lift, Drag, C_L , C_D and L/D ratio	
Flight	
Speed - km/h	300 km/h
Altitude - m	2000m
Size	
Chord - m	4.106
Span - m	13.21 m
Area - sq m	54.2 m
Shape	
Angle - deg	To be entered for each attack angle
Camber - %c	0.0
Thick - %crd	12.5

Worksheet 2 (cont.) Relationship of Lift and Drag in Flight

B. Effect of Angle of Attack on Lift and Drag Recording Form					
Angle of Attack	Lift	Drag	C_L	C_D	L/D Ratio
2°					
5°					
10°					
15°					
19°					

During the activity you had to change the area on the wing leaving all of the other data the same? Were the coefficient of lift and drag the same in both flights?

Answer: _____

7. Use the data that you recorded in the A. Effect of Angle of Attack on Lift and Drag Recording Form to produce a line graph for the Lift to Drag Graph with Angle of Attack. The Y axis is L/D and the X axis the angle of attack.

Lift to Drag Graph with Angle of Attack											
L/D											
12											
11											
10											
9											
8											
7											
6											
5											
4											
3											
2											
1											
0											
Angle of Attack	0	2	4	6	8	10	12	14	16	18	20

From the graph between what angles do you get the maximum lift to drag?
 Answer: _____

Worksheet 2 (cont.) Relationship of Lift and Drag in Flight

8. Use the data that you recorded in the A. Effect of Angle of Attack on Lift and Drag Recording Form to produce a line graph on the Coefficient of Lift as a Function of Angle of Attack Graph. The Y axis is the CL and the X axis the angle of attack.

Coefficient of Lift as a Function of Angle of Attack											
C _L											
1.3											
1.2											
1.1											
1.0											
0.9											
0.8											
0.7											
0.6											
0.5											
0.4											
0.3											
0.2											
0.1											
0.0											
Angle of Attack	0	2	4	6	8	10	12	14	16	18	20

Look at the graph and decide what is the stall angle? Answer: _____

Lift to Drag Problem

Assume the aircraft in this problem is the one that data has been gathered as part of Activity 2. This aircraft has a weight of 25184 Newtons. The aircraft's velocity is 300 km/hr and the angle of attack is 2°. From the data the Coefficient of Lift (CL) for a 2° angle of attack is approximately 0.239. For this problem Lift can be equal to the weight of the aircraft in Newtons otherwise the aircraft would not fly.

A simple formula for solving lift: **Lift = K * velocity squared * CL**

First solve for K (K is a constant value made up of the air density and the wing area).

Can assume the lift is equal to the weight in Newtons (25184 Newtons) since the lift must equal the weight in order for the aircraft to fly, so it must be 25184 Newtons.

$$\text{Lift} = K \times V^2 \times C_L$$

$$K =$$

L/D CURVE The ratio of Lift to Drag is a very important parameter for any airplane. Determine the speed to fly this aircraft at the most favorable lift for the amount of drag being created for this aircraft with a 6° angle of attack. The resultant speed is the most favorable lift for the amount of drag being created. This would be the speed to fly the aircraft for the maximum distance either gliding or under power.

$$\text{Lift} = K \times (v)^2 \times C_L$$

Given:

$$K = \text{Answer from above}$$

$$\text{Lift} = 25,184 \text{ Newtons}$$

$$C_L \text{ for } 6^\circ \text{ angle of attack from data} = .0685$$

Solve for speed (velocity)

$$(V)^2 = \frac{L}{C_L}$$

Answer: _____

Explain your answer:

Worksheet 2 (cont.) Relationship of Lift and Drag in Flight

Design a Wing

Given the following constraints, use FoilSim III to design an aircraft wing that generates 25,000 N of lift. Use the table shown below to record your answers.

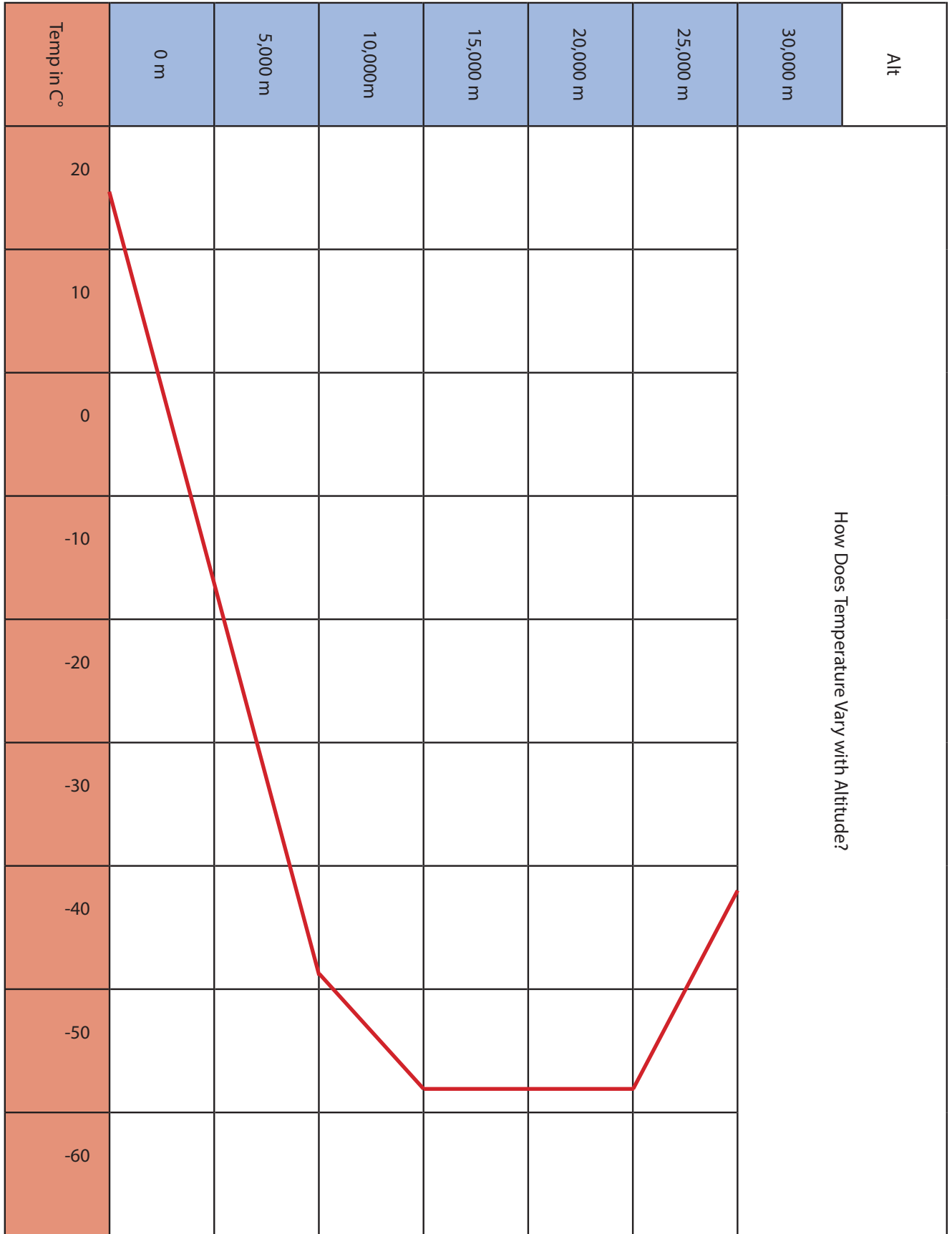
1. The maximum airspeed of the plane is 250 km/hr.
2. The airplane must be able to fly at an altitude of 7000 meters.
3. Lift = 25,000 N
4. Record your values.

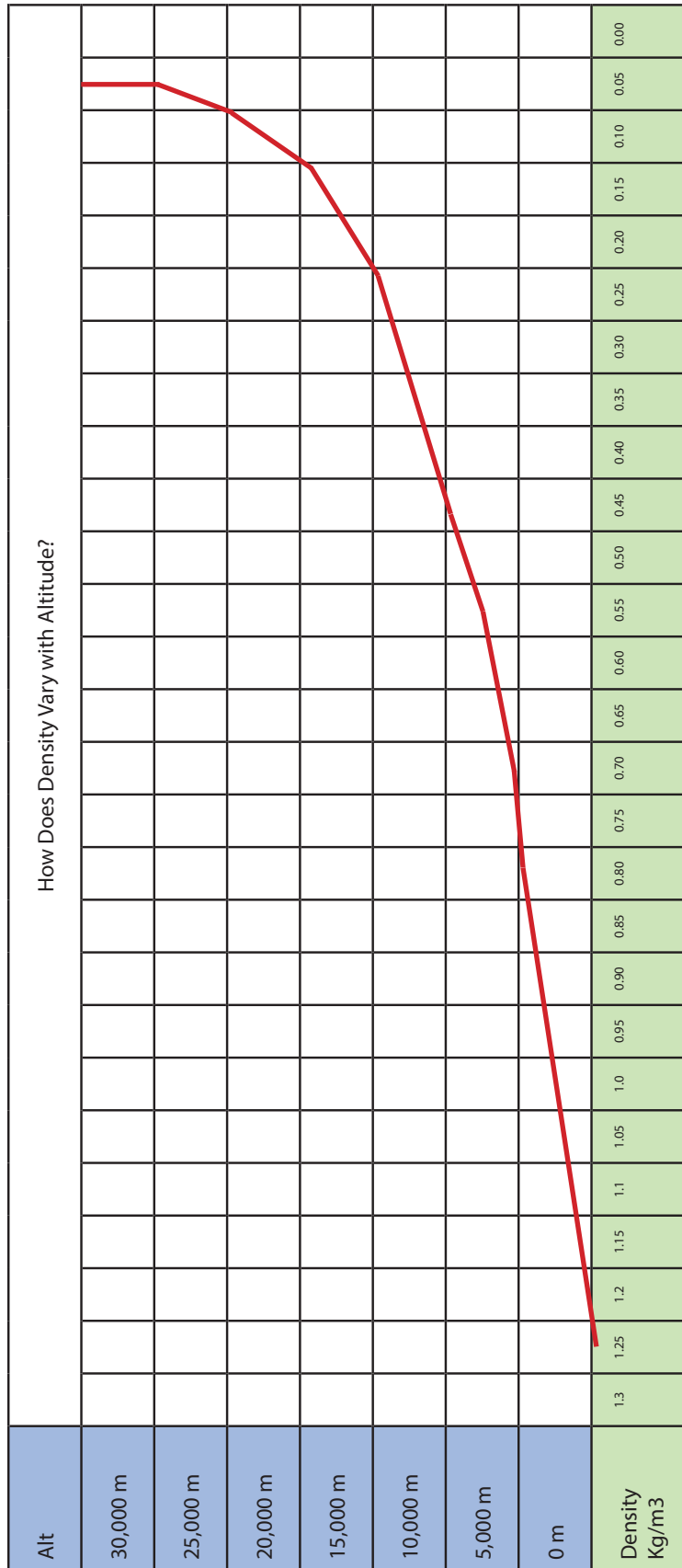
Design a Wing	
<u>Variable</u>	<u>Actual Value</u>
Airspeed:	250 km
Altitude:	7000 m
Angle:	
Chord:	
Span	
Camber %chord	0
Area:	
Lift:	25,000 N
Lift/Drag ratio	

How Does Temperature, Density, and Pressure Vary with Altitude?					
Altitude	Temperature C°	Density Kg/m ³	Pressure KPa	Speed of Sound km/h	Speed of Sound mph
0 - Sea Level	15	1.224	101.324	1225	340.3
5,000 meters	-17	0.736	54.085	1154	320.6
10,000 meters	-49	0.413	26.51	1078	299.4
15,000 meters	-56	0.193	12.012	1062	295
20,000 meters	-56	0.08774	5.461	1062	295
25,000 meters	-56	0.03989	2.483	1062	295
30,000 meters	-41	0.01775	1.179	1098	305

Worksheet 1

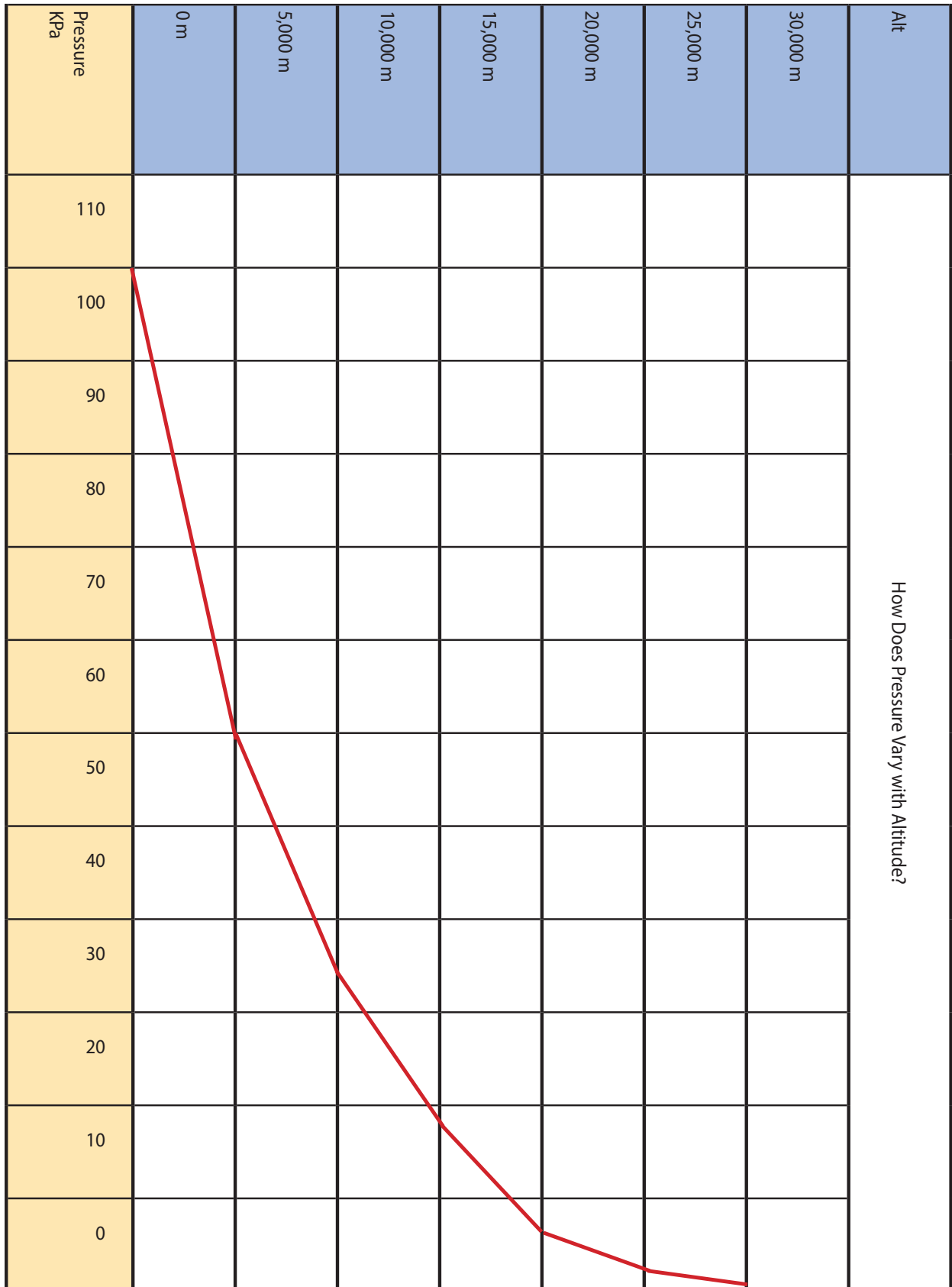
How Does Altitude Relate to Temperature, Density, and Pressure (Teacher Version)

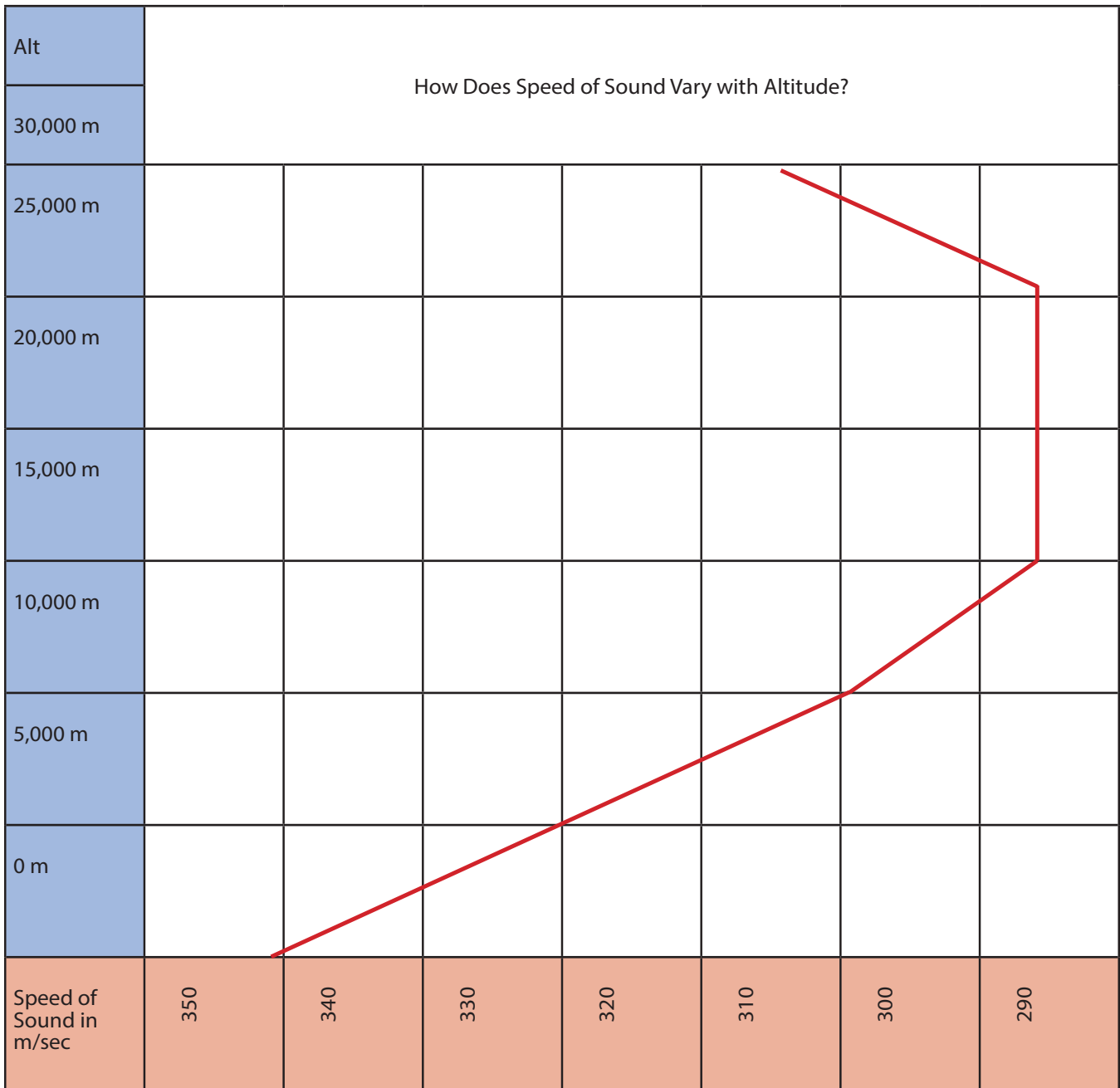




Worksheet 1

How Does Altitude Relate to Temperature, Density, and Pressure (Teacher Version)





Worksheet 1 How Does Altitude Relate to Temperature, Density, and Pressure (Teacher Version)

Dynamic Pressure

The formula for the dynamic pressure on the aircraft =

$$\text{Dynamic Pressure (q)} = \frac{\text{Density (velocity)}^2}{2}$$

Density of the atmosphere at 8,000 meters is .552 kg/cubic m

The aircraft is traveling at 1,500 km/hr

1. Convert km/hr to m/s
 - a. Multiply km/hr x 1000 m/km (1,500,000 m/hr)
2. Convert m/hr to m/sec
 - a. Divide m/hr by 3,600 sec/hr $\frac{(1,500,000 \text{ m/hr})}{3,600 \text{ sec/hr}} = 416 \text{ m/sec}$
3. Now solve for Dynamic Pressure

$$\text{Dynamic Pressure (q)} = \frac{.552 \text{ kg/cubic meter } (416 \text{ m/sec})^2}{2}$$

$$\text{Dynamic Pressure (q)} = \frac{95526.9}{2}$$

$$\text{Dynamic Pressure (q)} = 47,763.5 \text{ Pascals}$$

To convert to Kilo Pascals divide the number of Pascals found for the Dynamic Pressure by 1000 Pascal/kilo Pascal

Answer is 47.7 Pascals is the Dynamic Pressure

Mach Number

From the graph the students drew for the Speed of Sound they are to estimate the speed of sound at 8,000 meters. From the graph it appears that the speed of sound is approximately 305 m/sec at 8,000 meters. In this problem the aircraft has a velocity of 416 m/sec. Students are to use this speed in solving for the Mach number.

$$\text{Mach number} = \frac{\text{Speed of Aircraft}}{\text{Speed of Sound}}$$

$$\text{Mach Number} = \frac{416 \text{ m/sec}}{305 \text{ m/sec}}$$

$$\text{Mach Number} = 1.36$$

Solving for Temperature

For an altitude <11,000 meters (troposphere) atmospheric temperature in Celsius can be estimated using the formula:

$$T = 15.04 - .00649h \text{ (altitude in meters)}$$

$$\text{For an altitude of 8,000 m } T = 15.04 - .00649^\circ/\text{m} (9,000 \text{ m}) = 15.04 - 51.92$$

$$\text{Answer: } -36.88^\circ = -37^\circ$$

Solving for Pressure

To determine pressure in the troposphere use the formula:

-273.16° is the temperature of absolute zero

The pressure will be in kilo Pascals (KPa)

$$P = 101.29 \times \left[\frac{T + 273.1^\circ}{288.08} \right]^{5.256}$$

$$P = 101.29 \times \left[\frac{-37 + 273.1^\circ}{288.08} \right]^{5.256}$$

$$P = 101.29 \times [273]^{5.256}$$

$$P = 101.29 \times [.8196]^{5.256}$$

$$P = 101.29 \times .3514$$

$$P = 35.6 \text{ KPa}$$

Worksheet 2

Relationship of Lift and Drag in Flight (Teacher Version)

1. Open FoilSim III Student Version 1.4d
2. Familiarize yourself with the FoilSim III interactive.
3. Select metric units
4. Enter the following data for Flight, Size, and Shape

A. Data for FoilSim III to Determine Lift, Drag, C_L , C_D and L/D ratio	
Flight	
Speed - km/h	300 km/h
Altitude - m	2000m
Size	
Chord - m	3 m
Span - m	10 m
Area - sq m	30 sq m
Shape	
Angle - deg	To be entered for each attack angle
Camber - %c	0.0
Thick - %crd	12.5

5. Once the inputs have been completed, reopen the Size Tab. Now enter, one at a time, the angle of attack for each of the angles in the left column of the Form. For each angle record the data in the proper column on the Form. As an example, the data for an angle of attack -3° is listed.

A. Effect of Angle of Attack on Lift and Drag Recording Form					
Angle of Attack	Lift	Drag	C_L	C_D	L/D ratio
-3°	-37340 N	2750 N	-0.354	0.026	-13.577
-2°	-25184 N	2029 N	-0.239	0.019	-12.41
-1°	-12739 N	1629 N	-0.121	0.015	-7.817
0	0.0 N	1557 N	0.0	0.014	0.0
1°	12739 N	1817 N	0.121	0.017	7.008
2°	25184 N	2388 N	0.239	0.022	10.542
3°	37340 N	3248 N	0.354	0.03	11.493
4°	49214 N	4383 N	0.467	0.041	11.228
5°	60811 N	5784 N	0.578	0.054	10.513
6°	72139 N	7450 N	0.685	0.07	9.682
7°	83202 N	9387 N	0.79	0.089	8.879
8°	94007 N	94007 N	0.893	0.11	8.102
9°	104559 N	14108 N	0.993	0.134	7.411
10°	114865 N	16915 N	1.091	0.16	6.79
11°	124374 N	19886 N	1.182	0.189	6.254
12°	132385 N	22794 N	1.258	0.216	5.807
13°	138674 N	25510 N	1.318	0.242	5.435
14°	143021 N	27898 N	1.359	0.265	5.126
15°	145196 N	29822 N	1.373	0.283	4.868
16°	144949 N	31146 N	1.377	0.296	4.653
17°	141998 N	31736 N	1.349	0.301	4.474
18°	136017 N	31474 N	1.292	0.299	4.321
19°	126611 N	30262 N	1.203	0.287	4.183

6. Using the same procedure as above collect the required data for the parameters given in B. Entry Data for FoilSim III to Determine Lift, Drag, C_L , C_D , and L/D ratio.

B. Entry Data for FoilSim III to Determine Lift, Drag, C_L , C_D and L/D ratio	
Flight	
Speed - km/h	300 km/h
Altitude - m	2000m
Size	
Chord - m	4.106
Span - m	13.21 m
Area - sq m	54.2 m
Shape	
Angle - deg	To be entered for each attack angle
Camber - %c	0.0
Thick - %crd	12.5

Worksheet 2

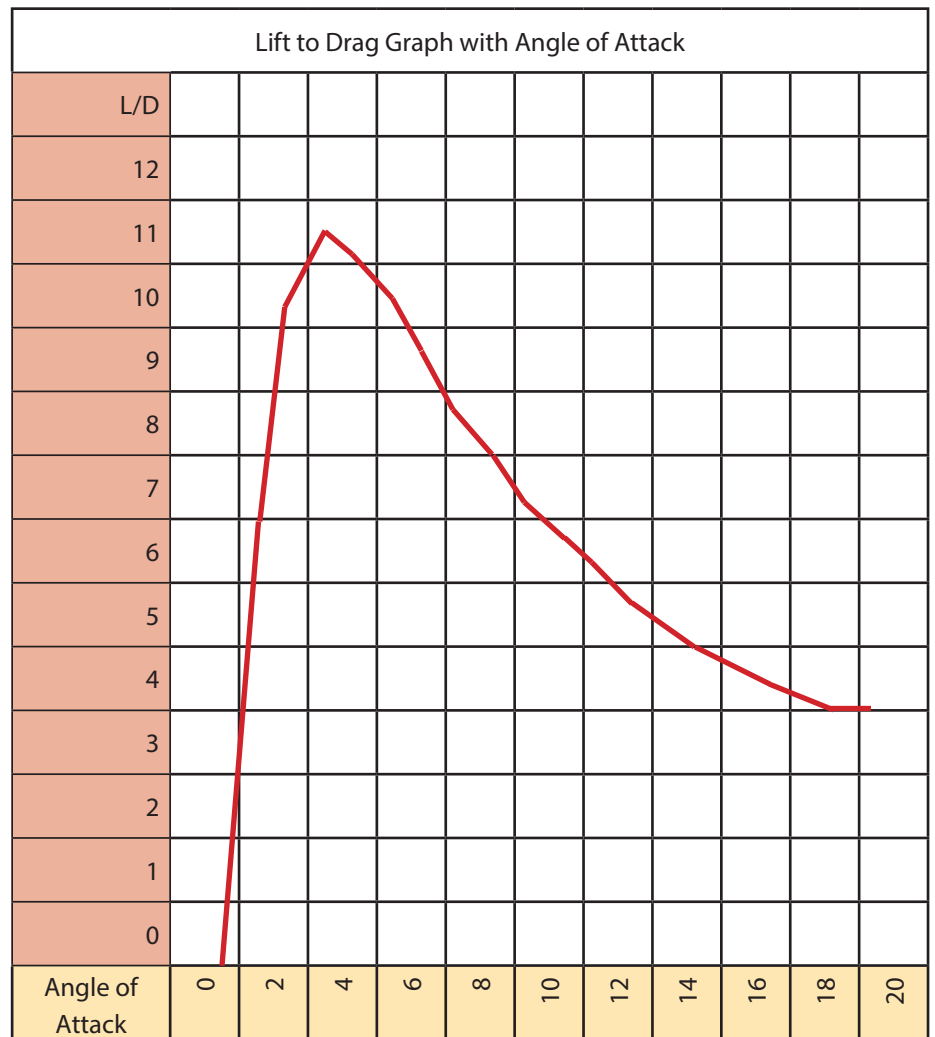
Relationship of Lift and Drag in Flight (Teacher Version)

B. Effect of Angle of Attack on Lift and Drag Recording Form					
Angle of Attack	Lift	Drag	C_L	C_D	L/D Ratio
2°	45333 N	4239 N	0.239	0.239	10.692
5°	109341 N	10525 N	0.576	0.055	10.387
10°	206182 N	30988 N	1.087	0.163	6.653
15°	260380 N	54301 N	1.373	0.286	4.795
19°	227184 N	54531 N	1.198	0.287	4.166

During the activity you had to change the area on the wing leaving all of the other data the same? Were the coefficient of lift and drag the same in both flights?

Answer: yes

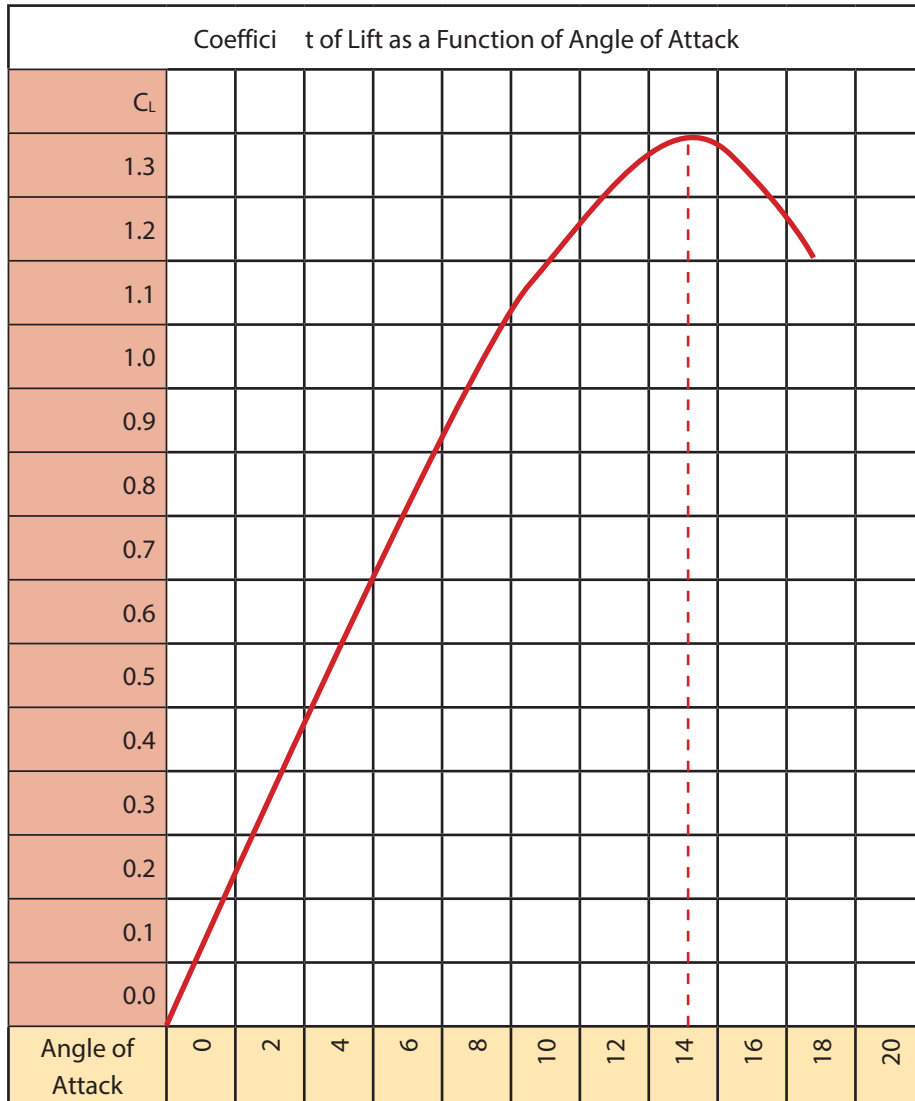
7. Use the data that you recorded in the A. Effect of Angle of Attack on Lift and Drag Recording Form to produce a line graph for the Lift to Drag Graph with Angle of Attack. The Y axis is L/D and the X axis the angle of attack.



From the graph between what angles do you get the maximum lift to drag?

Answer: 2°-6°

8. Use the data that you recorded in the A. Effect of Angle of Attack on Lift and Drag Recording Form to produce a line graph on the Coefficient of Lift as a Function of Angle of Attack Graph. The Y axis is the C_L and the X axis the angle of attack.



Look at the graph and decide what is the stall angle? Answer: 15°

Worksheet 2

Relationship of Lift and Drag in Flight (Teacher Version)

Lift to Drag Problem

Assume the aircraft in this problem is the one that data has been gathered as part of Activity 2. This aircraft has a weight of 25184 Newtons. The aircraft's velocity is 300 km/hr and the angle of attack is 2°. From the data the Coefficient of Lift (C_L) for a 2° angle of attack is approximately 0.239. For this problem Lift can be equal to the weight of the aircraft in Newtons otherwise the aircraft would not fly.

A simple formula for solving lift: **Lift = K * velocity squared * C_L**

First solve for K (K is a constant value made up of the air density and the wing area).

Can assume the lift is equal to the weight in Newtons (25184 Newtons) since the lift must equal the weight in order for the aircraft to fly, so it must be 25184 Newtons.

$$\text{Lift} = K \times V^2 \times C_L$$

$$25184 \text{ Newtons} = K \times (300 \text{ km/hr})^2 \times .239$$

$$25284 \text{ Newtons} = 21510K$$

$$K = 1.175$$

L/D CURVE The ratio of Lift to Drag is a very important parameter for any airplane. Determine the speed to fly this aircraft at the most favorable lift for the amount of drag being created for this aircraft with a 6° angle of attack. The resultant speed is the most favorable lift for the amount of drag being created. This would be the speed to fly the aircraft for the maximum distance either gliding or under power.

$$\text{Lift} = K \times (v)^2 \times C_L$$

Given:

$$K = 1.17$$

Now solve for the speed that will give the maximum distance with the least amount of fuel when flying with a 6° angle of attack.

$$\text{Lift} = 25,184 \text{ Newtons}$$

$$C_L \text{ for } 6^\circ \text{ angle of attack from data} = .0685$$

Solve for speed (velocity)

$$(v^2) = \frac{L}{C_L \times K} = (v^2) = \frac{25,184 \text{ Newtons}}{.080145} = (v^2) = 314,230 \frac{\text{km}}{\text{hr}} = 560.5 \text{ km/hr}$$

Answer: 560.5 km/hr

Explain your answer:

Flying the aircraft with a 6° angle of attack with a speed of 560.5 km/hr will produce the same lift as flying the aircraft at 300 km/hr with a 2° angle of attack. From the data flying the aircraft at 560.5 km/hr would provide the maximum distance with the same amount of fuel.

Design a Wing

Given the following constraints, use FoilSim III to design an aircraft wing that generates 25,000 N of lift. Use the table shown below to record your answers.

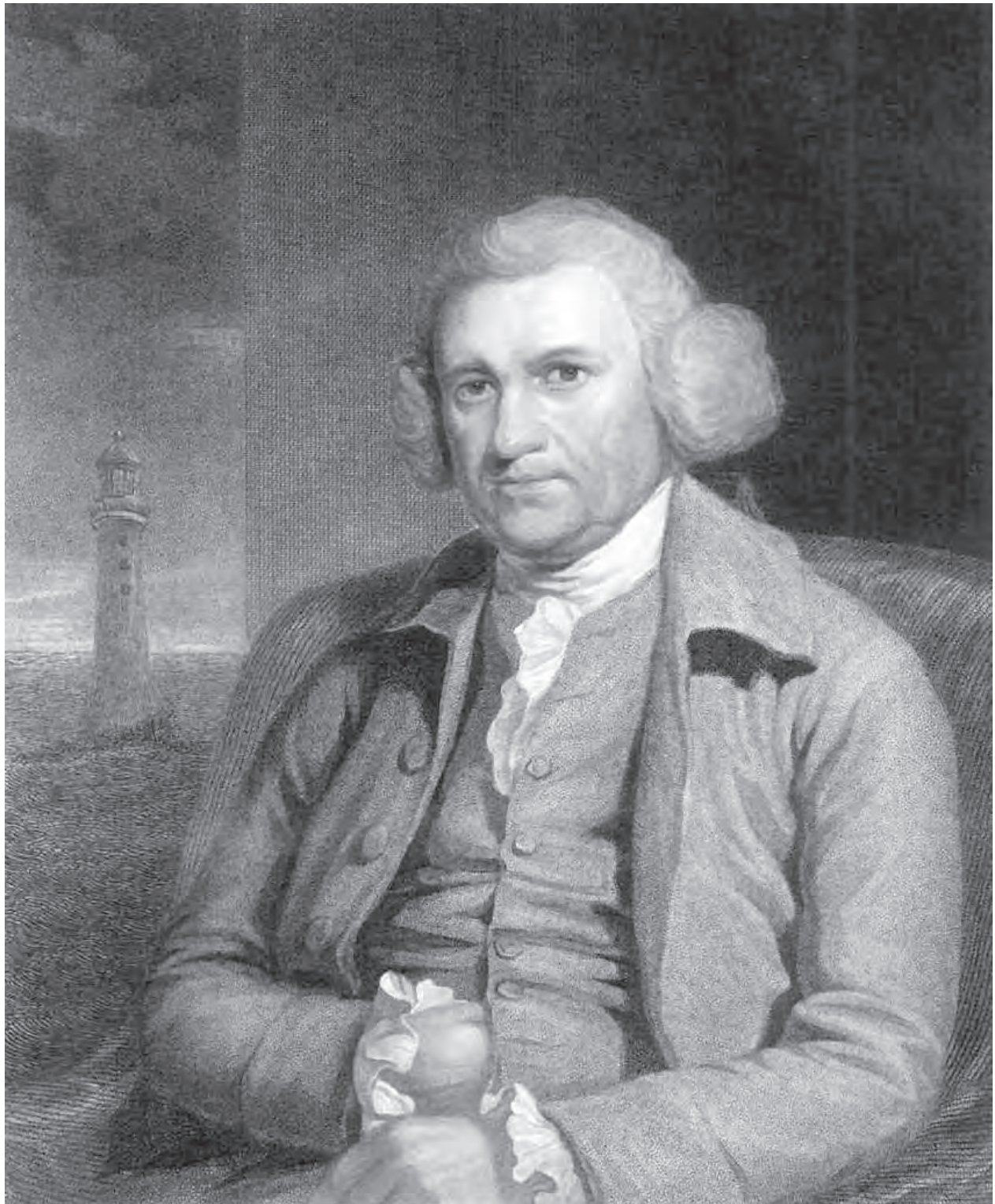
1. The maximum airspeed of the plane is 250 km/hr.
2. The airplane must be able to fly at an altitude of 7000 meters.
3. Lift = 25,000 N
4. Record your values.

Design a Wing	
<u>Variable</u>	<u>Actual Value</u>
Airspeed:	250 km
Altitude:	7000 m
Angle:	4°
Chord:	3.4986625 m
Span	10.77468 m
Camber %chord	0
Area:	37.696968 sq m
Lift:	25,000 N
Lift/Drag ratio	10.512



Images

Img. 1 John Smeaton



(Public Domain)

Img. 2 George Cayley



(Public Domain)

Img. 3 Otto Lilienthal



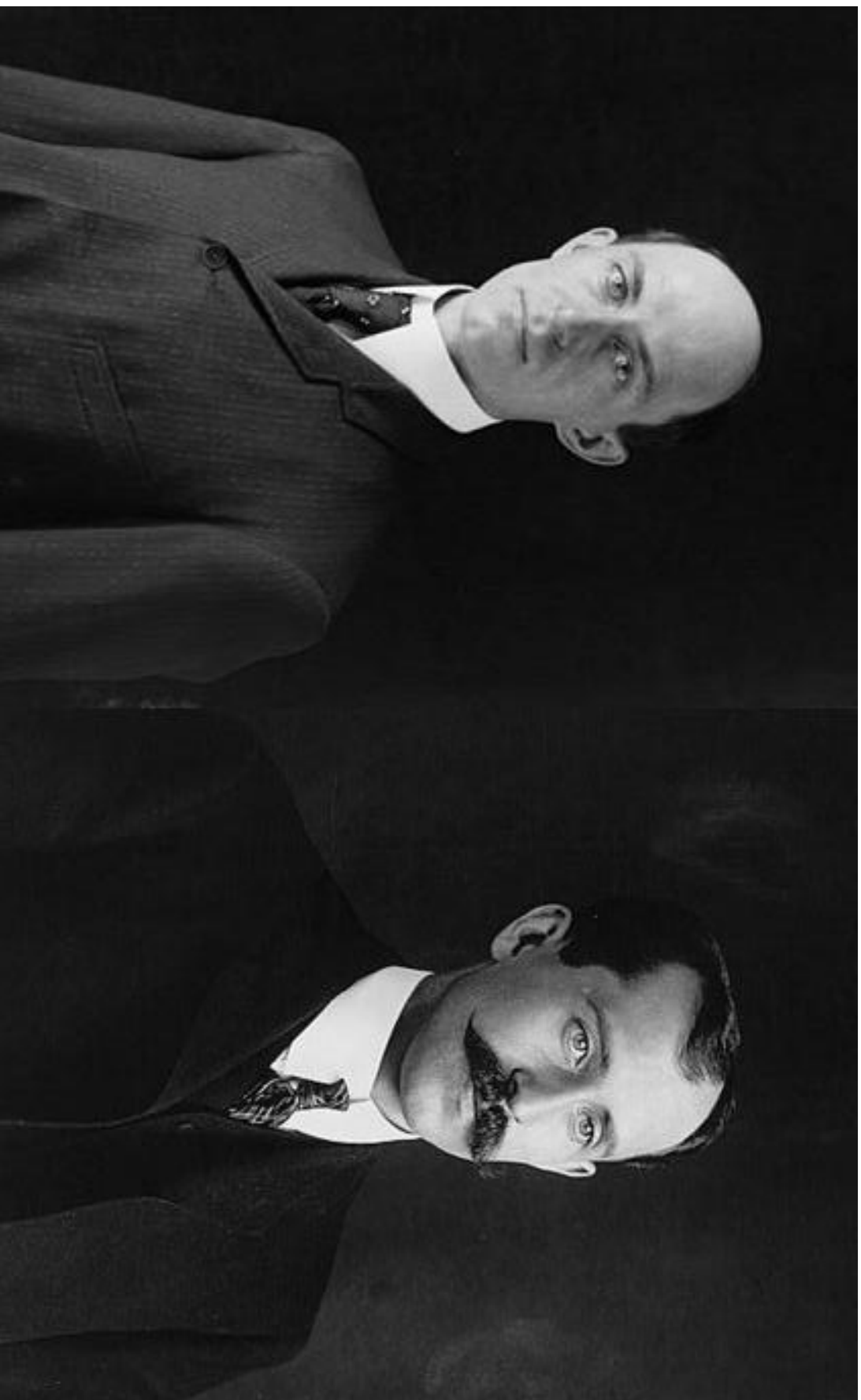
(Public Domain)

Img. 4 Samuel Pierpont Langley



(Public Domain)

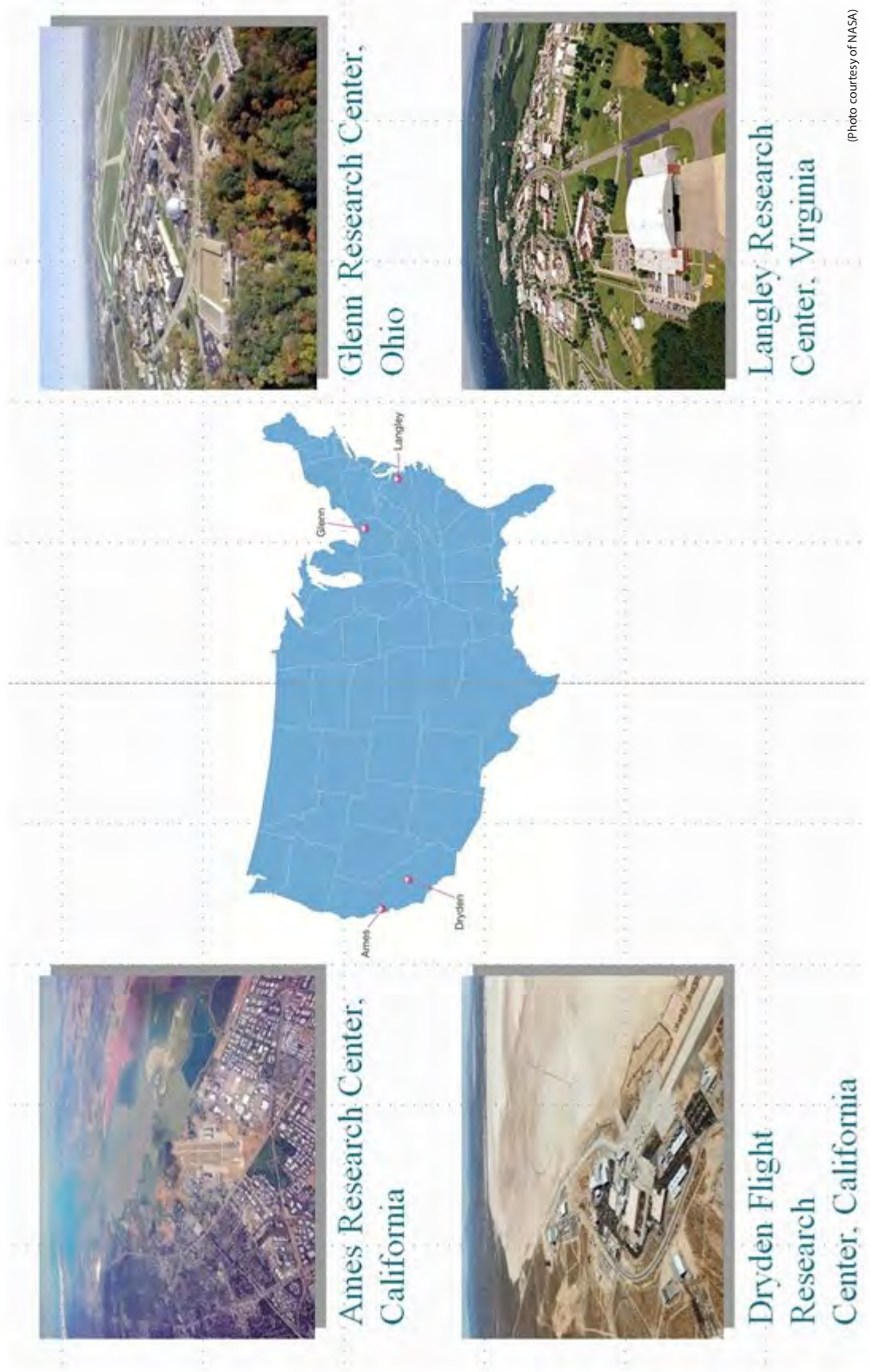
Img. 5 Wright Brothers



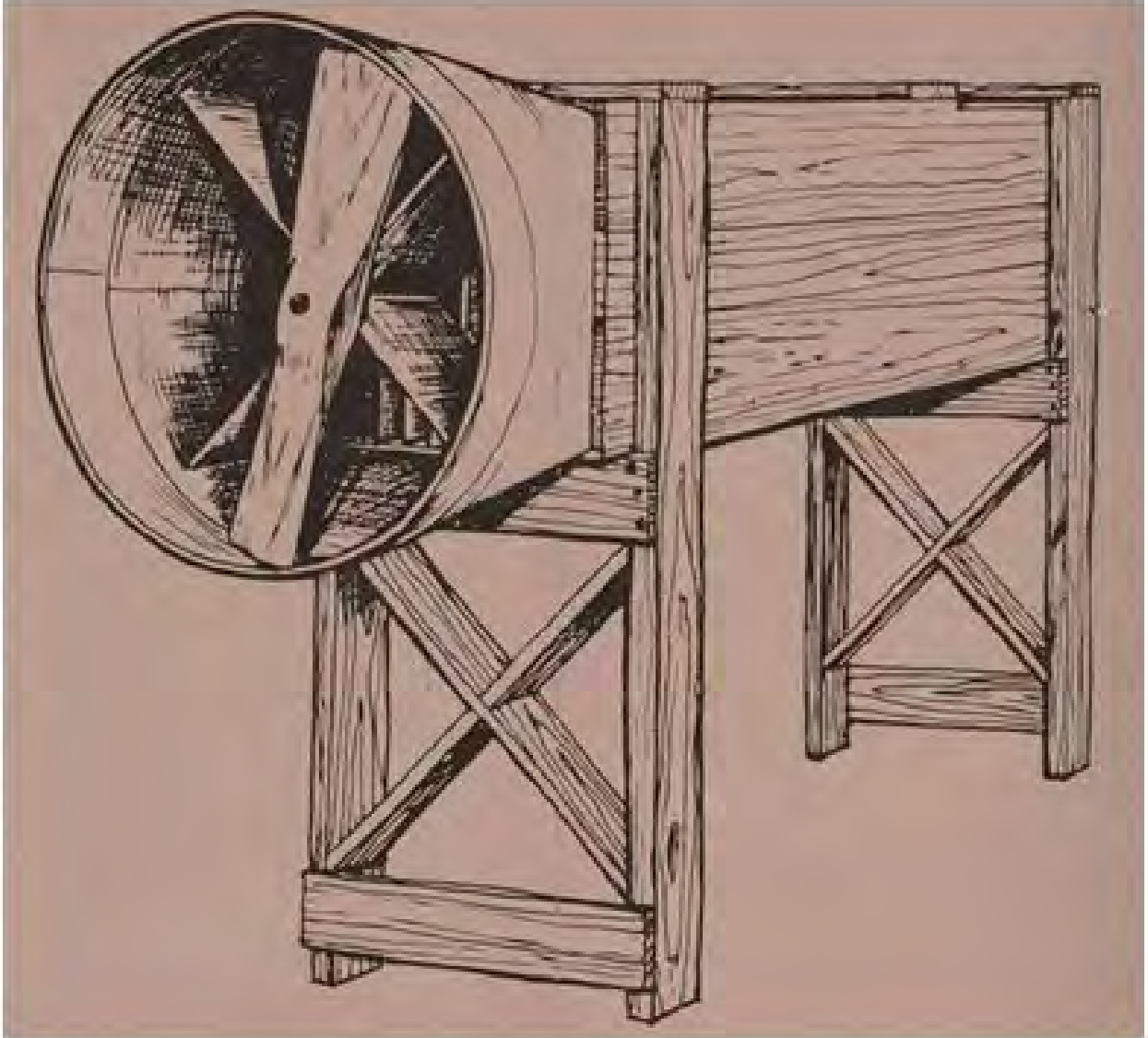
(Public Domain)

Img. 6 NASA's Aeronautical Research Centers

NASA's Aeronautical Research Centers



Img. 7 Wright Brothers Wind Tunnel



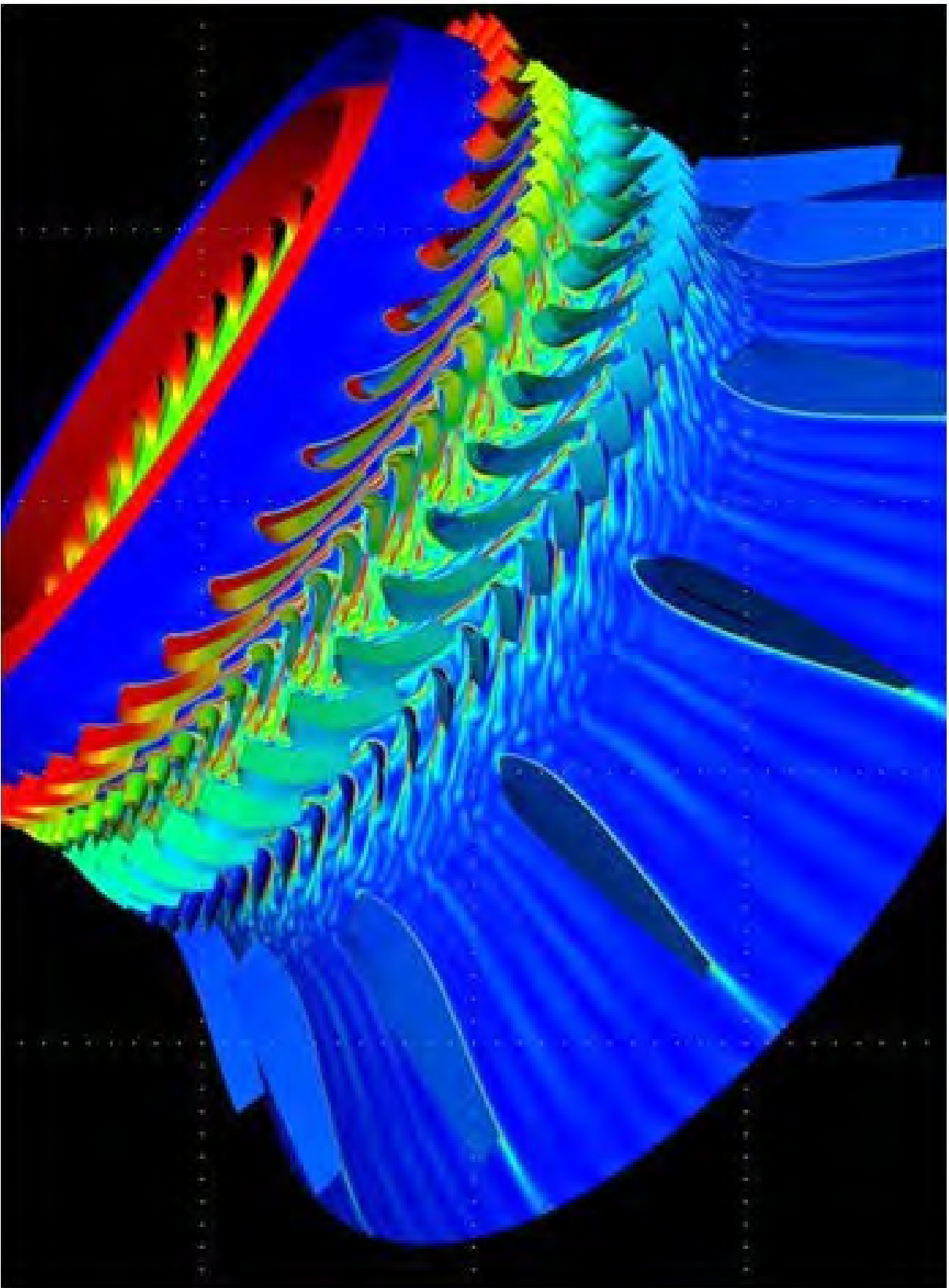
(Image courtesy of NASA)

Img. 8 Big Fan in a Langley Research Center Tunnel



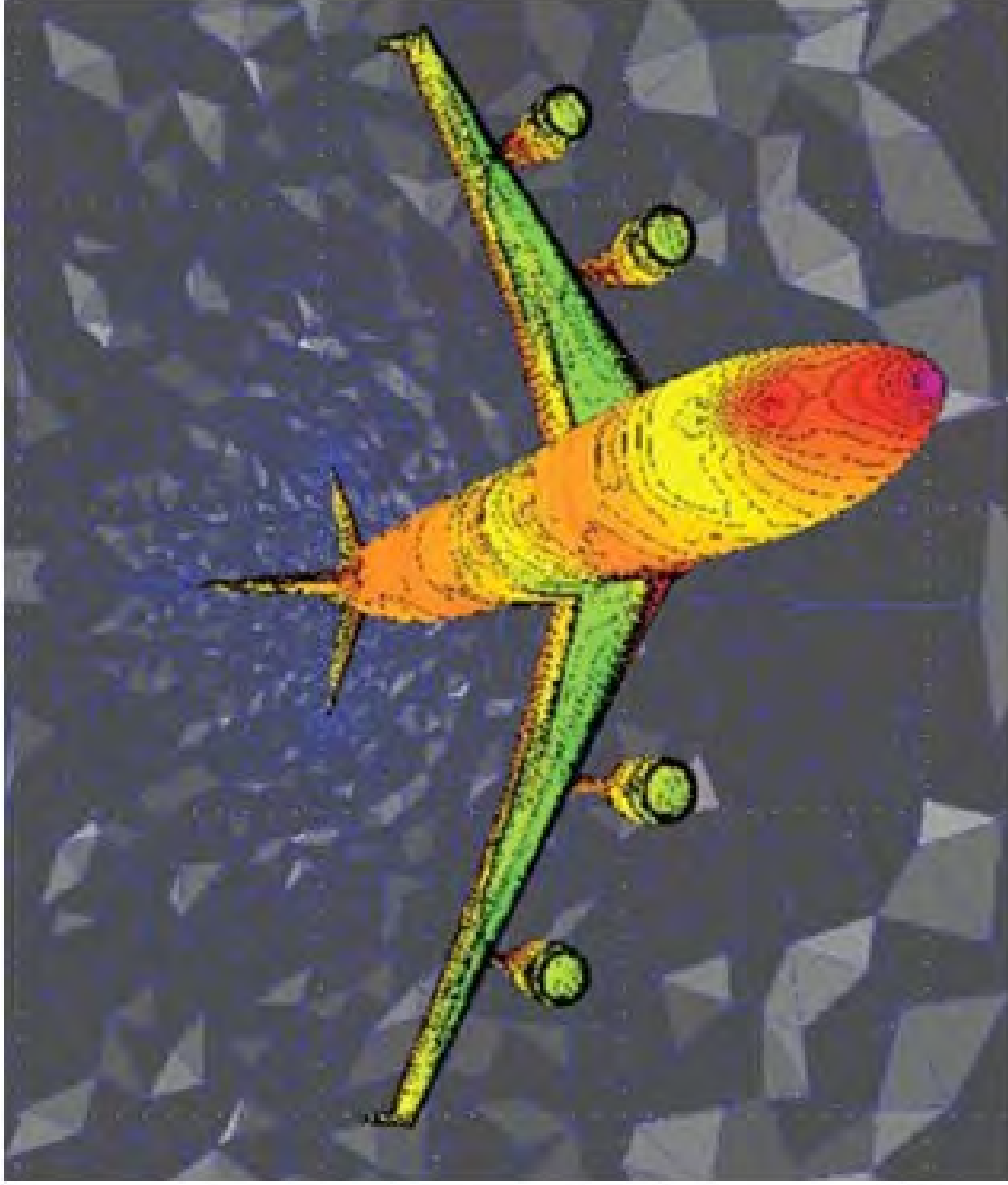
(Image courtesy of NASA)

Img. 9 Super Computer Image of a Fan



(Image courtesy of NASA)

Img. 10 Su



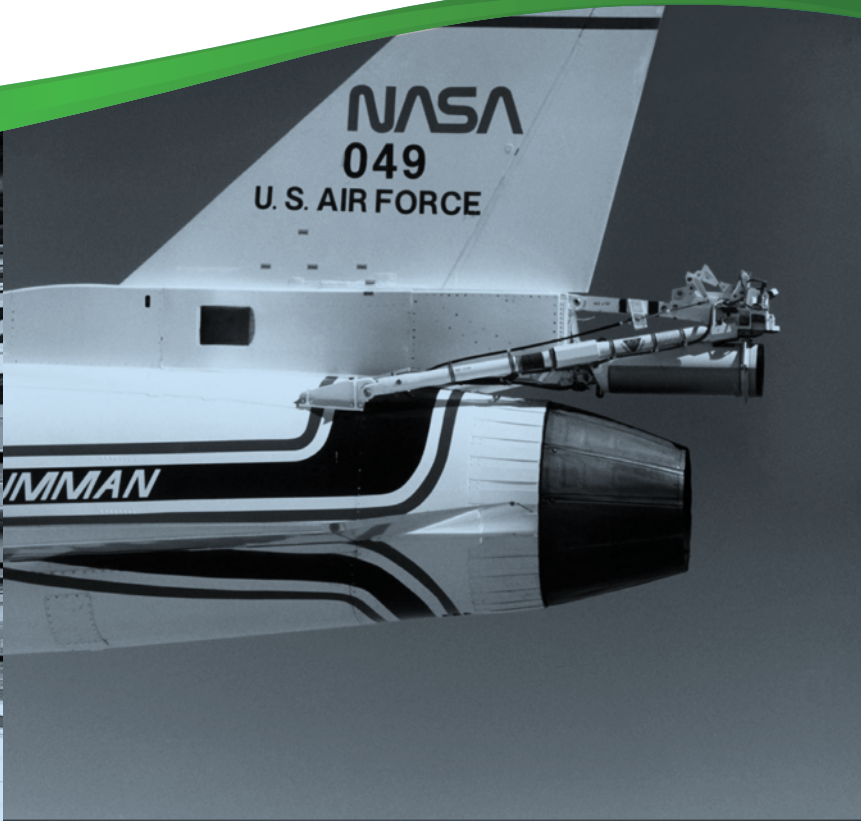
(Image courtesy of NASA)

Img. 1 1 Earth from space showing our thin atmosphere

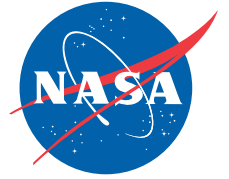


(Image courtesy of NASA)

Aeronautics
Research
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Directorate



principles of flight



GRADES

K-12

Foam Wing



principles of flight

Aeronautics
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Foam Wing

Lesson Overview

Participants in the foam wing activities will learn about motions and forces, and transfer of energy as they explore Bernoulli's Principle. They will also have the opportunity to wear a giant foam wing while standing before a simulated wind tunnel in order to experience the sensation of lift. The instructor will present information about airfoil design, lift, and the Bernoulli Principle for all participants, but those in the 5th – 12th grades may engage in a brief discussion about the Area Rule and the difference between laminar flow airfoils and conventional airfoils.

Objectives

Students will:

1. Identify the general design of an airfoil and relate the design to lift.
2. Explain how the Bernoulli Principle contributes to lift.
3. Explain how greater curvature on the top of an airfoil results in greater lift.
4. Experience the physical sensation of lift and drag during the foam wing simulation.
5. Explore NASA technologies including the Area Rule and fuel-efficient winglets.

Materials:

In the Box

Foam wing
Drinking straws
Fan

Provided by User

Paper
A quarter

GRADES

K-12

Time Requirements: 1 hour 10 minutes

Background

What causes an airplane to have lift? The 18th century Swiss physician and mathematician Daniel Bernoulli discovered that an increase in the speed of a fluid occurs simultaneously with a decrease in pressure.

An airplane's wing has a special shape called an airfoil. The airfoil is shaped so that the air traveling over the top of the wing travels farther and faster than the air traveling below the wing. Thus, the faster moving air above the wing exerts less pressure than the slower moving air below the wing. According to the Bernoulli Principle, this pressure differential pushes the airplane upward, giving it lift.

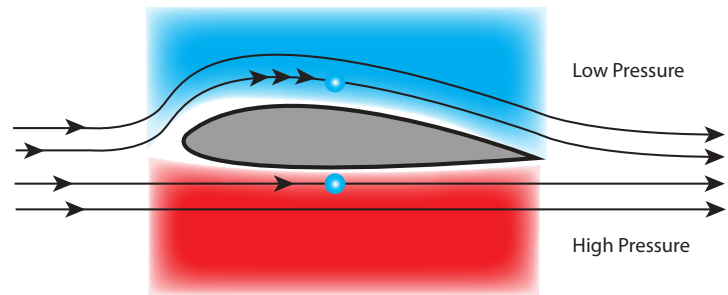


Fig. 1 Wing pressure areas

The Coanda Effect provides another important explanation for lift. While the shape of a wing (airfoil) is designed to create differences in air pressure, the Coanda Effect explains that a wing's trailing edge must be sharp, and it must be aimed diagonally downward if it is to create lift. Both the upper and lower surfaces of the wing act to deflect the air. The upper surface deflects air downwards because the airflow "sticks" to the wing surface and follows the tilted wing down. This phenomena is also called Flow Attachment. After the wing has passed through the air, the air must remain flowing downwards for the lifting force to work. The Coanda effect rarely occurs naturally but it can be produced on the wing of an aircraft to increase lift by a factor of 3. Vertical Takeoff and Landing (VTOL) aircraft as well as the C-17 Globemaster III utilize the Coanda effect. A method to produce the Coanda effect is to deflect a part of the exhaust from an aircraft engine over the wing of an aircraft in flight.

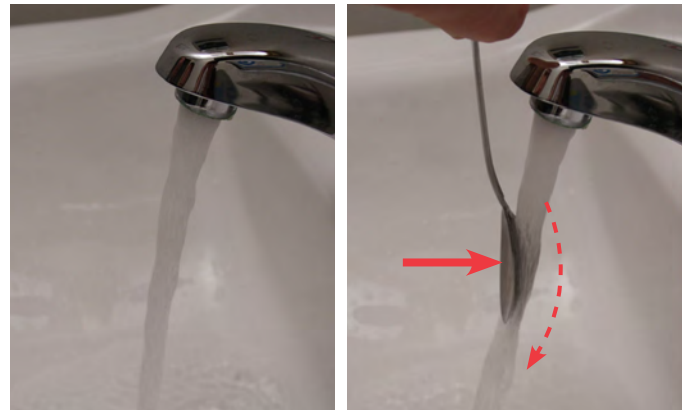


Fig. 2 Coanda effect

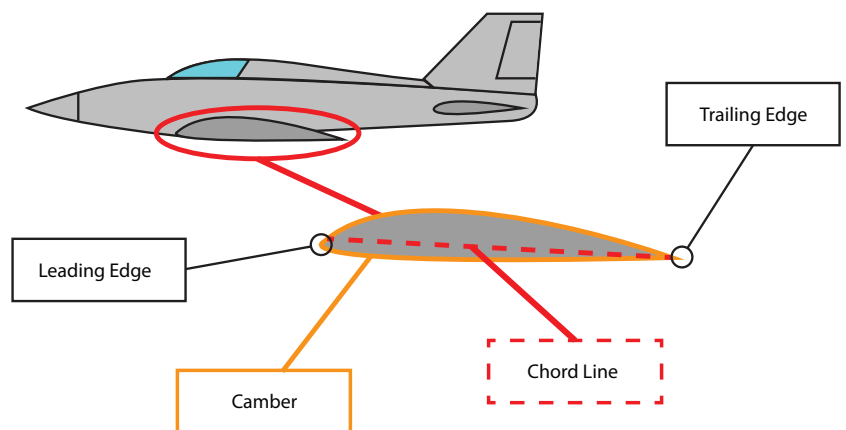


Fig. 3 Airfoil diagram

In general, the operation for which an airplane is designed determines the shape and design of its wings. If the airplane is designed for low-speed flight, a thick airfoil is most efficient, whereas a thin airfoil is more efficient for high-speed flight. There are generally two kinds of airfoils: laminar flow and conventional. Laminar flow airfoils were originally developed to make an airplane fly faster. The laminar flow wing is usually thinner than the conventional airfoil, the leading edge is also more pointed, and its upper and lower surfaces are nearly symmetrical. However, the most important difference between the airfoils is that the thickest part of a laminar flow wing occurs at 50% chord, while in the conventional design, the thickest part is at 25% chord (the distance from the leading to the trailing edges of a wing).

The laminar flow airfoil greatly reduces drag since it requires less energy to slice through the air. The pressure distribution on the laminar flow wing is more uniform since the camber of the wing from the leading edge to the point of maximum thickness is more gradual. The conventional airfoil is still preferred in commercial aircrafts though, because it is more resistant to stalling.

So what explains lift? Lift is explained in part by the Bernoulli Principle, the Coanda Effect, and Newton's Third Law of Motion.

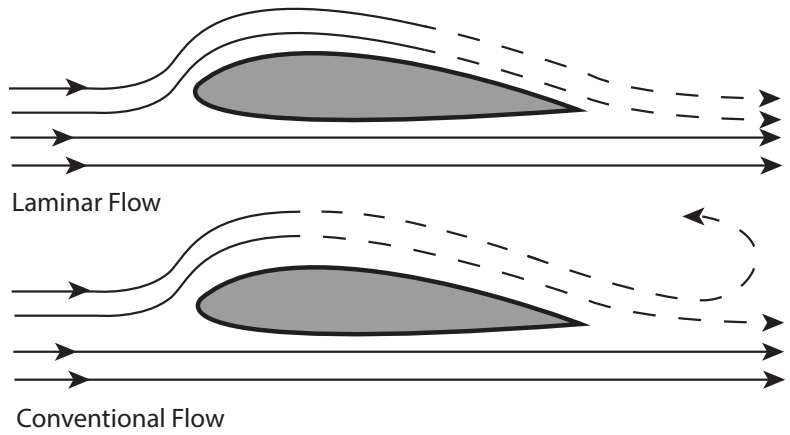






Fig. 4 Laminar vs conventional flow


CONVENTIONAL AIRFOILS


- 

Low camber - low drag - high speed - thin wing section. Suitable for race planes, fighters, interceptors, etc.
- 

Deep camber - high lift - low speed - thick wing section. Suitable for transports, freighters, bombers, etc.
- 

Deep camber - high lift - low speed - thin wing section. Suitable as above
- 

Low lift - high drag - reflex trailing edge wing section
Very little movement of centre of pressure. Good stability
- 

Symmetrical (cambered top and bottom) wing sections. Similar to above
- 

GA(W) -1 airfoil - thicker for better structure and lower weight - camber is maintained farther rear-ward which increases lifting capability over more of the airfoil and decreases drag

Fig. 5 Conventional airfoils

Activity 1

Paper Tent

GRADES**K-12****Time Requirements:** 10 minutes**Materials:**In the Box

A straight drinking straw

Provided by User

Paper

Worksheets

None

Reference Materials

None

Key Terms:

Air pressure
 Bernoulli Principle
 Camber
 Chord
 Lift
 Newton's Third Law

Objective:

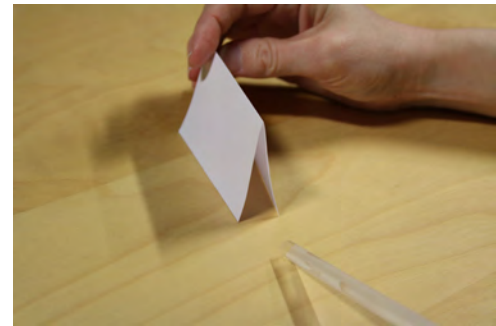
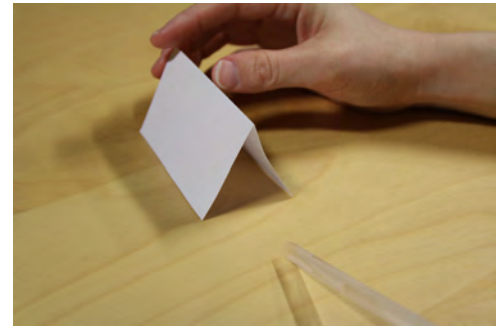
In this lesson .students will learn about motions and forces as they observe the Bernoulli Principle at work.

Activity Overview:

In this lesson students will experiment with the Bernoulli Principle using a straw and piece of paper.

Activity:

1. **Distribute a straw and piece of paper to each participant.**
2. **Participants should fold the paper in half to make a tent.**
3. **Have participants set the paper tent on a table and then predict what will happen if they blow air forcefully through the inside of the tent.**
4. **Once predictions have been made, have participants perform the activity.** Instruct students to blow forcefully but to keep the airfl w steady (making sure not to just make a short, forceful burst). Participants will observe that when air is blown forcefully, but steadily, under the paper tent, the sides of the tent will pull together.
5. **Ask the participants: Why did the tent pull together?**
6. **Explain that the Bernoulli Principle states that the fast-moving air under the tent creates an area of low pressure in that location, and the resulting higher air pressure on the outside of the tent pushes the tent downward.**



NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Position and motion of objects

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Motions and forces

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Motions and forces
- Interactions of energy and matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

Activity 2

Bernoulli Coin Experiment

GRADES **K-12****Time Requirements:** 15 minutes**Materials:**In the Box

1 straw per student

Provided by UserA Quarter
(one per student)One-inch squares of paper
(one per student)

Paper

Worksheets

None

Reference Materials

None

Key Terms:

Lift

Objective:

In this lesson students will learn about motion and forces as they observe the Bernoulli Principle at work.

Activity Overview:

In this lesson students will experiment with the Bernoulli Principle using a quarter and small piece of paper.

Activity:

1. Have participants place a 1-inch square of paper in the palm of their hands.
2. Instruct participants to hold a quarter, face up between their thumb and forefinger, about an inch above the paper square and ask: *How can you get the paper square to stick to the coin without touching the paper square?*
3. Tell participants to blow a steady stream of air forcefully and directly on the upward facing surface of the coin. This takes a little practice, but the paper square should rise toward the underside of the coin and “stick” there as long as the participants continue to blow. Participants may use a straw to blow on the quarter if desired.
4. **Ask: What caused the paper to lift?** Explain that the faster moving air above the coin creates an area of low pressure, and since the air pressure below the paper is greater, the high pressure pushes the paper square upward and against the coin. The paper appears to stick to the coin.



NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Motions and forces

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Motions and forces

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Motions and forces

Activity 3

Foam Wing

GRADES**K-12****Time Requirements:** 40 minutes**Materials:**In the Box

Foam wing

Provided by User

A quarter

Paper

Worksheets

None

Reference Materials

Airfoil diagram (figure 3)

Conventional airfoils (figure 4)

Winglets (image 2)

Key Terms:

Air foil

Air pressure

Air resistance

Area Rule

Bernoulli Principle

Camber

Chord

Coanda Effect

Drag

Laminar flow

Mach Number

Supersonic

Transonic

Objective:

In this lesson students will learn about motions and forces as they:

1. Examine a giant foam wing and discuss the shape of the wing and airfoil, relating how the wing is shaped to create lift.
2. Experience the potential of lift while wearing a giant foam wing and standing in a stream of air from a fan that is meant to simulate a wind tunnel.

Activity Overview:

In this activity, participants will have the opportunity to wear an arm-sized foam wing and stand in a simulated wind tunnel in order to experience the potential of lift.

Activity:

1. **Show participants the giant foam wing.** Ask them to make a few preliminary observations about the wing.



2. **Direct participants to examine the shape of one of the wing's airfoils, which you will define as the cross-section of the wing.** Ask participants to describe the shape of the airfoil. They will probably recognize that the upper surface of the airfoil is curved while the underside is relatively flat.
3. **Show students the diagram of the airfoil.** Discuss the locations and definitions of camber, chord, leading edge, and trailing edge.
4. **Ask participants to identify the leading edge, trailing edge, camber, and chord of the foam wing.**

5. **Explain how air traveling over the curved upper surface of the wing moves faster than air moving under the wing.** The faster air flows over the top of the wing creates lower pressure than the slower moving air under the wing. Lift is partially achieved because high-pressure air pushes toward low-pressure air, pulling the airplane upward.
6. **Show the participants the diagram of conventional airfoil shapes.** Discuss how the shape of an airfoil will depend on the function of the airplane.
7. **Select a participant to wear the giant foam wing.** Have that participant stand in the simulated wind tunnel (the stream of air coming from the fan) in order to simulate a “lift” experience. Make sure the participant directs the leading edge of the wing into the wind while holding on to the internal handgrips in order to maintain control of the wing’s position.
8. **Ask: *If our wing wearer were to flap the wing, would he/she be able to achieve lift?*** Participants will likely answer that lift would not be possible because the mass of the person wearing the wing is too great compared to the size of the wing. In addition, lift needs thrust (Newton’s third law). Because there is no thrust, it is not possible for a person wearing the wing to fly.”
9. **Ask the wing-wearing participant: “So while you cannot actually fly with the giant foam wing, can you feel the potential of lift?”**
Students should be able to feel the lift potential.
10. **Now have the wing-wearing participant tilt the wing’s leading edge upward.**
11. **Ask: “What do you feel now?”**
Students should be able to feel resistance or drag.
12. **Elaborate on the participant’s response by introducing the terms: drag, air resistance, air pressure, Coanda Effect, the Bernoulli Principle and Newton’s Third Law.** Determine how complex your explanations may need to be based on the ages and experiences of your audience.
13. **Next, have the participant wearing the wings pivot those wings so that the leading edge is angled slightly downward.**
14. **Ask: “What do you feel now?”**
Students should be able to feel more pressure on the top of the wing than they did with the wing tilted in the other direction.
15. **Have the participant compare and describe the feeling of different wing angles.**
16. **Allow other participants to wear the wings.** Have each participant experiment with other movements, such as quickly changing from an upward to a downward tilt and back again. Try flapping or pivoting the wings so the tip of the wing is facing the wind (fan).

17. Ask the participants to verbalize the physical feelings they experience and make connections to what they have learned about drag and lift.
18. After allowing students to experience lift in the simulated wind tunnel, explain that NASA engineers and scientists continue to test different airplane models in wind tunnels and simulate flight on computers in order to advance their understanding of flight. Through their research, NASA researchers and engineers are able to design and build safer, quieter, and more fuel-efficient airplanes.
19. At this point older participants may be introduced to the Area Rule, a theory introduced in the 1950s by NASA scientist Richard Whitcomb. In 1952, Richard

Whitcomb discovered an important aeronautical design process while working at the NASA Langley Research Center in Langley, Virginia. His design process is most often referred to as the Area Rule (Fig 6.). What Whitcomb discovered was that by narrowing the fuselage of an airplane, the drag of an aircraft could be reduced while at the same time provide an increase of aircraft speed without the addition of power. The fuselage is the body of the airplane that holds together all parts of an aircraft. Airplanes that employ the Area Rule have a fuselage resembling an old fashion "Coke bottle."



Img. 1 Richard Whitcomb

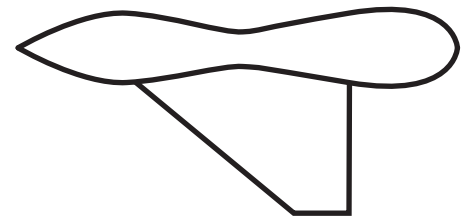


Fig. 6 Area rule

Since 1952, aircraft designers have been utilizing Whitcomb's Area Rule to design aircraft that fly higher, faster, and farther (Fig. 7).

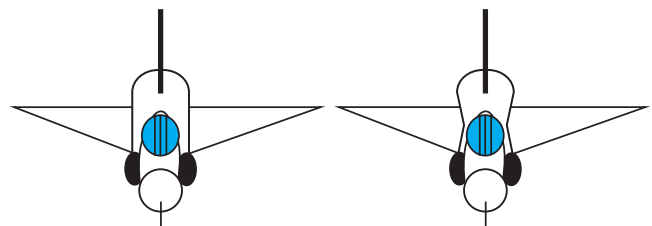


Fig. 7 Before and after area ruling

20. Explain that in addition to Whitcomb's Area Rule, winglets are one of the most successful examples of a NASA aeronautical innovation that is presently being utilized all around the world on all types of aircraft.



Img. 2 Winglets

When the price of aircraft fuel was increasing in the 1970s, aircraft designers began to look for additional ways to improve fuel efficiency. During that time, Richard Whitcomb advanced the concept for winglets through wind tunnel tests and computer studies at the NASA Langley Research Center.

Winglets (Img. 2) are vertical extensions on wingtips that improve an aircraft's fuel efficiency and cruising range. Designed as small airfoils, winglets



Img. 3 A Boeing B-1B Lancer over the Pacific Ocean

reduce the aerodynamic drag associated with vortices that develop at the wingtips as the airplane moves through the air. Vortices are tubes of rotating air that are left behind a wing as it produces lift.

Through his research, Whitcomb concluded that winglets produced twice the benefit of a wingtip extension with the equivalent area. As a result, winglets imposed much less weight and drag penalty than increased wingspan. By reducing wingtip drag, fuel consumption goes down and range is extended.

Aircraft of various types and sizes can have winglets, from single-seat hang gliders and ultra-lights all the way up to jumbo jets.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Motions and forces

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Motions and forces
- Interactions of energy and matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology



Reference Materials

Glossary

Airfoil:

The cross-section of an airplane wing

Air pressure:

The force exerted on objects by the weight of tiny particles of air (air molecules)

Air resistance:

Also known as drag

Area Rule:

Developed by Richard Whitcomb, the Whitcomb Area Rule is also known as the Transonic Area Rule; the Area Rule is used in the design of an aircraft to reduce its drag at transonic and supersonic speeds, particularly between Mach 0.75 and 1.2

Bernoulli Principle:

A physical phenomenon named after the Swiss scientist Daniel Bernoulli who lived during the eighteenth century; the principle states that "the pressure of a fluid [liquid or gas] decreases as the speed of the fluid increase

Camber:

The asymmetry between the top and the bottom surfaces of an airfoil; an airfoil that is not cambered is called a symmetric airfoil

Chord / Chord Line:

The distance from the leading to the trailing edges of a wing

Coanda Effect:

A phenomenon in which a stream of air or liquid attaches itself to a nearby surface

Drag:

The aerodynamic force that opposes an aircraft's motion through the air; drag is a mechanical force generated by the contact of a solid body with a fluid (liquid or gas)

Laminar Flow:

A non-turbulent flow that occurs when a fluid flows in parallel layers with no disruption between the lay

Leading Edge:

The part of the wing that first contacts the air; alternatively it is the front edge of a wing

Lift:

The force that directly opposes the weight of an airplane and helps keep the airplane in the air

Mach number:

The Mach number is given as a ratio to the speed of sound; for example an aircraft flying at 1.5 times the speed of sound is traveling at Mach 1.5

Newton's Third Law:

A physical law that states that for every action of motion there is an equal and opposite reaction

Supersonic:

A speed greater than the speed of sound in a given medium, especially air; M (Mach) = 1.2 to 5.0 supersonic

Trailing edge

The rear edge of the wing; where the airflow separated by the leading edge rejoins

Transonic:

Speeds close to the speed of sound; M (Mach) = 0.8 to 1.2

Fig. 1 Wing pressure areas

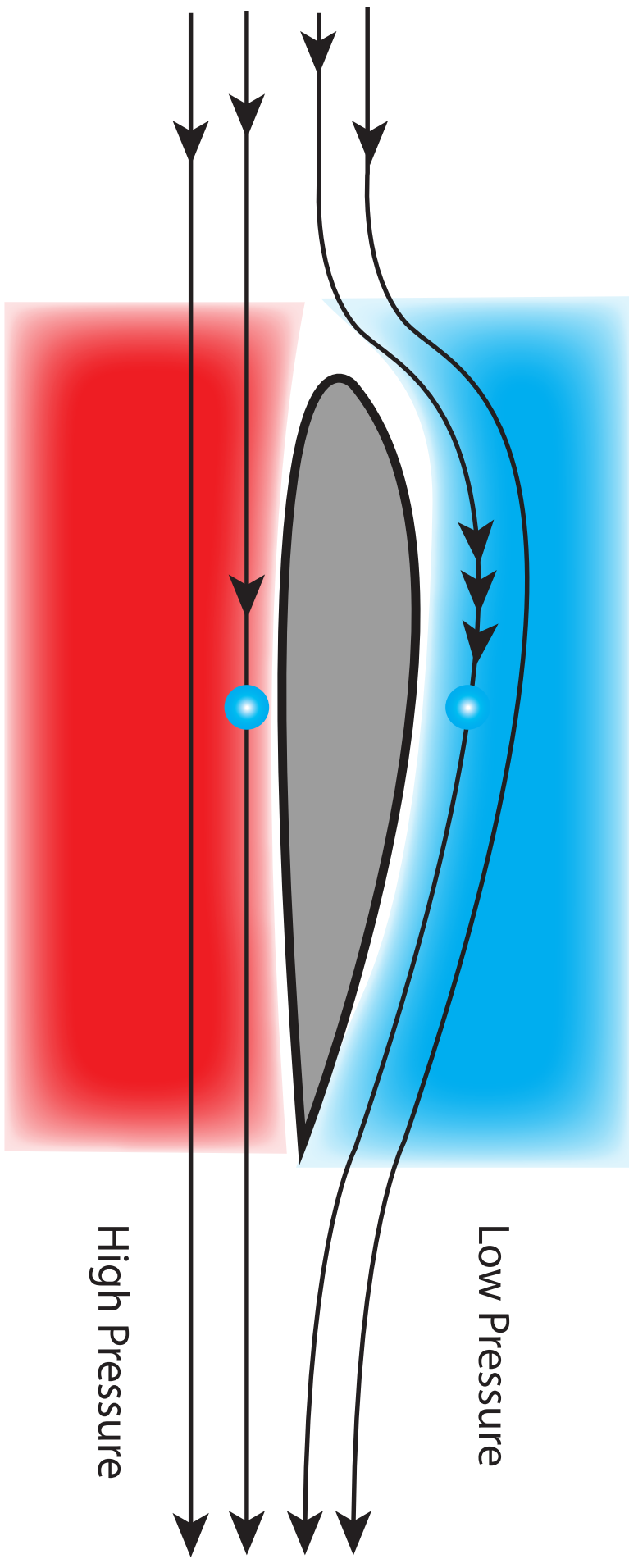


Fig. 2 Coanda effect

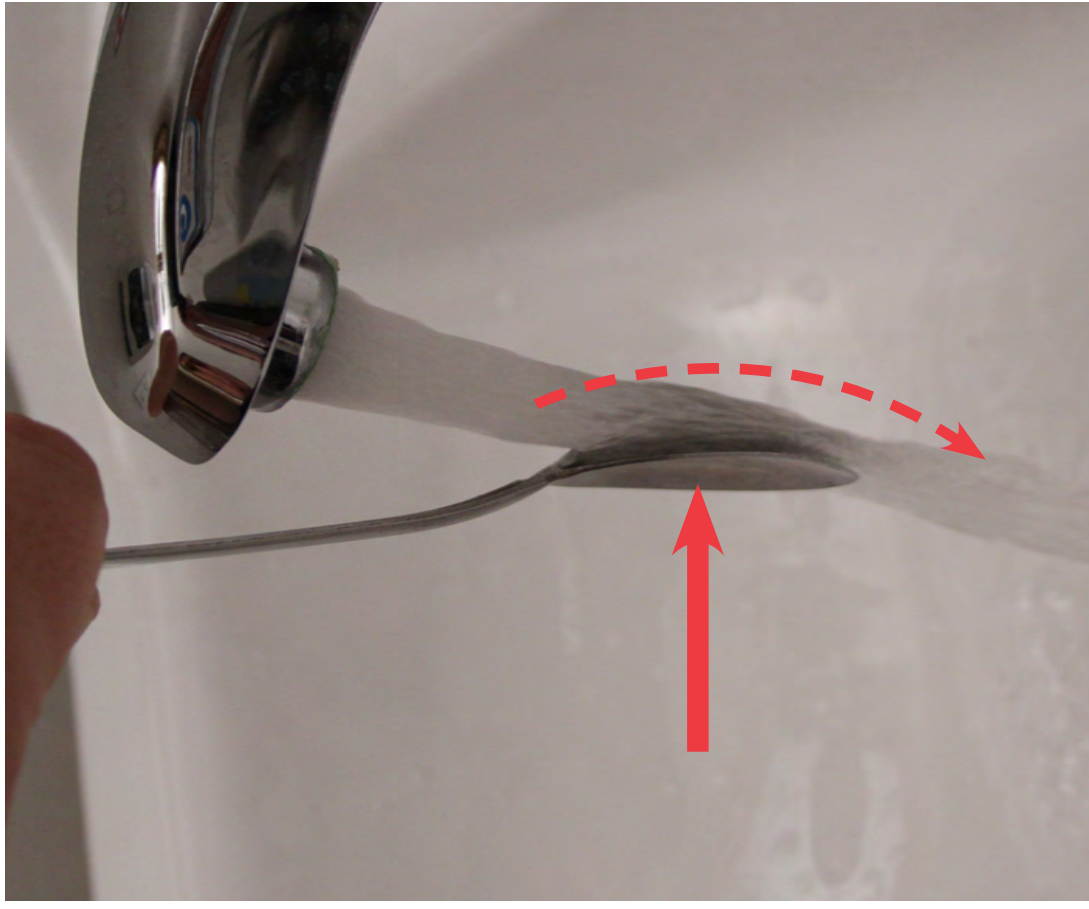


Fig. 3 Airfoil diagram

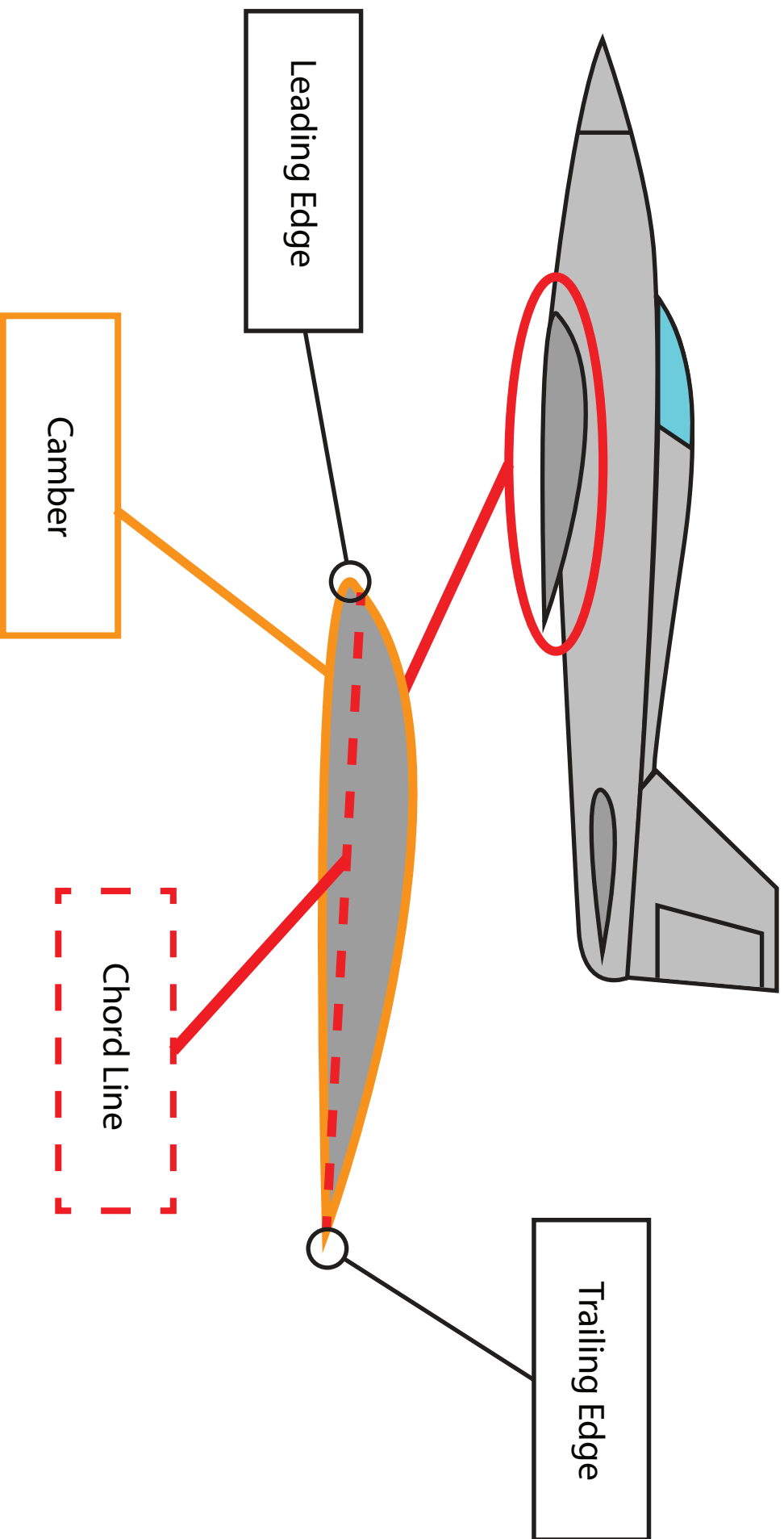


Fig. 4 Laminar vs conventional fl ws

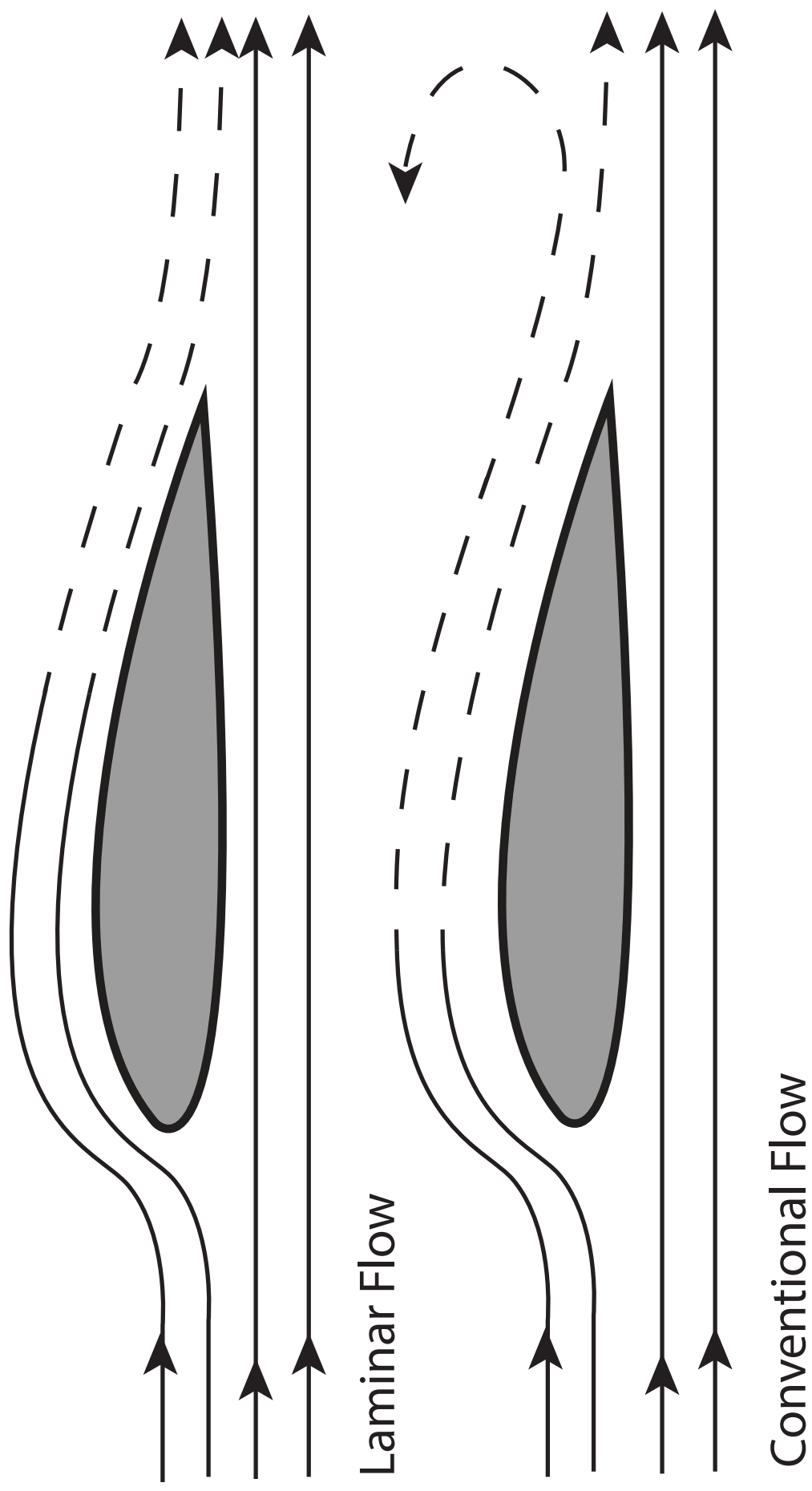


Fig. 5 Conventional airfoils

CONVENTIONAL AIRFOILS



Low camber - low drag - high speed - thin wing section. Suitable for race planes, fighters, interceptors, etc.



Deep camber - high lift - low speed - thick wing section. Suitable for transports, freighters, bombers, etc.



Deep camber - high lift - low speed - thin wing section. Suitable as above



Low lift - high drag - reflex trailing edge wing section
Very little movement of centre of pressure. Good stability



Symmetrical (cambered top and bottom) wing sections. Similar to above

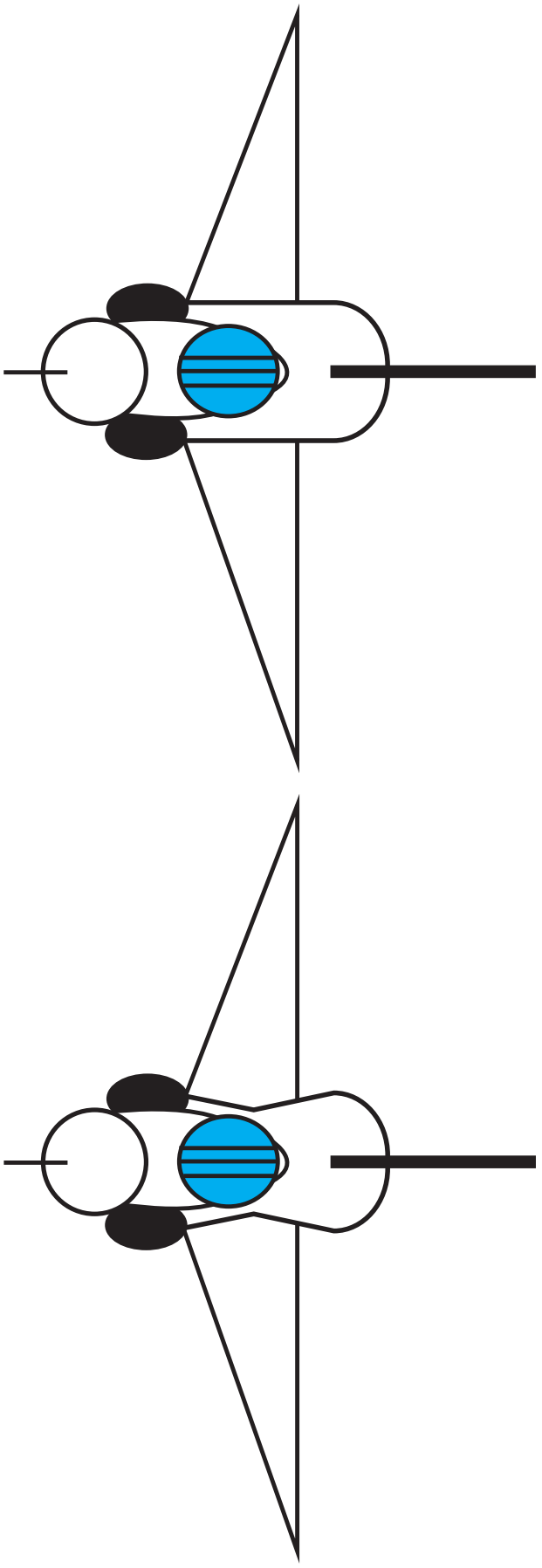


GA(W) -1 airfoil - thicker for better structure and lower weight - camber is maintained farther rear-ward which increases lifting capability over more of the airfoil and decreases drag

Fig. 6 Area Rule



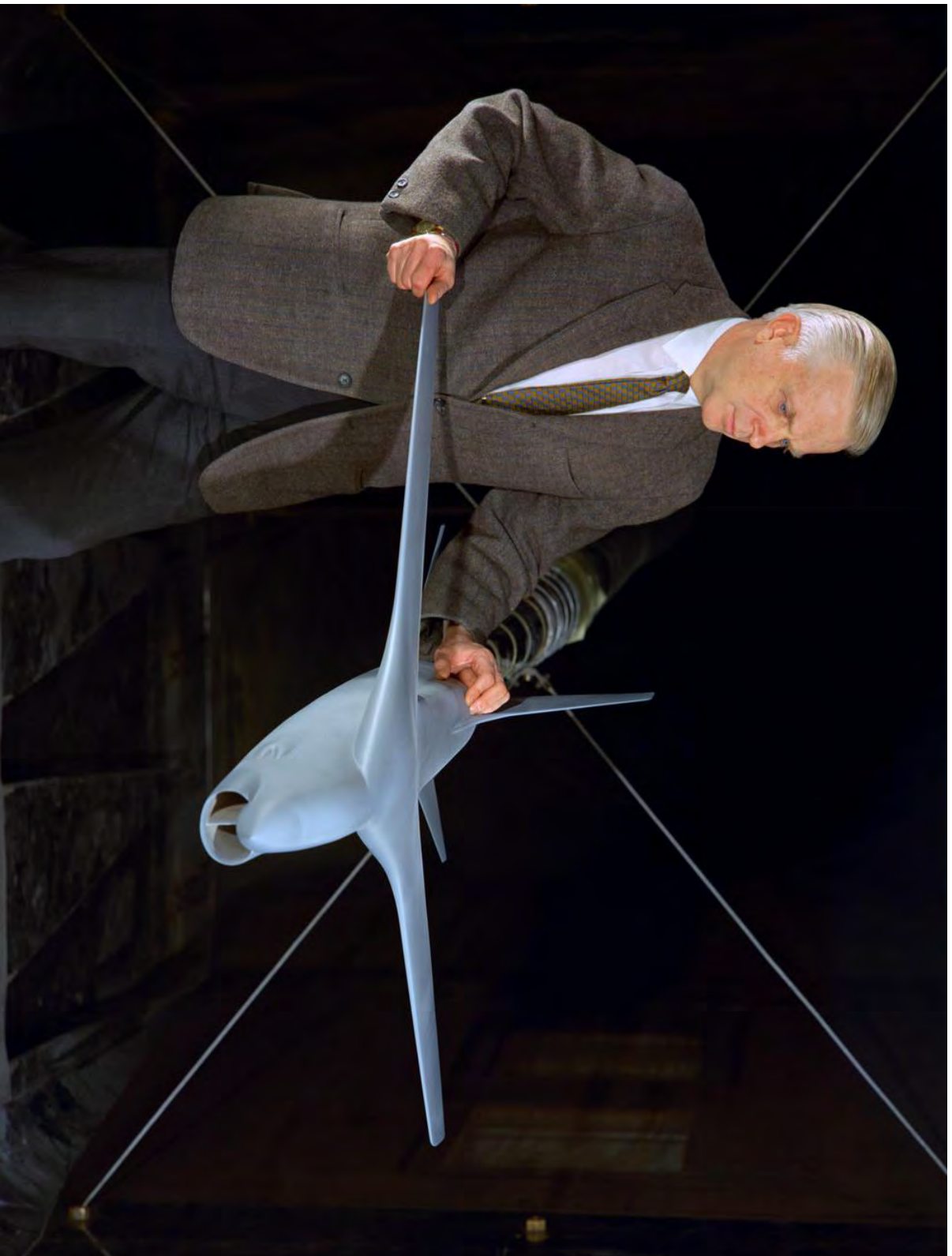
Fig. 7 Before and after area ruling





Images

Img. 1 Richard Whitcomb



(Photo courtesy of NASA)

Img. 2 Winglets



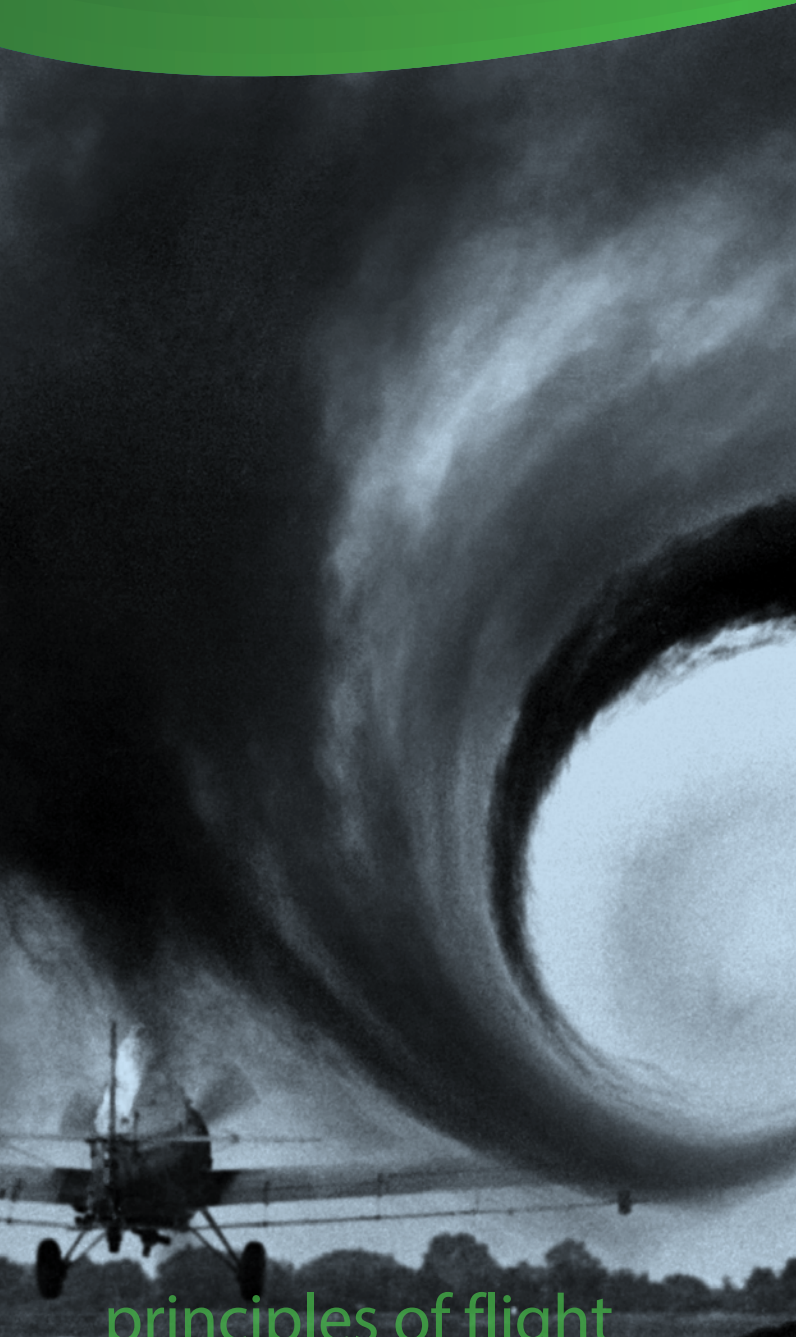
(Photo courtesy of NASA)

Img. 3 A Boeing B-1B Lancer over the Pacific Ocean

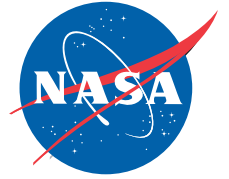


(Photo courtesy of the United States Air Force)

Aeronautics
Research
Mission
Directorate



principles of flight



GRADES

K-4

Space Shuttle Tires



structures and materials

Aeronautics
Research
Mission
Directorate



Space Shuttle Tires

Lesson Overview

In this lesson, students will compare tires from three different vehicles: a bicycle, a truck and the Space Shuttle. They will explore the structure of the tires, discovering the similarities and differences between them. They will also compare the tires of several passenger vehicles and discover how the size of the tire directly relates to the size of the vehicle.

Objectives

Students will:

1. Identify the parts of each tire and note their differences by observing the tire sections from the Space Shuttle, a truck and a bicycle.
2. Identify the information stamped on the sidewalls of tires found on vehicles in a parking lot.



(Photo courtesy of the Dryden Flight Research Center)

Space Shuttle Columbia's first landing as at NASA's Dryden Flight Research Center, located at Edwards Air Force Base, CA.

Materials:

In the Box

Space Shuttle tire section
Truck tire section
Bicycle tire section

Provided by User

None

GRADES

K-4

Time Requirements: 2 hours

Background

Landing the Shuttle

Although the Space Shuttle departs Earth vertically as a rocket, it lands horizontally, like an airplane. This requires a landing gear system comprised of struts, shock absorbers and most importantly to these activities, tires. The Shuttle normally lands at the Kennedy Space Center in Florida, using Edwards Air Force Base in California as an alternate runway during periods of unsuitable weather.

To land, the orbiter (which is the part of the Space Shuttle remaining after the solid rocket boosters and fuel tank have jettisoned upon launch), aligns with the runway. It begins a steep descent with its nose angled as much as 19 degrees down from horizontal. This 'glide slope' as it is known is nearly seven times steeper than the average commercial airliner landing which causes the Shuttle to descend toward the runway approximately 20 times faster. At about 610 meters (2,000 feet) above the ground, the Shuttle commander raises the nose, which slows both the rate of descent and airspeed in preparation for touchdown. At approximately 75 meters (250 feet) above the ground, the speed will have slowed to less than 556 km/hr (300 kts/345mph) and the landing gear is deployed and locked into place.

At touchdown, the main landing gear tires contact the runway first at approximately 354 km/hr (191 kts/220mph). Next, the nose gear lowers slowly as the orbiter loses speed. If necessary, a drag shoot can be deployed to assist in slowing the orbiter as well as maintaining directional control down the runway.

Shuttle Tires

The Shuttle has two main landing gear, which consist of two tires each. There are also two tires on the nose landing gear, for a total of six tires.

Like most aircraft tires, the Space Shuttle tires are filled with nitrogen because of its stability at different altitudes and temperatures. Also, Nitrogen molecules are larger than Oxygen molecules, which means Nitrogen escapes less easily from the tires, resulting in a more gradual loss of pressure over time. Nitrogen is also non-flammable which prevents problems should a tire puncture upon landing.

When landing, the orbiter weighs approximately 109,000 kg (240,000 lbs). Because of this, shuttle tires are inflated to a much higher pressure than a small airliner or car. The main gear tires are inflated to 315 psi while the nose gear is inflated to 300 psi. The main gear tires can only be used one time, while the nose gear tires can be used for two landings.

Tire Basics

Every tire manufactured in the United States is required to have its designation stamped into the sidewall of the tire.

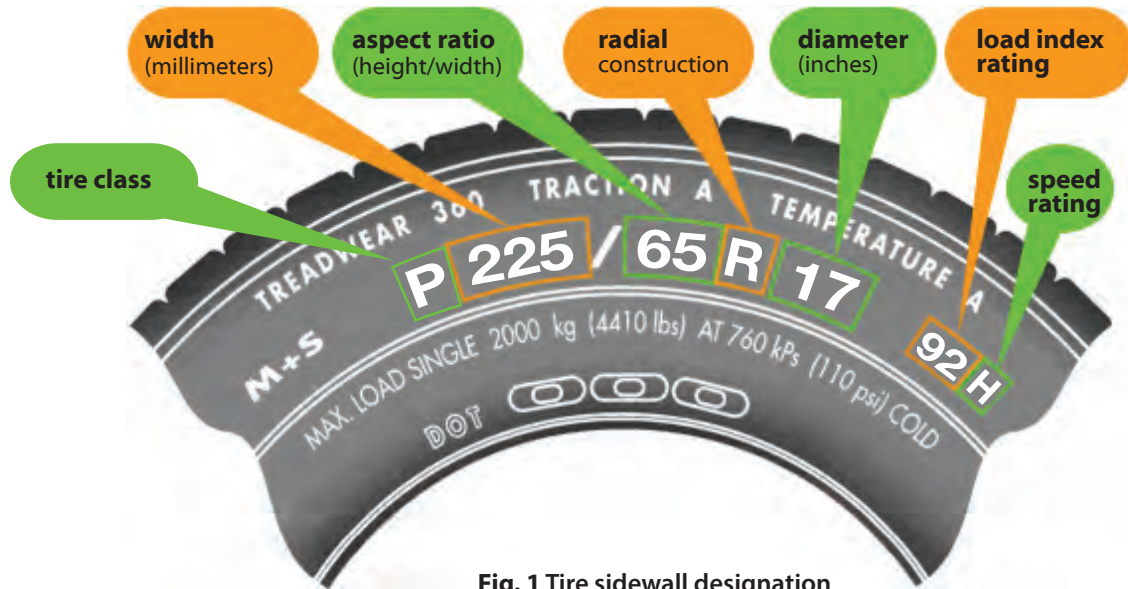


Fig. 1 Tire sidewall designation

In this example you can see the following designation on the tire: P225/65R16 92H

- **P** designates the tire’s class. In this example, “P” indicates that the tire is a passenger car tire. An “LT” would designate it as a light truck tire.
- **225** is the tire’s section width measured in millimeters. This measurement is taken from sidewall to sidewall. In this example, the section width of the tire is 225mm.
- **65** is the aspect ratio of the tire. The aspect ratio refers to the height of the sidewall as a percentage of the section width.
- **R** refers to the tire construction. In this example the tire is a radial tire. Although rare, you may also see the letter C, which refers to a cross-ply tire.
- **17** refers to the wheel diameter in inches.
- **92** refers to the load index for the tire. Load index ranges from 0 to 279 and corresponds with the load-carrying capacity of a tire. Passenger car tire load indices typically range from 75 to 105. (See the Load Index Table, Fig. 10 in the Reference Material Section.)
- **H** indicates the speed rating for the tire, which is the maximum speed for which the tire is allowed to travel per the manufacturer’s recommendation.

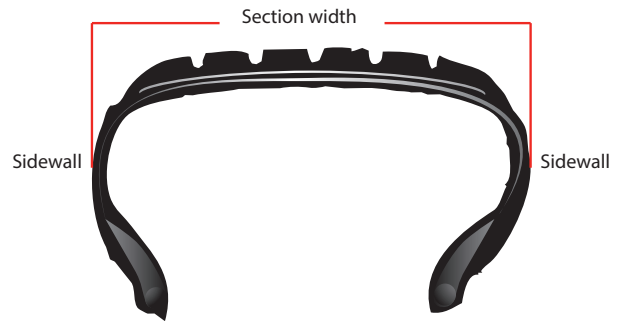


Fig. 2 Tire cross section

Activity 1

Comparing Tires

GRADES**K-4****Time Requirement:** 60 minutes**Materials:**In the Box

Tire Sections:
Space Shuttle
Truck
Bicycle

Worksheets

None

Reference Materials

None

Key Terms:

Bead
Chafer
Filler
Liner
Nylon Belt
Plies
Sidewall
Steel Belt
Tread

Objective:

Observing the tire sections from the Space Shuttle, a truck and a bicycle, students will identify the parts of each tire and note their differences.



Img. 1 Tire Cross Sections

Activity Overview:

In this activity you will use the pieces of tire provided to explore the differences between tires used on three different vehicles: a bicycle, a pickup truck and the Space Shuttle. You can either keep the students in one group or divide them into three groups, with each group getting a tire section.



Fig. 3 Tire with cross section

Activity:

1. **Examine the three tires provided (shuttle, truck, and bicycle).**

Hold up each piece of tire and tell the students which one belongs to which vehicle. Explain that each piece of tire is just a cross-section of the entire tire. (A cross-section is a slice of tire cut perpendicular to the wheel and extracted from the whole tire so we can easily see what the tire is made of and how it is constructed). Using the "Tire Cross-Section" (Fig. 3) diagram, demonstrate how the cross-section relates to the whole tire.

2. **Identify the parts of each tire.**

Using the Space Shuttle tire, along with (Fig. 4) in the *Reference Materials* section, explain to the students the purpose for each part of the tire.

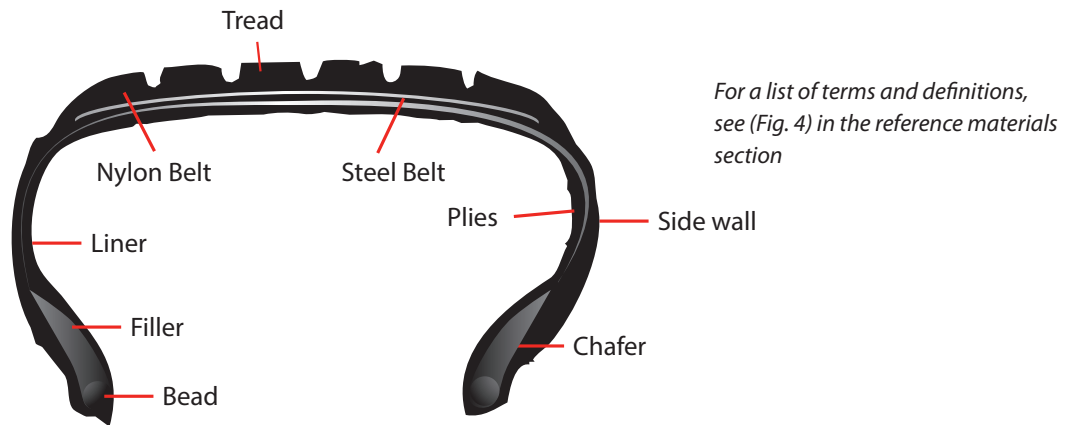


Fig. 4 Parts of a tire

3. **Compare and contrast the parts of the three tires.**

- a. Pass the tire pieces around so that every student has the opportunity to feel and see each piece.
- b. Encourage students to examine the tires closely and to take note of similarities and differences.
- c. Point out that some tires have components that others do not. For example, the bicycle tire has a bead, but not a steel belt.
- d. Suggest the students think about the vehicle each piece of tire supports while they are examining its tire.
- e. If necessary, point out that larger/heavier vehicles require larger tires.

Discussion Points:

1. **How are the tires similar? How are they different?**

If you have access to a white board, chalk board or large pad of paper, create a list of the similarities and differences between the tires.

2. **Why is the shuttle tire so much bigger than the bicycle tire?**

The tires on the shuttle must be larger than those on a bicycle in order to support the extra weight; the shuttle is a much heavier vehicle.

3. **Name some other items that use rubber tires.**

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL MATH STANDARDS K-4

NUMBER AND OPERATIONS

- Understand numbers, ways of representing numbers, relationships among numbers, and number systems
- Understand meanings of operations and how they relate to one another

MEASUREMENT

- Understand measurable attributes of objects and the units, systems, and processes of measurement
- Apply appropriate techniques, tools, and formulas to determine measurements

DATA ANALYSIS AND PROBABILITY

- Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them

PROCESS

- Problem Solving
- Communication
- Connections
- Representation

Activity 2

Parking Lot Research

GRADES**K-4****Time Requirements:** 60 minutes**Materials:**In the Box

None

Provided by User:Cars and
other vehicles
in a parking lotLong strips of paper
(4 per student)WorksheetsVehicle Data Sheet
(Worksheet 1)Reference Materials

None

Key Terms:Sidewall
Load Index**Objective:**

Students will identify the information stamped on the sidewalls of tires found on vehicles in a parking lot.

Activity Overview:

In this activity, students will compare the sidewall designations of tires found on several passenger vehicles. Prior to beginning the lesson, review your facility's safety procedures with the students.

Activity:

The information on a vehicle's tire can explain a lot about the vehicle. Begin this activity by reviewing the [Tire Basics](#) section of this lesson with your students to ensure they are familiar with how to read a tire's sidewall information.

1. **Divide the class into teams.**

Divide students into groups of 3-5 to perform their parking lot research. Make sure there are multiple vehicles in the parking lot to use as research subjects.

2. Depending on the age and ability of the students perform one of the following steps.
 - a. Using the Vehicle Data Worksheet, have each team collect the Vehicle Type, Make, Model and Sidewall Numbers from several vehicles.



Img. 2 Tire Sidewall

- b. Using the strips of paper, have students measure the diameter of the tires of several vehicles by tearing the paper to length. If able, write on the strip of paper the make and model of the vehicle.



Discussion Points:***If step 2a was performed:***

1. Discuss what each of the sidewall numbers means, using one of the collected datasets as an example.
You can use the Tire sidewall designation (Fig. 1) as well if required to assist in the review.
2. Is there any correlation to the specific tions of the tire compared to the size of vehicle?
It should be noticed that in general, larger tires are used on larger vehicles. Also, trucks will typically have deeper treads than passenger cars of the same size, as trucks need additional traction when working off-road.
3. Did any of the vehicles have the same tire dimensions?

If step 2b was performed:

1. Have the students compare their strips of paper with others. Are some the same length? If so, why?
It should be discovered that similar sized vehicles use similar sized tires.
2. Was the Space Shuttle tire bigger or smaller than the tires they looked at? If so, why?
The vehicle tires will be considerably smaller than the Space Shuttle tire. This is because the vehicle tires have to support much less weight and operate at slower speeds.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL MATH STANDARDS K-4

NUMBER AND OPERATIONS

- Understand numbers, ways of representing numbers, relationships among numbers, and number systems
- Understand meanings of operations and how they relate to one another

MEASUREMENT

- Understand measurable attributes of objects and the units, systems, and processes of measurement
- Apply appropriate techniques, tools, and formulas to determine measurements

DATA ANALYSIS AND PROBABILITY

- Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them

PROCESS

- Problem Solving
- Communication
- Connections
- Representation



Reference Materials

Fig. 1 Tire sidewall designation



Fig. 2 Tire cross section

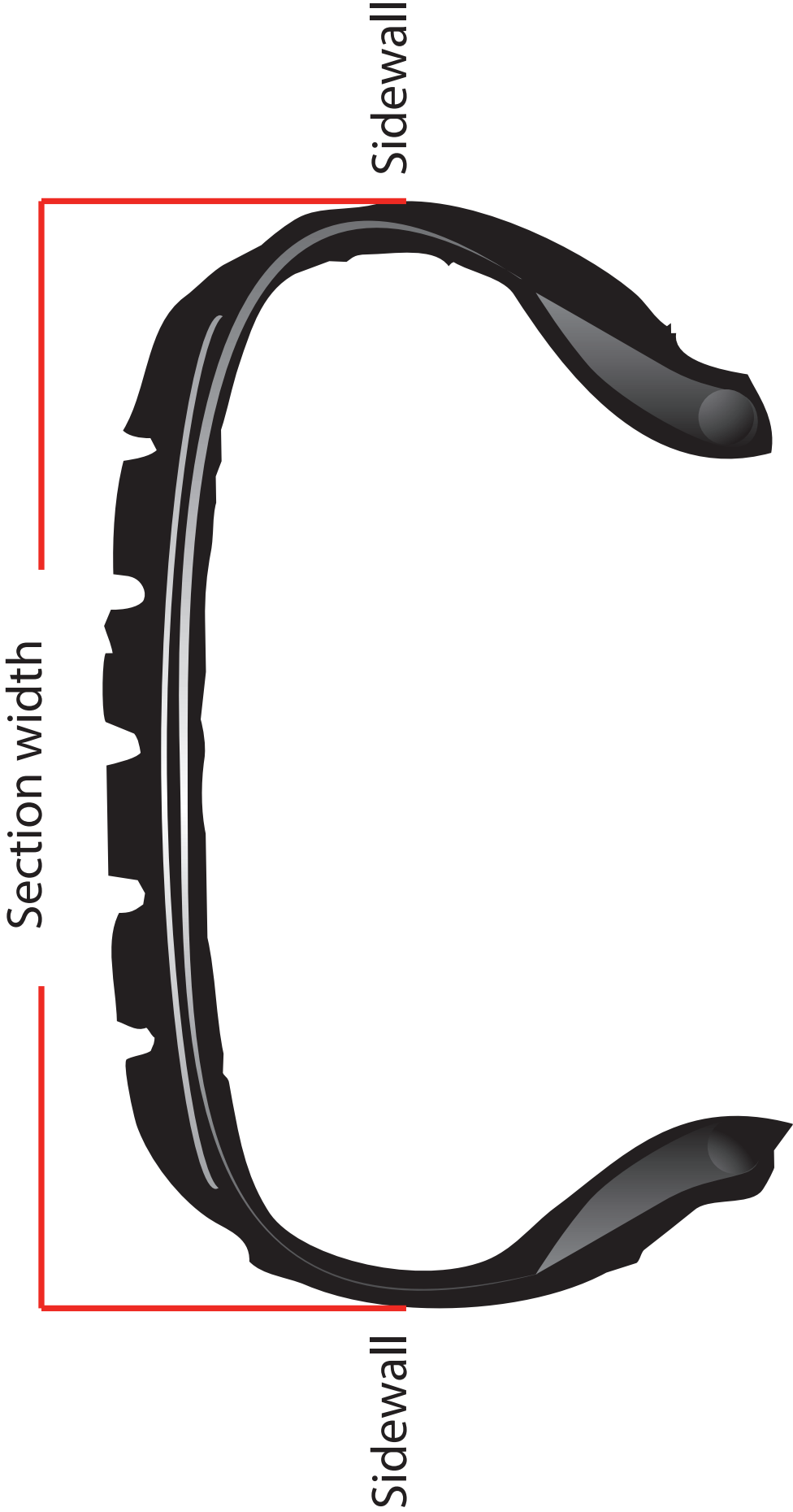
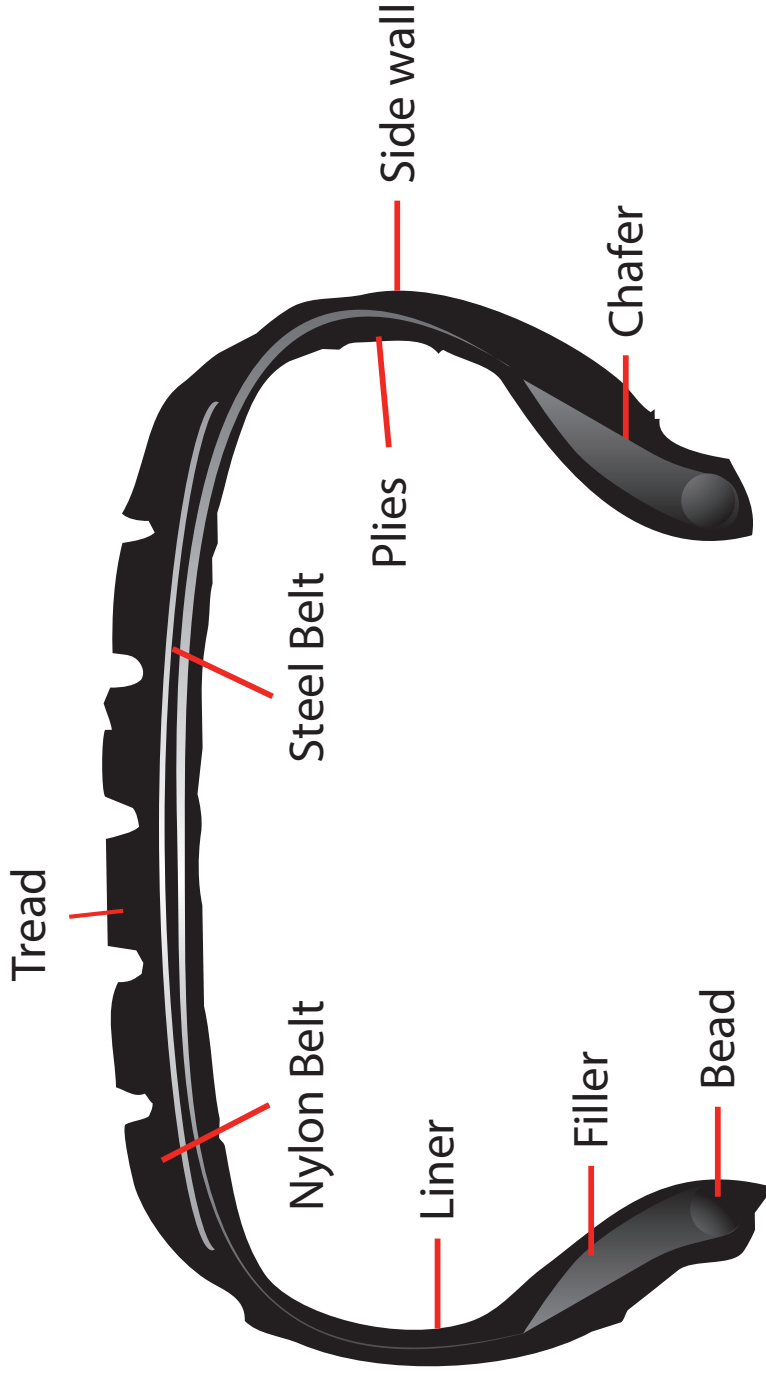


Fig. 3 Tire with cross section



Fig. 4 Parts of a tire



Bead

A mix of high-strength steel wire and rubber that hold the plies and the tire assembly onto the rim of the wheel.

Belt (Nylon and Steel Belts)

Narrow layer of coated tire cord or rubber-encased steel cord located directly under the tire tread that are designed to resist deformation.

Chafer

A layer of rubber compound that is applied to the bead; the chafer provides protection against rim chafing and other external damage.

Filler

A rubber compound that smoothly fits the plies to the bead.

Liner

A thin layer of rubber inside the tire which contains compressed air. Some tires use a tube in place of the liner.

Pliers

Layers of fabric cord extending from bead to bead that reinforce the tire.

Sidewall

The part of the tire between the bead and the tread.

Tread

The most recognizable part of the tire. It is composed of a wear-resistant rubber compound that provides traction and assists in removing road surface water and contaminants.

Glossary

Bead:

A mix of high-strength steel wire and rubber that hold the plies and the tire assembly onto the rim of the wheel

Belt:

Narrow layer of coated tire cord or rubber-encased steel cord located directly under the tire tread that are designed to resist deformation

Chafer:

A layer of rubber compound that is applied to the bead; the chafer provides protection against rim chafing and other external damage

Filler:

A rubber compound that smoothly fits the plies to the bead

Liner:

A thin layer of rubber inside the tire which contains compressed air; some tires use a tube in place of the liner

Load Index:

The maximum load each tire can carry

PSI:

Pounds per Square Inch; one psi is one pound of force applied to one square inch of surface material

Plies:

Layers of fabric cord extending from bead to bead that reinforce the tire

Sidewall:

The part of the tire between the bead and the tread

Tread:

The most recognizable part of the tire. It is composed of a wear-resistant rubber compound that provides traction and assists in removing road surface water and contaminants

Tire Class:

The group or category to which the tire belongs (ex: P=Passenger, LT=light truck)

Tread Depth:

The distance from the top of the tread to the bottom of the grooves

Tread Life:

The number of miles the tread on a tire is expected to last



Student Worksheets

Worksheet 1

Vehicle Data

Vehicle Type	Make	Model	Sidewall Numbers
Car	Dodge	Neon	185/60R15



Images

Img. 1 Tire Cross Sections



(Photo courtesy of Lost Tribe Media, Inc.)

Img. 2 Tire Sidewall



(Photo courtesy of Lost Tribe Media, Inc.)

Img. 3 Installing a main shuttle tire



(Photo courtesy of NASA – www.nasaimages.org)

Img. 4 The Space Shuttle at lift-off



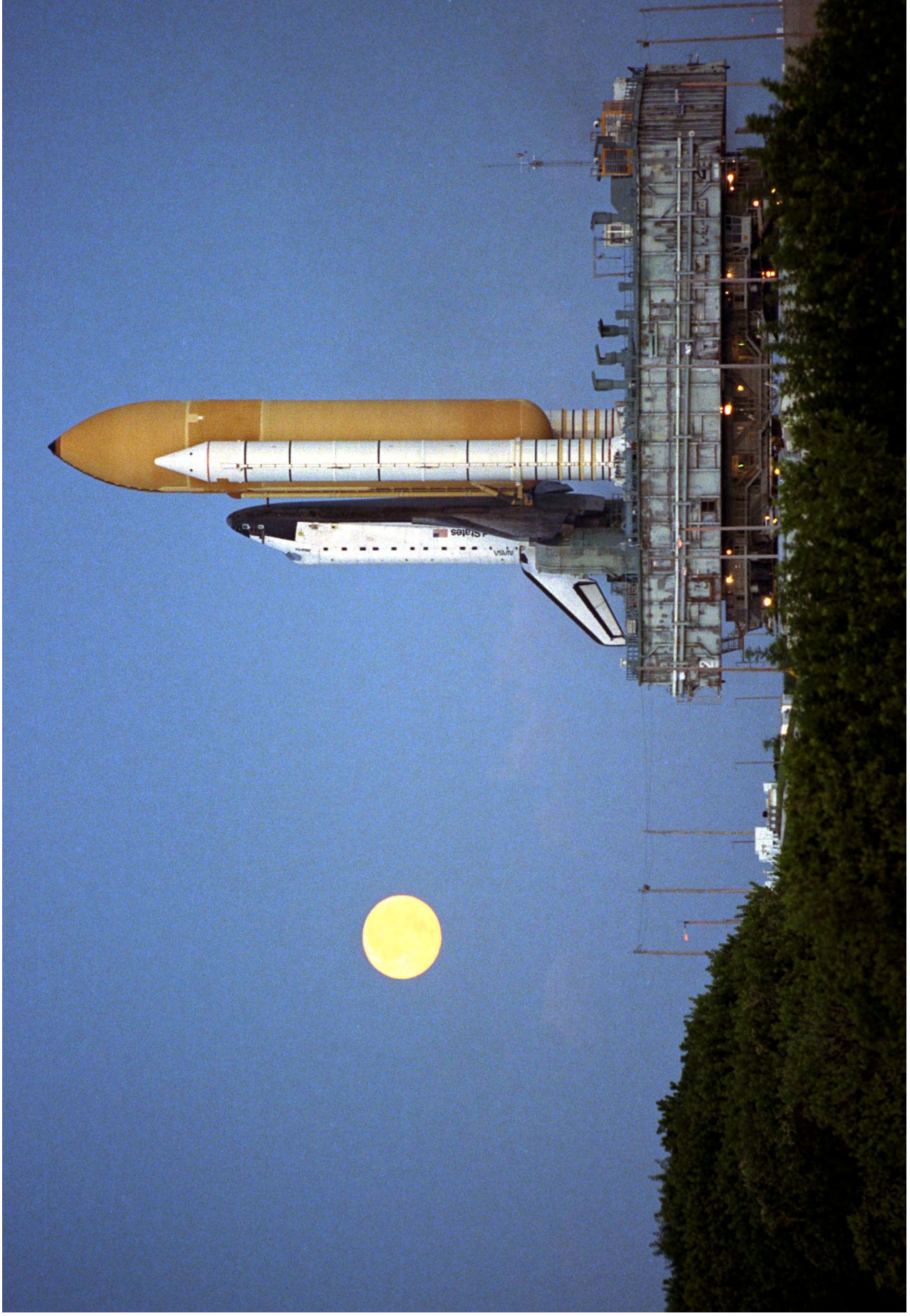
(Photo courtesy of NASA – www.nasaimages.org)

Img. 5 The Space Shuttle en-route to the launch pad



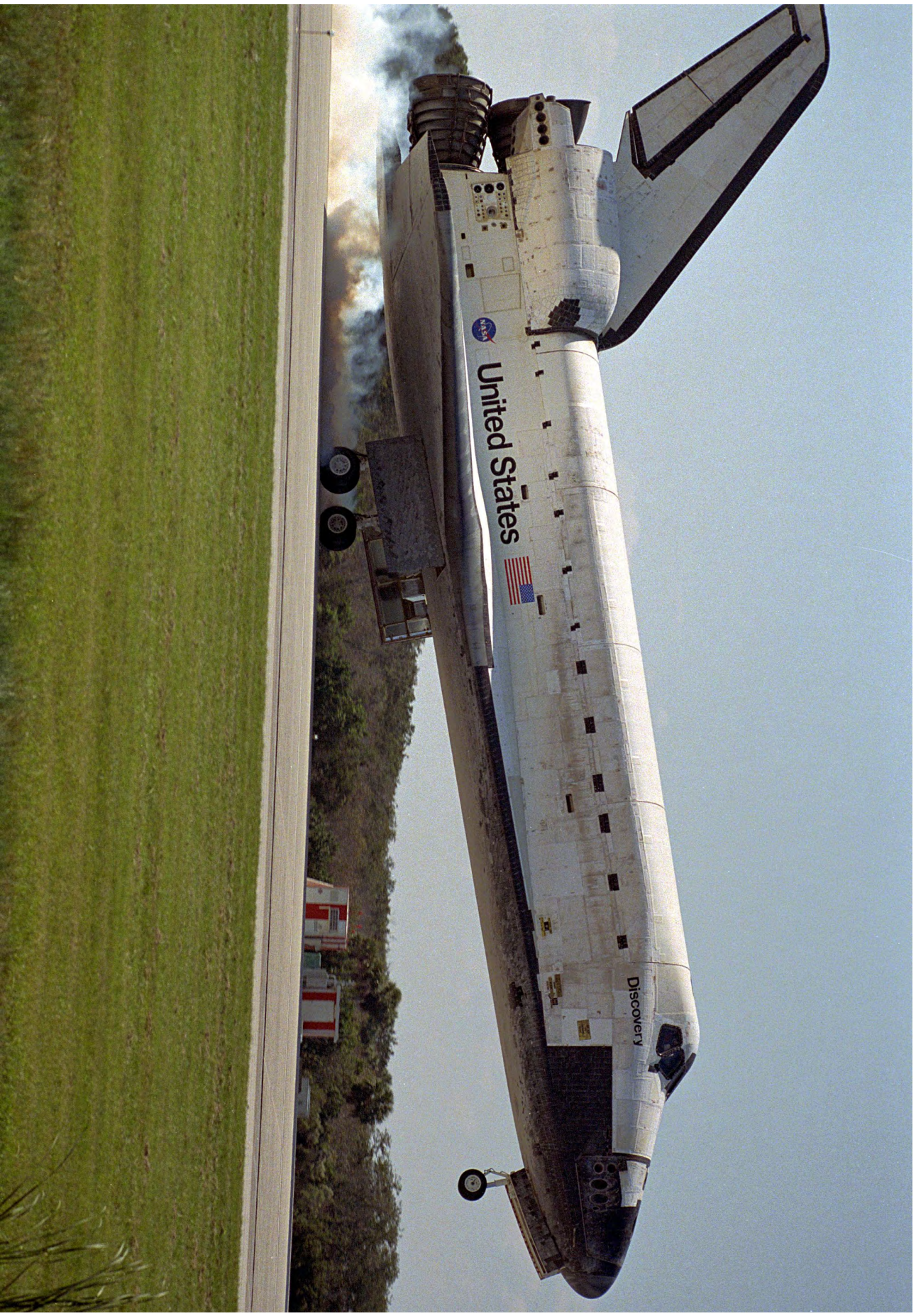
(Photo courtesy of NASA – www.nasaimages.org)

Img. 6 The Space Shuttle on the launch pad



(Photo courtesy of NASA – www.nasaimages.org)

Img. 7 The Shuttle Discovery landing at Kennedy Space Center



(Photo courtesy of NASA – www.nasaimages.org)

Img. 8 The Shuttle Endeavour landing at Kennedy Space Center



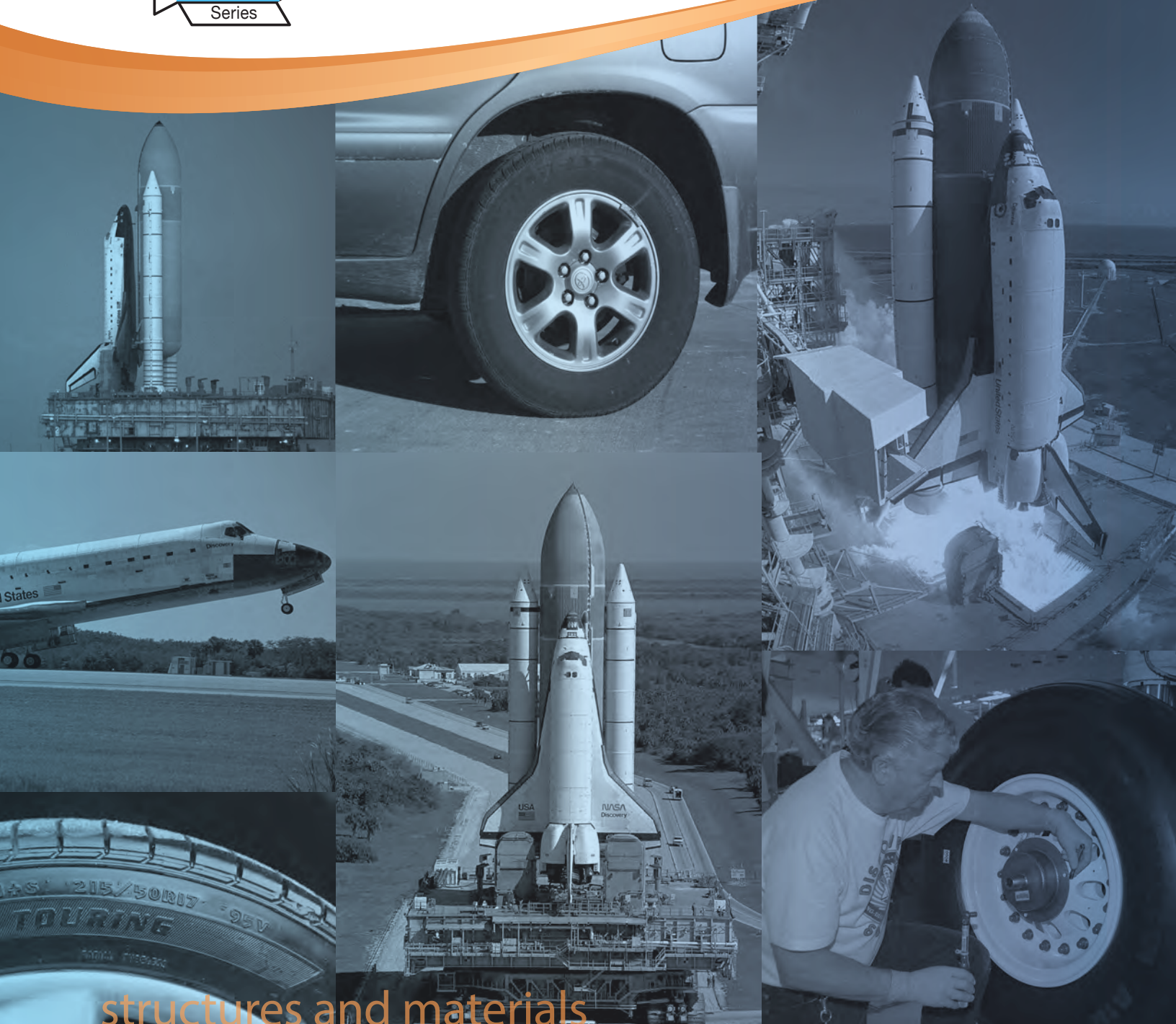
(Photo courtesy of NASA – www.nasaimages.org)

Img. 9 The Shuttle Columbia landing at Edwards Air Force Base

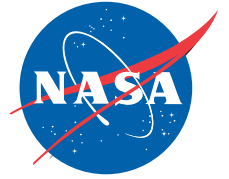


(Photo courtesy of NASA - www.nasainages.org)

Aeronautics
Research
Mission
Directorate



structures and materials



GRADES

5-12

Space Shuttle Tires



structures and materials

Aeronautics
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Space Shuttle Tires

Lesson Overview

Through demonstration and math activities, students will learn about tire technology and the effects of air pressure. A section of tire from the Space Shuttle, a light truck and a bicycle are provided for students to compare and contrast. In addition, math activities are provided for students to complete and discuss the basic formulas for air pressure, circumference and the number of revolutions of a tire over a given distance.

Objectives

1. By observing the tire sections from the Space Shuttle, a truck and a bicycle, students will identify the parts of each tire and note the differences between them.
2. Students will determine the tread depth of a tire using a penny or a quarter.
3. After reviewing [Tire Basics](#), students will identify the information stamped on the sidewalls of tires found on vehicles in a parking lot.
4. Students will use mathematical formulas to determine the diameter and circumference of a tire, as well as the number of revolutions made over a given distance.
5. Students will calculate how tire pressure can impact the life of a tire along with its affect on fuel efficiency.



(Photo courtesy of the Dryden Flight Research Center)

Space Shuttle Columbia's first landing as at NASA's Dryden Flight Research Center, located at Edwards Air Force Base, CA.

Materials:

Included in MIB

Space Shuttle tire section
Truck tire section
Bicycle tire section

Provided by User

United States Coins: one penny and one quarter for each group of 3 to 5 students

GRADES

5-12

Time Requirements: 2 hours 50 minutes

Background

Landing the Shuttle

Although the Space Shuttle departs Earth vertically as a rocket, it lands horizontally, like an airplane. This requires a landing gear system comprised of struts, shock absorbers and most importantly to these activities, tires. The Shuttle normally lands at the Kennedy Space Center in Florida, using Edwards Air Force Base in California as an alternate runway during periods of unsuitable weather.

To land, the orbiter (which is the part of the Space Shuttle remaining after the solid rocket boosters and fuel tank have jettisoned upon launch), aligns with the runway. It begins a steep descent with its nose angled as much as 19 degrees down from horizontal. This 'glide slope' as it is known is nearly seven times steeper than the average commercial airliner landing which causes the Shuttle to descend toward the runway approximately 20 times faster. At about 610 meters (2,000 feet) above the ground, the Shuttle commander raises the nose, which slows both the rate of descent and airspeed in preparation for touchdown. At approximately 75 meters (250 feet) above the ground, the speed will have slowed to less than 556 km/hr (300 kts/345mph) and the landing gear is deployed and locked into place.

At touchdown, the main landing gear tires contact the runway first at approximately 354 km/hr (191 kts/220mph). Next, the nose gear lowers slowly as the orbiter loses speed. If necessary, a drag shoot can be deployed to assist in slowing the orbiter as well as maintaining directional control down the runway.

Shuttle Tires

The Shuttle has two main landing gear, which consist of two tires each. There are also two tires on the nose landing gear, for a total of six tires.

Like most aircraft tires, the Space Shuttle tires are filled with nitrogen because of its stability at different altitudes and temperatures. Also, Nitrogen molecules are larger than Oxygen molecules, which means Nitrogen escapes less easily from the tires, resulting in a more gradual loss of pressure over time. Nitrogen is also non-flammable which prevents problems should a tire puncture upon landing.

When landing, the orbiter weighs approximately 109,000 kg (240,000 lbs). Because of this, shuttle tires are inflated to a much higher pressure than a small airliner or car. The main gear tires are inflated to 315 psi while the nose gear is inflated to 300 psi. The main gear tires can only be used one time, while the nose gear tires can be used for two landings.

Tire Basics

Every tire manufactured in the United States is required to have its designation stamped into the sidewall of the tire.

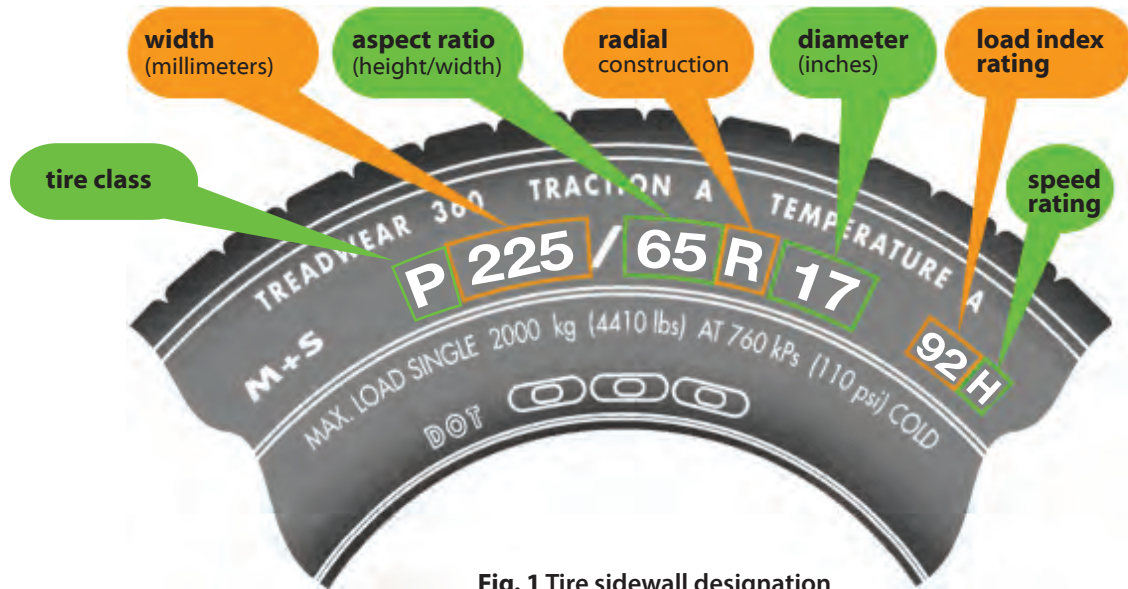


Fig. 1 Tire sidewall designation

In this example you can see the following designation on the tire: P225/65R16 92H

- **P** designates the tire's class. In this example, "P" indicates that the tire is a passenger car tire. An "LT" would designate it as a light truck tire.
- **225** is the tire's section width measured in millimeters. This measurement is taken from sidewall to sidewall. In this example, the section width of the tire is 225mm.
- **65** is the aspect ratio of the tire. The aspect ratio refers to the height of the sidewall as a percentage of the section width.
- **R** refers to the tire construction. In this example the tire is a radial tire. Although rare, you may also see the letter C, which refers to a cross-ply tire.
- **17** refers to the wheel diameter in inches.
- **92** refers to the load index for the tire. Load index ranges from 0 to 279 and corresponds with the load-carrying capacity of a tire. Passenger car tire load indices typically range from 75 to 105. (See the Load Index Table, Fig. 10 in the Reference Material Section.)
- **H** indicates the speed rating for the tire, which is the maximum speed for which the tire is allowed to travel per the manufacturer's recommendation.

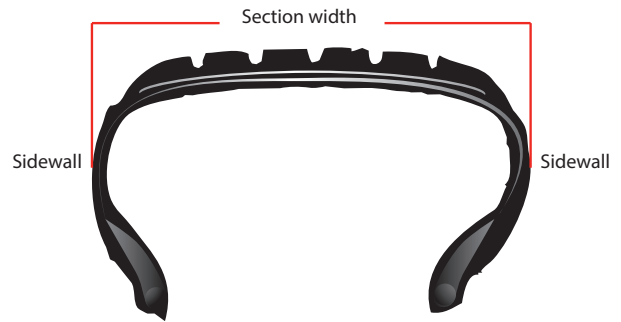


Fig. 2 Tire cross section

Activity 1

Comparing Tires

GRADES 5-12**Time Requirement:** 30 minutes**Materials:**In the Box

Tire Sections:
Space Shuttle
Truck
Bicycle

Worksheets

Venn Diagram
(Worksheet 1)

Reference Materials

Figure 1
Figure 2
Figure 3
Figure 4
Figure 5

Key Terms:

Bead
Chafer
Filler
Liner
Nylon Belt
Plies
Sidewall
Steel Belt
Tread

Objective:

Observing the tire sections from the Space Shuttle, a truck and a bicycle, students will identify the parts of each tire and note their differences.



Img. 1 Tire Cross Sections

Activity Overview:

In this activity you will use the pieces of tire provided to explore the differences between tires used on three different vehicles: a bicycle, a pickup truck and the Space Shuttle. You can either keep the students in one group or divide them into three groups, with each group getting a tire section.

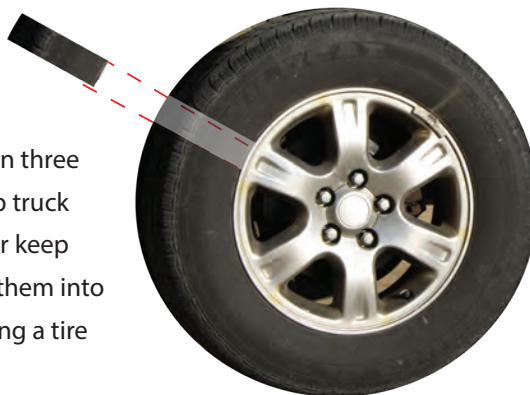


Fig. 3 Tire with cross section

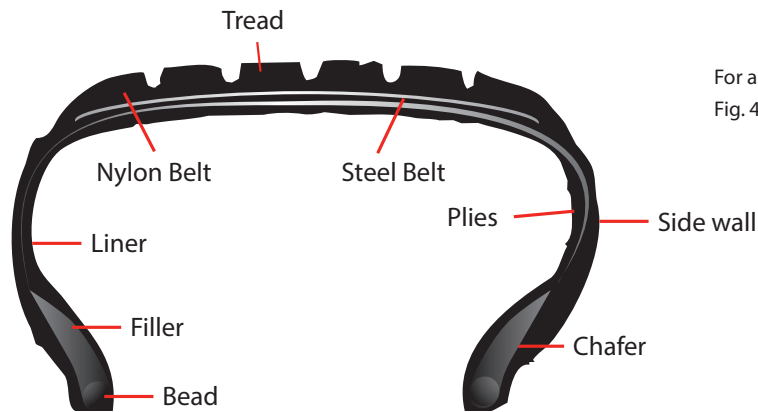
Activity:

1. Examine the three tires provided (shuttle, truck, and bicycle).

Hold up each piece of tire and tell the students which one belongs to which vehicle. Explain that each piece of tire is just a cross-section of the entire tire. (A cross-section is a slice of tire cut perpendicular to the wheel and extracted from the whole tire so we can easily see what the tire is made of and how it is constructed.) Using the "Tire Cross-Section" (Fig. 3) diagram, demonstrate how the cross-section relates to the whole tire.

2. Identify the parts of each tire.

Display the "Parts of a Tire" (Fig. 4) diagram. Hold the shuttle tire segment up and point out the parts of the tire mentioned on the diagram, explaining each term.



For a list of terms and definition, see Fig. 4 in the reference materials section

Fig. 4 Parts of a tire

3. Compare and contrast the parts of the three tires.

Pass the tire pieces around so that every student has the opportunity to feel and see each piece.

Encourage students to examine the tires closely and to take note of similarities and differences.

Point out that some tires have components that others do not. For example, the bicycle tire has a bead, but not a steel belt.

Suggest the students think about the vehicle each piece of tire supports while they are examining its tire.

If necessary, point out that larger/heavier vehicles require larger tires.

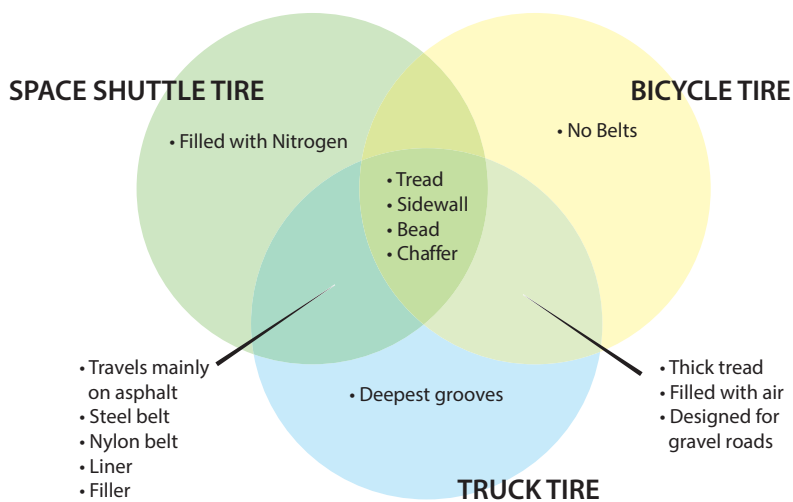


Fig. 5 Venn Diagram

Discussion Points:

If you have access to a white board, chalk board or large pad of paper, draw or display the following Venn diagram. If not, use the blank diagram provided in the worksheet section. Discuss with the students the differences and similarities of the tires, placing the items on the chart in their appropriate locations. Your finished diagram should look similar to Fig. 5.

1. How are the tires similar?
2. How are the tires different?
3. Why do you think the tires are created differently?

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Properties and changes of properties in matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Structure and properties of matter
- Interactions of energy and matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL MATH STANDARDS K-12

NUMBER AND OPERATIONS

- Understand numbers, ways of representing numbers, relationships among numbers, and number systems
- Understand meanings of operations and how they relate to one another
- Compute fluently and make reasonable estimates

ALGEBRA

- Represent and analyze mathematical situations and structures using algebraic symbols
- Use mathematical models to represent and understand quantitative relationships

MEASUREMENT

- Understand measurable attributes of objects and the units, systems, and processes of measurement
- Apply appropriate techniques, tools, and formulas to determine measurements.

DATA ANALYSIS AND PROBABILITY

- Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them

PROCESS

- Problem Solving
- Communication
- Connections
- Representation

Activity 2

Measuring Tire Tread

GRADES

5-12

Time Requirements: 20 minutes

Materials:

In the Box

Tire Sections:
Space Shuttle
Truck
Bicycle

Provided by User

United States Coins:
one penny and one
quarter for each group

Worksheets

None

Reference Materials

Figure 6
Figure 7
Figure 8

Key Terms:

Tread
Tread Depth

Objective:

Students will determine the tread depth of a tire using a U.S. penny and quarter.

Activity Overview:

In this activity you will teach your students how to measure the approximate tread depth of the three tire samples using coins. You will also discuss with them the need for tread and how various tread depths affect the performance of the vehicle.

Activity:

To begin, divide the students into three groups, one for each tire. Have each group of students measure each tire with the two coins then pass the tire on to the next group.



Fig. 6 Penny (head) tread measurement

1. Place a penny into several tread grooves with Lincoln's head toward the tire. If the tire tread covers any portion of Lincoln's head, there is more than $\frac{2}{32}$ inch of tread depth remaining on the tire. This is the minimum legal tread depth in the United States.



Fig. 7 Quarter (head) tread measurement

- Place a quarter into several tread grooves with Washington's head towards the tire. If the tire tread covers any portion of Washington's head, there is more than $4/32$ inch of tread depth remaining on the tire.

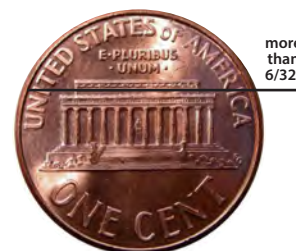


Fig. 8 Penny (tails) tread measurement

- Place a penny into several tread grooves with the top of the Lincoln Memorial towards the tire. If the tire tread covers any portion of the Lincoln Memorial, there is more than $6/32$ of an inch of tread depth remaining on the tire.

Discussion Points:

- What is the difference between the tread depths for each of the three different tires?

It should have been discovered that the bicycle tire has the least amount of tread, with the truck tire having the most. The primary purpose of the grooves in the tread is to allow contaminants such as rain or snow to be removed, so that the rest of the tread can contact the surface. Generally speaking, the deeper the grooves, the more contaminants can be removed. As the bicycle is the slowest vehicle, it needs to remove less water in any given moment than a truck tire. For safety reasons however, the shuttle is not permitted to land while it is raining.

2. Why is the tread depth important to a tire's performance, traction, noise and comfort?

The primary purpose of the grooves in the tread are to remove contaminants from the road. However, the design of the tread plays an important part in many other aspects. While a deep groove provides better traction in the rain, or off-road, it also greatly increases the noise from the tire as the rubber has to be stiffer. Smaller grooves, or groove-less tires (slicks), provide incredible traction on dry pavements which is why they are used on race cars, but would perform horribly when the road was even slightly wet.

NATIONAL SCIENCE STANDARDS 5-8

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- Abilities necessary to do scientific inquiry
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PHYSICAL SCIENCE

- Properties and changes of properties in matter

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NATIONAL SCIENCE STANDARDS 9-12

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PROCESS

- Problem Solving
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- Representation

Activity 3

Parking Lot Research

GRADES 5-12**Time Requirements:** 45 minutes**Materials:**

Cars and
other vehicles
in a parking lot

Worksheets

Vehicle Data Sheet
(Worksheet 2)

Reference Materials

Figure 1

Key Terms:

Sidewall
Load Index

**Objective:**

After reviewing **Tire Basics**, students will identify the information stamped on the sidewalls of tires found on vehicles in a parking lot.

Activity Overview:

In this activity, students will compare the sidewall designations of tires found on several passenger vehicles. The data collected in this activity can be used in **Activity 4, Tire Math** if desired. Prior to beginning the lesson, review your facility's safety procedures with the students.

Activity:

The information on a vehicle's tire can explain a lot about the vehicle. Begin this activity by reviewing the **Tire Basics section of this lesson with your students to ensure they are familiar with how to read a tire's sidewall information.**

1. Divide the class into teams.

Divide students into groups of 3-5 to perform their parking lot research. Make sure there are multiple vehicles in the parking lot to use as research subjects.



Img. 2 Tire Sidewall

2. Using the Vehicle Data Worksheet, have each team collect the Vehicle Type, Make, Model and Sidewall Numbers from several vehicles.

In case a parking lot is not available, or there are an insufficient number of vehicles, you can use the sample data provided on the Vehicle Data Worksheet.

Discussion Points:

1. Discuss what each of the sidewall numbers means, using one of the collected datasets as an example.

You can use the Tire sidewall designation (Fig. 1) as well if required to assist in the review.

2. Is there any correlation to the specific tions of the tire compared to the size of vehicle?

It should be noticed that in general, larger tires are used on larger vehicles. Also, trucks will typically have deeper treads than passenger cars of the same size, as trucks need additional traction when working off-road.

3. Did any of the vehicles have the same tire dimensions?

4. What are the dangers of not having the same size and rating on all four tires of a vehicle?

With limited exceptions such as race cars, it is vital that a vehicle have identical tires.

The following is a list of problems that may be experienced by not having properly matching tires:

- Difficulty steering or cornering
- Vehicle may skid frequently, or experience a loss of traction
- Tires are more likely to wear at different rates, which could cause one to explosively fail while in motion
- Fuel economy may be reduced

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PROCESS

- Problem Solving
- Communication
- Connections
- Representation

Activity 4

Tire Math

GRADES 5-12

Time Requirements: 45 minutes

Materials:
Worksheets

Vehicle Data Sheet
(Worksheet 2)
Tire Math
(Worksheet 3)

Reference Materials

Figure 1

Key Terms:

Sidewall

Objective:

Students will use mathematical formulas to determine the diameter and circumference of a tire, as well as the number of revolutions made over a given distance.

Activity Overview:

In this activity, students will use the information found on a tire's sidewall as a basis to calculate additional information. This activity can be done individually, or using the same groups as in [Activity 3, Parking Lot Research](#). This lesson can reinforce concepts learned in math class (such as percentages, conversion factors and using formulas) as well as give students a tangible example of where they might apply some of the concepts they are learning.

If the students have already completed [Activity 3, Parking Lot Research](#), use the same worksheets and their recorded data for this activity. If not, sample data is provided on the Vehicle Data Worksheet.

Depending on skill level, have students work through each problem on the worksheet, or work through them together as a group. Note: the work for each calculation is shown below.

Activity:

Calculate additional information from a tire's sidewall designation.

1. Tire Diameter: Using the example of P225/65R17 92H from Fig. 1 in [Tire Basics](#), determine the diameter of the tire.

a. Convert the tire's width to inches

There are 25.4 mm in an inch. Divide the width of the tire (225mm) by 25.4 mm/inch to find the width in inches.

$$\frac{225 \text{ mm}}{25.4 \text{ mm}} = \frac{225 \text{ mm}}{1} \cdot \frac{1 \text{ inch}}{25.4 \text{ mm}} = 8.86 \text{ inches}$$

- b. **Determine sidewall height of the tire.**
 Multiply the width of the tire in inches (8.86 inches) by the aspect ratio (.65 or 65%).

$$8.86 \text{ inches} \cdot 0.65 = 5.76 \text{ inches}$$

- c. **Determine the diameter of the tire.**
 Add the two sidewall heights and the wheel diameter.

$$5.76 \text{ inches} + 5.76 \text{ inches} + 17 \text{ inches} = 28.52 \text{ inches}$$

- d. **Determine the diameter of the other tires on the Vehicle Data Worksheet.**

2. Tire Circumference: The circumference is the distance around the outside edge of a circle. Using P225/65R17 92H and the diameter calculated in #1 determine the circumference of this tire.

$$\pi = 3.141592, C = \text{circumference}, D = \text{diameter}, r = \text{radius}$$

$$C = 2\pi r \text{ or } C = \pi D$$

- a. **Use the formula for the circumference of a circle to find the circumference of the tire.**

$$\pi \cdot 28.53 \text{ inches} = 89.63 \text{ inches}$$

- b. **The Space Shuttle tire has a diameter of 44.9 inches; what is its circumference?**

$$\pi \cdot 44.9 \text{ inches} = 141 \text{ inches}$$

- c. **Determine the circumference of the other tires on the Vehicle Data Worksheet.**

3. Tire Revolutions: Determine the speed and revolutions of the Space Shuttle tires during a landing.

When the first Space Shuttle, Columbia, landed at Edwards Air Force Base on April 14, 1981, it was traveling at 353 km/hr (190 kts/219 mph) and traveled 8,993 feet before coming to a complete stop.

- a. **Determine the tire's speed during touchdown in inches per second.**

Convert miles per hour (mph) into inches per hour.

Multiply miles per hour (219) by the number of feet in a mile (5,280) and the number of inches in a foot (12).

$$\frac{219 \text{ miles}}{1 \text{ hour}} \cdot \frac{5,280 \text{ feet}}{1 \text{ mile}} \cdot \frac{12 \text{ inches}}{1 \text{ foot}} = 13,875,840 \text{ inches/hours}$$

Determine the number of seconds in an hour.

Multiply the number of minutes in an hour (60) by the number of seconds in a minute (60).

$$\frac{60 \text{ minutes}}{1 \text{ hour}} \cdot \frac{60 \text{ seconds}}{1 \text{ minute}} = 3600 \text{ seconds/hour}$$

Convert inches per hour into inches per second.

$$\frac{\frac{13,875,840 \text{ inches}}{1 \text{ hour}}}{\frac{3600 \text{ seconds}}{1 \text{ hour}}} = \frac{13,875,840 \text{ inches}}{1 \text{ hour}} \cdot \frac{1 \text{ hour}}{3600 \text{ seconds}} = 3,854.4 \text{ inches/seconds}$$

- b. Calculate the rotational speed of the wheel in revolutions per minute.

Revolutions per second: Divide the number of inches traveled per second (3,854.4) by the tire's circumference (141 inches) to calculate the number of revolutions the tire made each second.

$$\frac{\frac{3,854.4 \text{ inches}}{1 \text{ seconds}}}{141 \text{ inches}} = \frac{3,854.4 \text{ inches}}{1 \text{ seconds}} \cdot \frac{1}{141 \text{ inches}} = 27.3 \text{ revolutions/second}$$

Revolutions per minute: Multiply the number of revolutions per second the tires made (27.3) by the number of seconds per minute (60).

$$\frac{27.3 \text{ revolutions}}{1 \text{ second}} \cdot \frac{60 \text{ seconds}}{1 \text{ minute}} = 1,638 \text{ revolutions/minute}$$

- c. Calculate the number of revolutions the tires made while traveling the entire stopping distance.

Convert feet into inches.

Multiply the number of feet traveled (8,993) by the number of inches in a foot (12).

$$\frac{8,993 \text{ feet}}{8,993 \text{ feet}} \cdot \frac{12 \text{ inches}}{1 \text{ foot}} = 107,916 \text{ inches}$$

Divide inches traveled (107,916) by the tire's circumference (141 inches) to determine the total number of revolutions the tire made.

$$\frac{107,916 \text{ inches}}{141 \text{ inches}} = 765.36 \text{ revolutions}$$

- d. Determine how many revolutions the other tires from the Vehicle Data Worksheet would make if they traveled 30,000 miles.

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- Connections
- Representation

Activity 5 Tire Air Pressure

GRADES 5-12

Time Requirements: 30 minutes

Materials:

Worksheets

Tire Air Pressure
(Worksheet 4)

Reference Materials

None

Key Terms:

PSI (Pounds
per Square Inch)

Objective:

Students will explore how tire pressure can impact the life of a tire along with its effects on fuel efficiency.

Activity Overview:

Having properly inflated tires is not only necessary for safety but also helps in increasing a vehicle's fuel efficiency. Before beginning with the lessons below, discuss with the students the causes for air pressure loss. In addition to the usual culprits of leaks and punctures, temperature changes can also cause pressure loss especially during the winter months. This is due to the air molecules being closer together at lower temperatures.

Worksheets are included for the students to use when making the calculations below.

Activity:

1. **Tire Life:** The expected mileage of a tire decreases by approximately 1% for every 1% the tire is under-inflated. If your tires were supposed to be inflated to 32 psi, and you drove the last 4,000 miles with your tires inflated to 29 psi, how many miles did you lose from each tire's life?

- a. **Determine the percentage of under-inflation.**

Divide the actual air pressure measurement by the recommended air pressure measurement, then subtract from 100 to give the final answer.

$$\frac{\frac{29 \text{ pounds}}{1 \text{ inch}^2}}{\frac{32 \text{ pounds}}{1 \text{ inch}^2}} = \frac{29 \text{ pounds}}{1 \text{ inch}^2} \cdot \frac{1 \text{ inch}^2}{32 \text{ pounds}} = 90.6\%$$

$$100\% - 90.6\% = 9.4\%$$

- b. **Determine mileage lost due to under inflation.**

Multiply the distance driven (4,000 miles) by the percentage of under inflation (9.4%) to calculate the number of miles lost from the tire's overall life.

$$4000 \text{ miles} \cdot 0.094 = 376 \text{ miles}$$

2. **Convert the numbers of miles lost over the life of the tire in #1 to kilometers.**

(1 mile = 1.61 kilometers)

$$376 \text{ miles} \cdot \frac{1.61 \text{ km}}{1 \text{ mile}} = 605.36 \text{ km}$$

3. **Tire Temperature:** Tires lose 1 psi for every 10°F (5.56°C) drop in temperature. If you travel from Phoenix (90°F) to Cleveland (30°F) and do not adjust your tire pressure, how much air pressure will your tires lose from the temperature change?

- a. **Determine the decrease in temperature.**

$$90^\circ\text{F} - 30^\circ\text{F} = 60 \text{ F}^\circ$$

- b. **To determine how much air pressure is lost, multiply the temperature difference by the ratio of air pressure loss (1 psi per 10F°).**

$$60 \text{ F}^\circ \cdot \frac{1 \text{ psi}}{10 \text{ F}^\circ} = 6 \text{ psi}$$

4. **Gas Mileage:** If your car gets 20 miles/gallon and you drive 1,000 miles with your tires under-inflated by 6 psi, how much extra fuel will you need? For this example, assume that if a tire is under-inflated by 6 psi, it will decrease gas mileage by 3%.

- a. **Determine the amount of fuel needed under ideal conditions.**

Divide mileage driven by miles/gallon.

$$\frac{1000 \text{ miles}}{\frac{20 \text{ miles}}{1 \text{ gallon}}} = \frac{1000 \text{ miles}}{1} \cdot \frac{1 \text{ gallon}}{20 \text{ miles}} = 50 \text{ gallons}$$

- b. **Determine the percentage of inefficiency.**

$$100\% - 3\% = 97\% (0.97)$$

- c. **Determine the number of additional miles traveled due to inefficiency.**

Divide the total mileage potential by the inefficiency percentage.

$$\frac{1000 \text{ miles}}{0.97} = 1030.90 \text{ miles}$$

- d. **Determine how many miles were lost due to under inflation.**

Subtract the mileage achieved (1,000 miles) from the total mileage potential.

$$1030.90 \text{ miles} - 1000 \text{ miles} = 30.90 \text{ miles lost due to under-inflation}$$

- e. Determine the additional number of gallons needed to drive 1000 miles on under-inflated tires.

$$\frac{1030.90 \text{ miles}}{\frac{20 \text{ miles}}{1 \text{ gallon}}} = \frac{1030.90 \text{ miles}}{1} \cdot \frac{1 \text{ gallon}}{20 \text{ miles}} = 51.50 \text{ gallons}$$

51.50 gallons - 50 gallons = 1.5 gallons of extra fuel needed for this trip

5. Assume gas costs \$3.00 per gallon. Determine how much extra you would pay to drive 1,000 miles on the under-inflated tires in #4.

$$1.5 \text{ gallons} \cdot \$3.00 = \$4.50$$

Discussion:

1. **Why do tires lose air pressure?**

The primary causes are punctures, leaks and temperature changes (any quantity of gas contained to a fixed volume will increase in pressure with an increase in temperature, and will decrease in pressure with any decrease in temperature) although rubber tires are porous and will naturally lose air over time).

2. **How can a change in temperature affect your car's fuel efficiency?**

A drop in temperature can cause the tires' air pressure to drop. A decreased air pressure results in decreased fuel efficiency.

3. **Why is it important for a tire to be properly inflated?**

An improperly inflated tire will cause vehicle handling issues which may lead to a crash. It also increases fuel consumption and reduces the life of the tire.

4. **An over-inflated tire causes less area of the tire to contact the road (the contact patch). How would this effect handling?**

An over-inflated tire reduces the amount of rubber in contact with the road at any one time. As such, the tire is not able to grip the road properly which may cause the vehicle to slide while turning.

5. **Research the consequences of under-inflated tires (Fig. 9).**

An under-inflated tire prevents the center of the tire tread from touching the road and instead runs on the tread edges. This greatly reduces the life of the tire and its ability to grip the road. It also causes much more road noise.



Fig. 9 Tire inflation

NATIONAL SCIENCE STANDARDS 5-8

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Reference Materials

Fig. 1 Tire sidewall designation

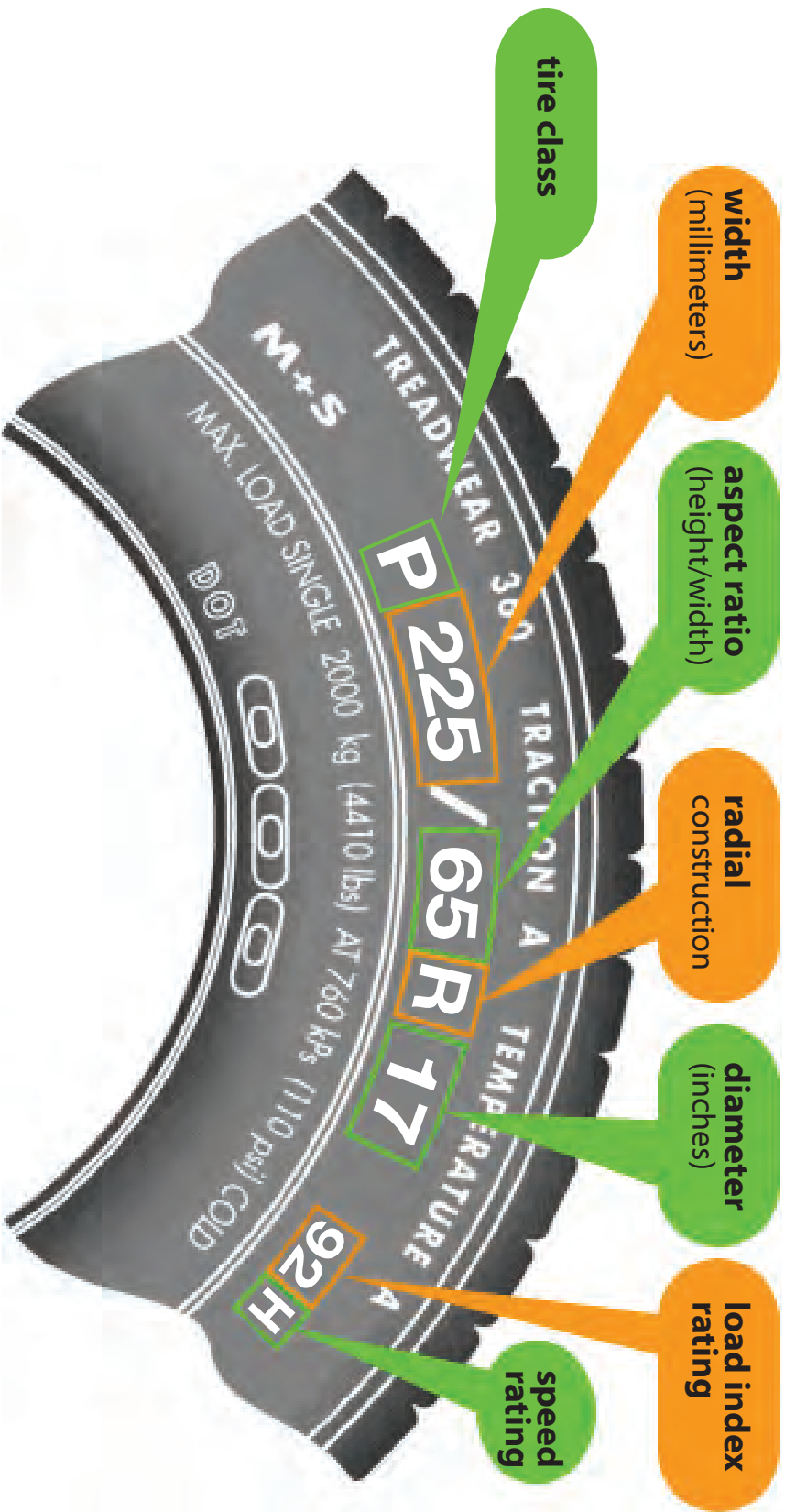


Fig. 2 Tire cross section

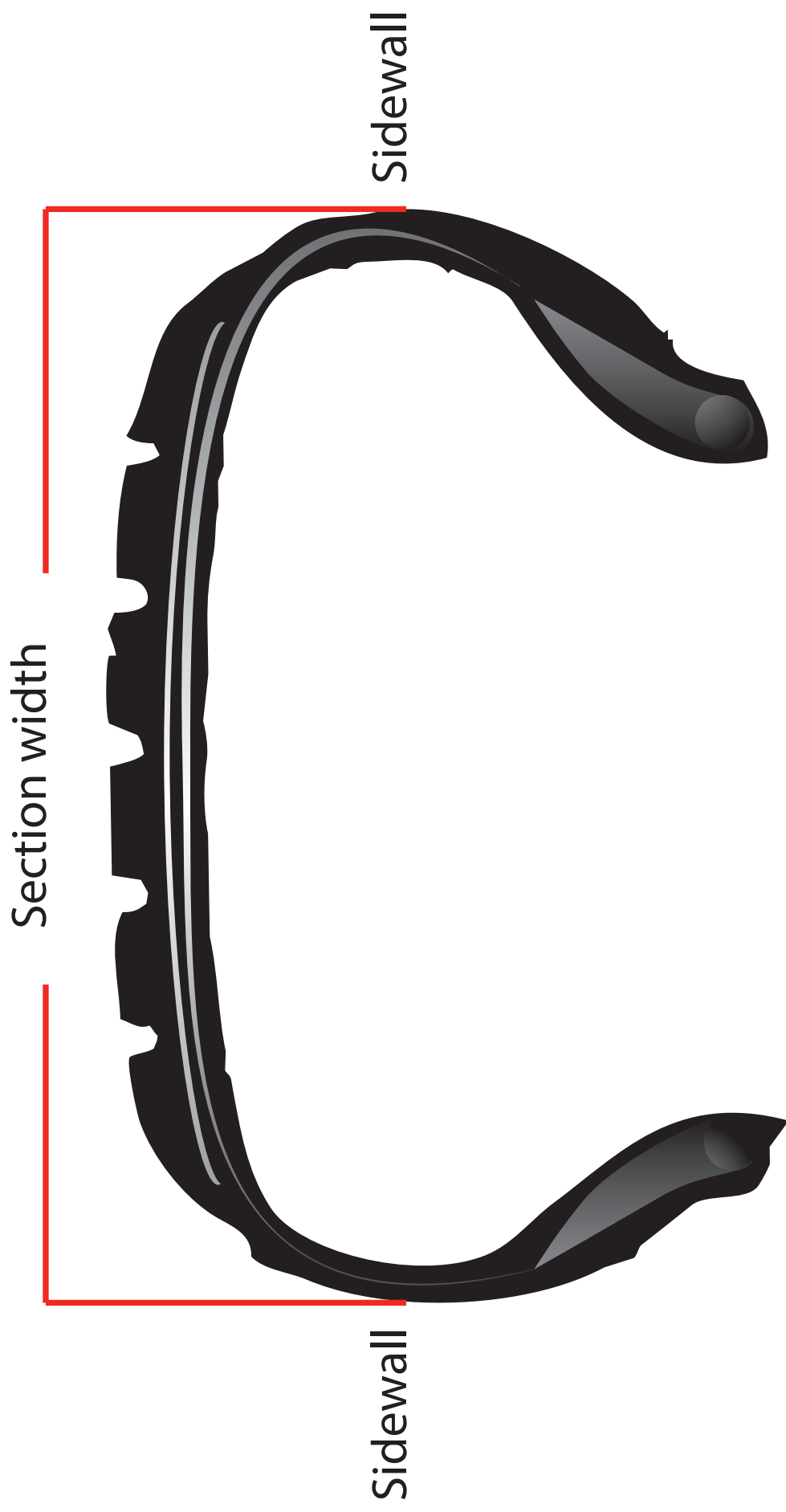
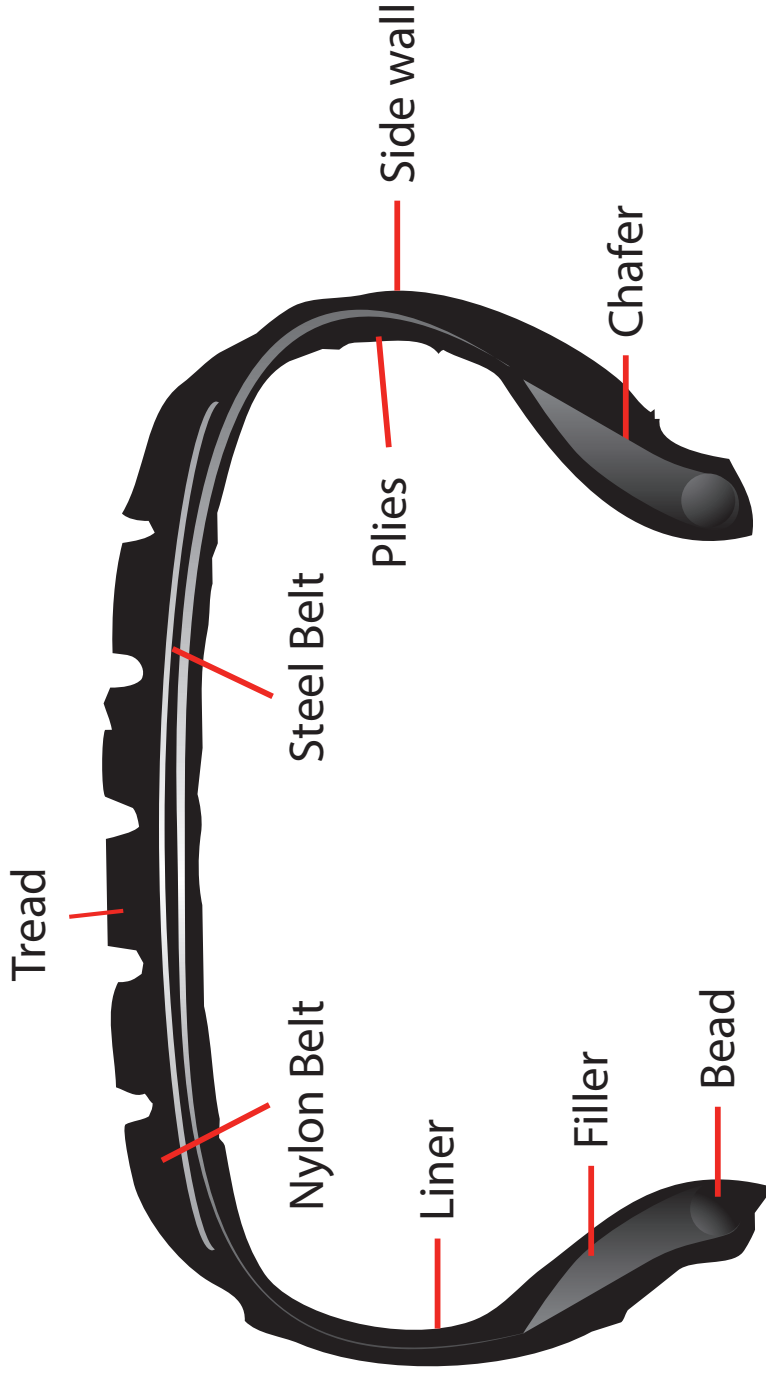


Fig. 3 Tire with cross section



Fig. 4 Parts of a tire



Bead

A high-strength steel wire and rubber that hold the plies and the tire assembly onto the rim of the wheel.

Belt (Nylon and Steel Belts)

Narrow layer of coated tire cord or rubber-encased steel cord located directly under the tire tread that are designed to resist deformation.

Chafer

A layer of rubber compound that is applied to the bead; the chafer provides protection against rim chafing and other external damage.

Filler

A rubber compound that smoothly fits the plies to the bead.

Liner

A thin layer of rubber inside the tire which contains compressed air. Some tires use a tube in place of the liner.

Plies

Layers of fabric cord extending from bead to bead that reinforce the tire.

Sidewall

The part of the tire between the bead and the tread.

Tread

The most recognizable part of the tire. It is composed of wear-resistant rubber compound that provides traction and assists in removing road surface water and contaminants.

Fig. 5 Venn Diagram

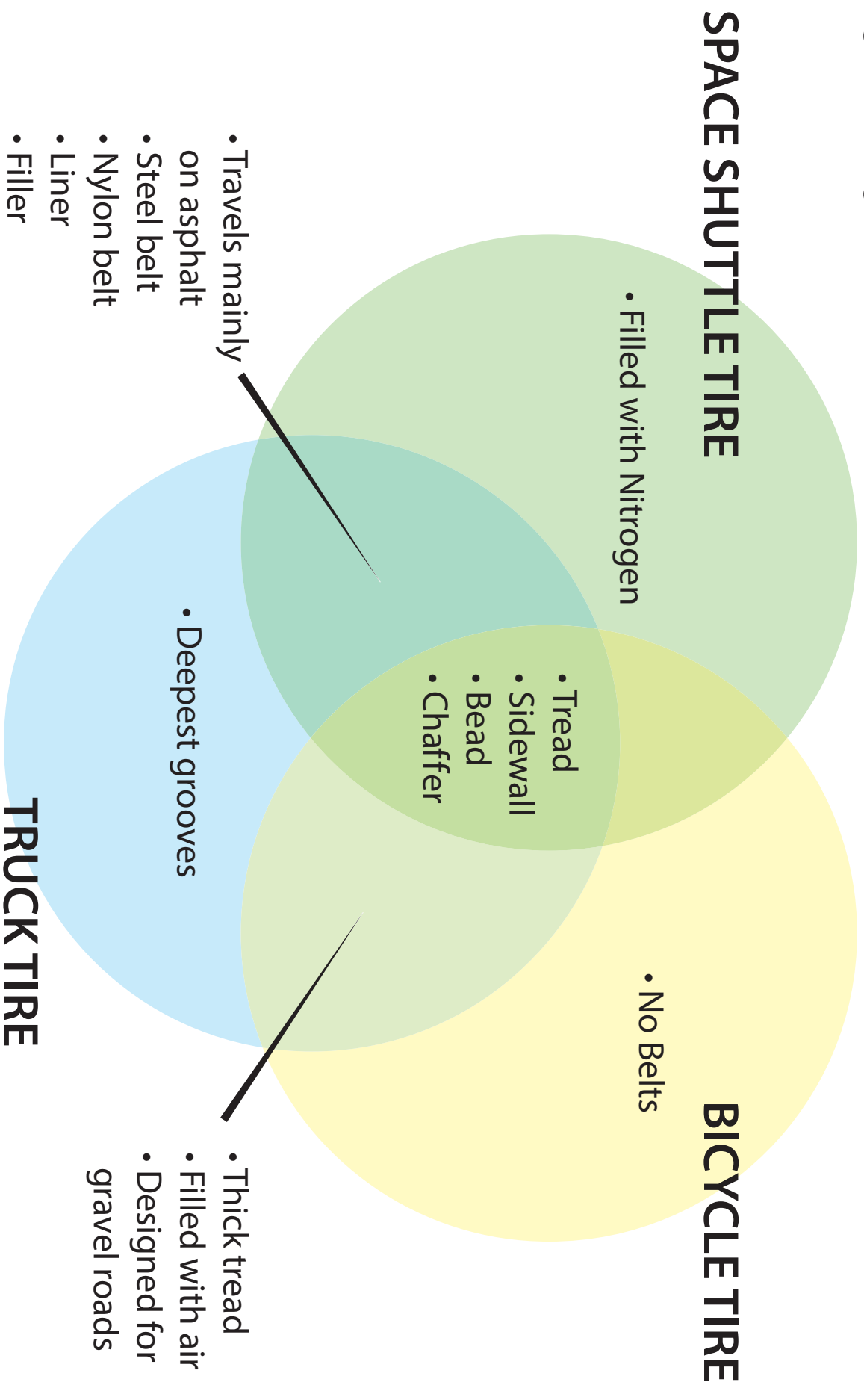


Fig. 6 Penny (head) tread measurement

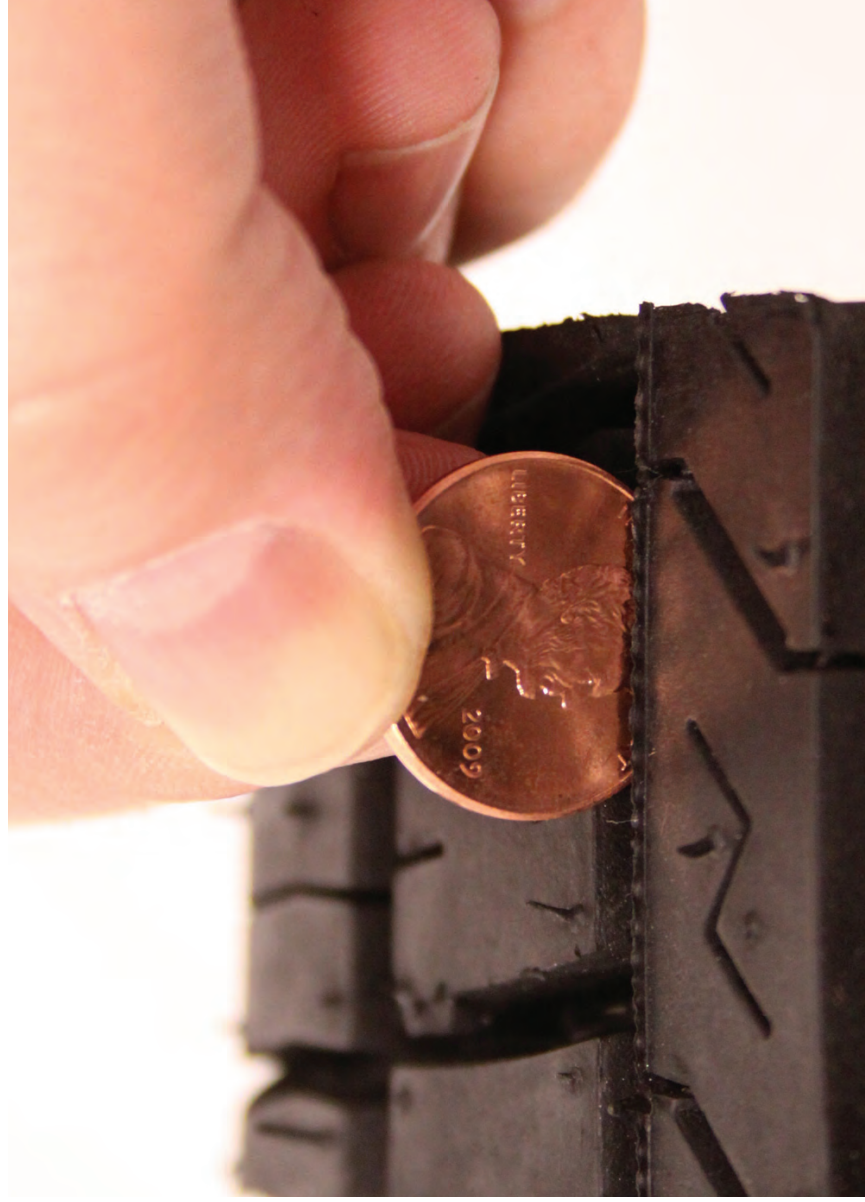


Fig. 7 Quarter (head) tread measurement



more
than
4/32"

Fig. 8 Penny (tails) tread measurement



Fig. 9 Tire inflation

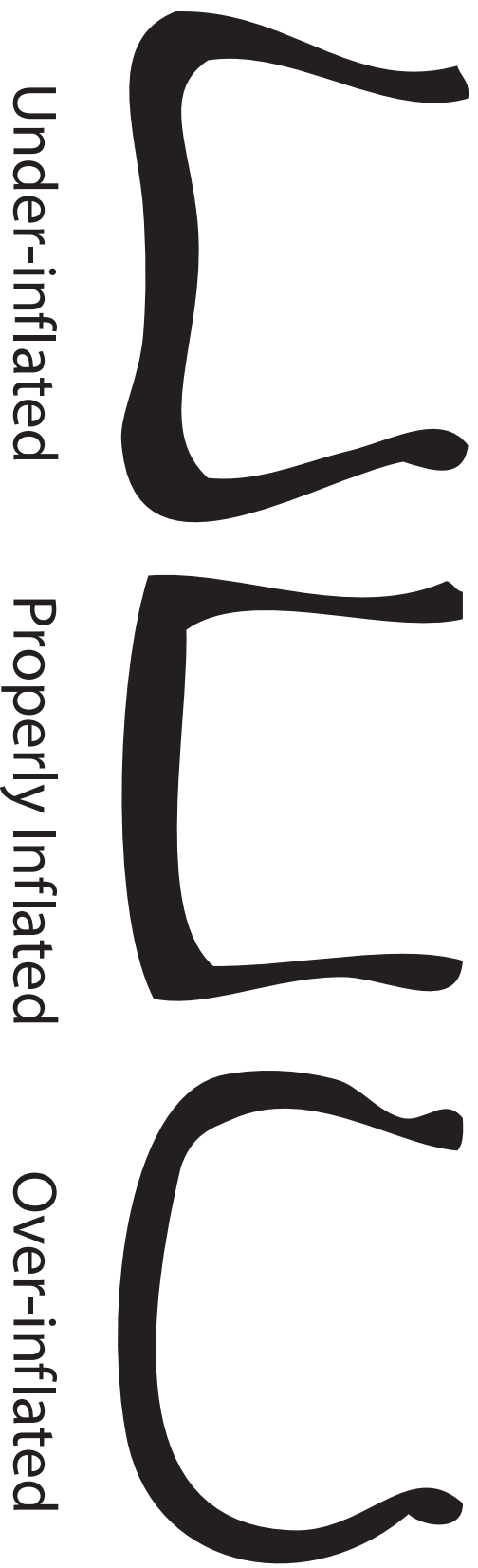


Fig. 10 Load Index Table

The load index refers to the load-carrying capacity of a tire, or how much weight a tire can support. For example, if a tire has a load index of 82, it can support 1,047 pounds at maximum air pressure. Multiply that by four ($4 \times 1,047 = 4,188$ pounds) to get your maximum load-carrying capacity. It is not recommended to install tires with a lower load-carrying capacity than what came on your car from the factory

Load Index	Load (lbs)	Load Index	Load (lbs)	Load Index	Load (lbs)	Load Index	Load (lbs)	Load Index	Load (lbs)	Load Index	Load (lbs)
0	99	25	204	50	419	75	852	100	1764	125	3638
1	102	26	209	51	130	76	882	101	1819	126	3748
2	105	27	215	52	441	77	908	102	1874	127	3858
3	107	28	220	53	454	78	937	103	1929	128	3968
4	110	29	227	54	467	79	963	104	1984	129	4079
5	114	30	234	55	481	80	992	105	2039	130	4189
6	117	31	240	56	494	81	1019	106	2094	131	4289
7	120	32	247	57	507	82	1047	107	2149	132	4409
8	123	33	254	58	520	83	1074	108	2205	133	4541
9	128	34	260	59	536	84	1102	109	2271	134	4674
10	132	35	267	60	551	85	1135	110	2337	135	4806
11	136	36	276	61	567	86	1168	111	2403	136	4938
12	139	37	282	62	584	87	1201	112	2469	137	5071
13	143	38	291	63	600	88	1235	113	2535	138	5203
14	148	39	300	64	617	89	1279	114	2601	139	5357
15	152	40	309	65	639	90	1323	115	2679	140	5512
16	157	41	309	66	639	91	1356	116	2756	141	5677
17	161	42	331	67	677	92	1389	117	2833	142	5842
18	165	43	342	68	694	93	1433	118	2910	143	6008
19	171	44	353	69	716	94	1477	119	2998	144	6173
20	176	45	364	70	739	95	1521	120	3086	145	6393
21	182	46	397	71	761	96	1565	121	3197	146	6614
22	187	47	386	72	783	97	1609	122	3307	147	6779
23	193	48	397	73	805	98	1653	123	3417	148	6844
24	198	49	408	74	827	99	1709	124	3527	149	7385

Glossary

Bead:

A high-strength steel wire and rubber that hold the plies and the tire assembly onto the rim of the wheel.

Belt:

Narrow layer of coated tire cord or rubber-encased steel cord located directly under the tire tread that are designed to resist deformation.

Chafer:

A layer of rubber compound that is applied to the bead; the chafer provides protection against rim chafing and other external damage.

Filler:

A rubber compound that smoothly fits the plies to the bead.

Liner:

A thin layer of rubber inside the tire which contains compressed air. Some tires use a tube in place of the liner.

Load Index:

The maximum load each tire can carry.

PSI:

Pounds per Square Inch; one psi is one pound of force applied to one square inch of surface material.

Plies:

Layers of fabric cord extending from bead to bead that reinforce the tire.

Sidewall:

The part of the tire between the bead and the tread.

Tread:

The most recognizable part of the tire. It is composed of wear-resistant rubber compound that provides traction and assists in removing road surface water and contaminants.

Tire Class:

The group or category to which the tire belongs (ex: P=Passenger, LT=light truck).

Tread Depth:

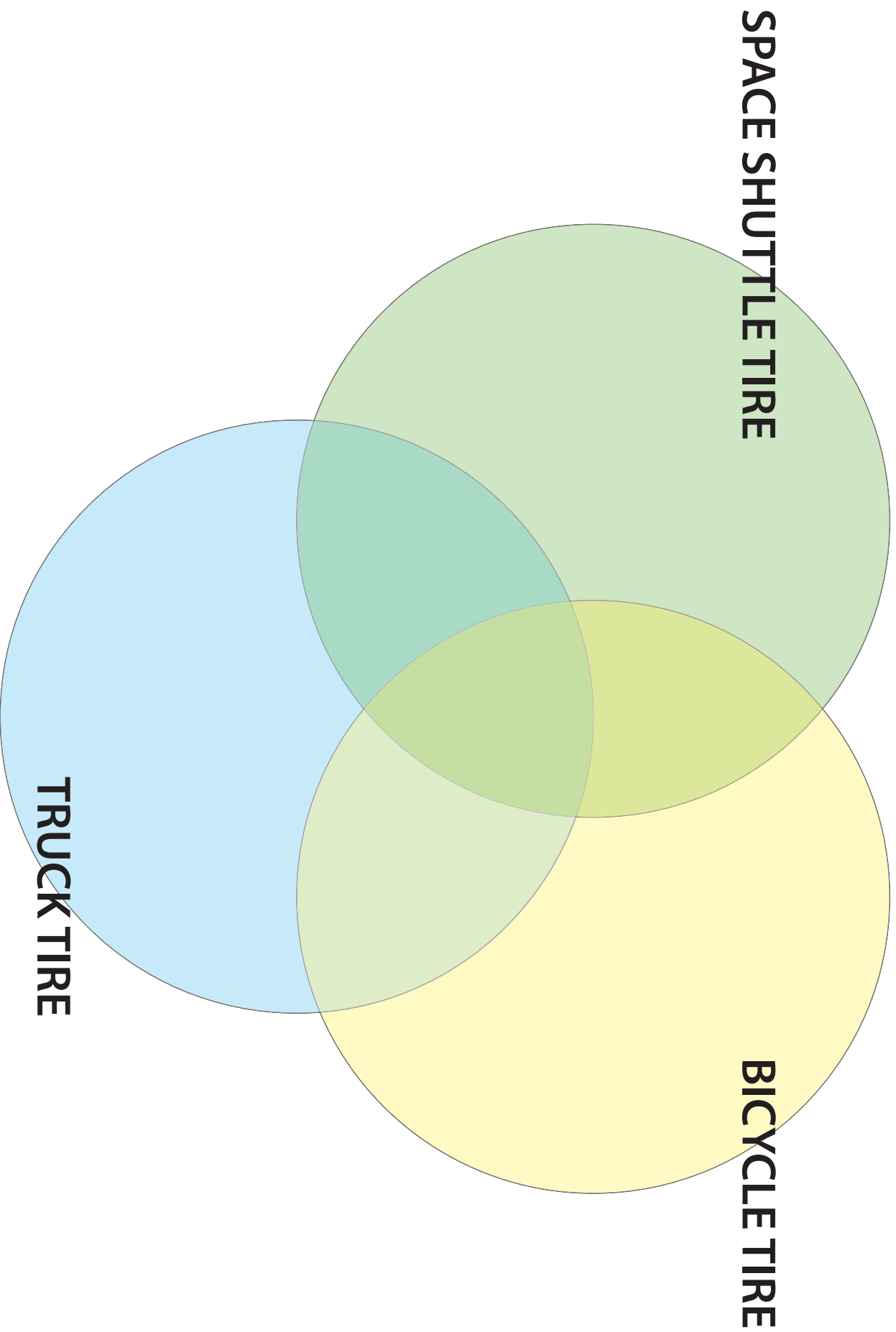
The distance from the top of the tread to the bottom of the grooves.

Tread Life:

The number of miles the tread on a tire is expected to last.



Student Worksheets



MUSEUM IN A BOX

Worksheet 2

Vehicle Data

Vehicle Type	Make	Model	Sidewall Numbers	Diameter	Circumference	Revolutions in 30,000 miles
Car	Dodge	Neon	185/60R15			
Car	Toyota	Matrix	205/55R16			
Truck	Ford	F150	255/65R17			
Truck	Nissan	Titan	285/70/R17			
SUV	Honda	CRV	205/70R15			

FORMULAS

Tire Circumference:

$$C = 2\pi r \text{ or } C = \pi D$$

$$\% \text{ Under Inflation} = 100\% - \frac{\text{Actual Air Pressure}}{\text{Recommended Air Pressure}}$$

$$\text{Revolutions} = \frac{\text{Distance Traveled}}{\text{Circumference}}$$

CONVERSIONS

$$1 \text{ inch} = 25.4 \text{ mm}$$

$$1 \text{ mile} = 1.61 \text{ km}$$

$$5,280 \text{ ft} = 1 \text{ mile}$$

$$12 \text{ inches} = 1 \text{ foot}$$

$$\pi = 3.141592$$

Worksheet 3 Tire Math

1. Tire Diameter: Using the example of P225/65R17 92H from Figure 1 in **Tire Basics**, determine the diameter of the tire.

- a. **Convert the tire's width to inches**

There are 25.4 mm in an inch. Divide the width of the tire by 25.4 mm/inch to find the width in inches .

$$\frac{225 \text{ mm}}{25.4 \text{ mm}} = \frac{225 \text{ mm}}{1} \cdot \frac{1 \text{ inch}}{25.4 \text{ mm}} = 8.86 \text{ inches}$$

- b. **Determine sidewall height of the tire.**

Multiply the width of the tire in inches by the aspect ratio (.65 or 65%).

$$8.86 \text{ inches} \cdot 0.65 = 5.76 \text{ inches}$$

- c. **Determine the diameter of the tire.**

Add the two sidewall heights and the wheel diameter.

$$5.76 \text{ inches} + 5.76 \text{ inches} + 17 \text{ inches} = 28.52 \text{ inches}$$

- d. **Determine the diameter of the other tires on the Vehicle Data Worksheet.**

Worksheet 3 Continued

2. Tire Circumference: The circumference is the distance around the outside edge of a circle. Using P225/65R17 92H and the diameter calculated in #1 determine the circumference of this tire.

$\pi = \pi = 3.141592$, C = circumference, D = diameter, r = radius

$$C = 2\pi r \text{ or } C = \pi D$$

- a. Use the formula for the circumference of a circle to find the circumference of the tire.

- b. The Space Shuttle tire has a diameter of 44.9 inches; what is its circumference?

- c. Determine the circumference of the other tires on the Vehicle Data Worksheet.

Worksheet 3 Continued

3. Tire Revolutions: Determine the speed and revolutions of the Space Shuttle tires during a landing.

When the first Space Shuttle, Columbia, landed at Edwards Air Force Base on April 14, 1981, it was traveling at 353 km/hr (190 kts/219 mph) and traveled 8,993 feet before coming to a complete stop.

- a. **Determine the tire's speed during touchdown in inches per second.**

Convert miles per hour (mph) into inches per hour.

$$\frac{219 \text{ miles}}{1 \text{ hour}} \cdot \frac{5,280 \text{ feet}}{1 \text{ mile}} \cdot \frac{12 \text{ inches}}{1 \text{ foot}} = 13,875,840 \text{ inches/hours}$$

Determine the number of seconds in an hour.

$$\frac{60 \text{ minutes}}{1 \text{ hour}} \cdot \frac{60 \text{ seconds}}{1 \text{ minute}} = 3,600 \text{ seconds/hour}$$

Convert inches per hour into inches per second.

$$\frac{\text{inches}}{1 \text{ hour}} = \frac{\text{inches}}{1 \text{ hour}} \cdot \frac{1 \text{ hour}}{\text{seconds}} = \text{inches/seconds}$$

- b. **Calculate the rotational speed of the wheel in revolutions per minute.**

Revolutions per second: Divide the number of inches traveled per second by the tire's circumference to calculate the number of revolutions the tire made each second.

$$\frac{3,854.4 \text{ inches}}{1 \text{ seconds}} = \frac{3,854.4 \text{ inches}}{1 \text{ seconds}} \cdot \frac{1}{141 \text{ inches}} = 27.3 \text{ revolutions/second}$$

Revolutions per minute: Multiply the number of revolutions per second the tires made by the number of seconds per minute (60).

$$\frac{27.3 \text{ revolutions}}{1 \text{ second}} \cdot \frac{60 \text{ seconds}}{1 \text{ minute}} = 1,638 \text{ revolutions/minute}$$

- c. **Calculate the number of revolutions the tires made while traveling the entire stopping distance.**

Convert feet into inches by multiplying the number of feet traveled by the number of inches in a foot.

$$\frac{8,993 \text{ feet}}{8,993 \text{ feet}} \cdot \frac{12 \text{ inches}}{1 \text{ foot}} = 107,916 \text{ inches}$$

Worksheet 3 Continued

Divide inches traveled by the tire's circumference to determine the total number of revolutions the tire made.

- d. Determine how many revolutions the other tires from the Vehicle Data Worksheet would make if they traveled 30,000 miles.

Worksheet 4 Tire Air Pressure

1. Tire Life: The expected mileage of a tire decreases by approximately 1% for every 1% the tire is under-inflated. If your tires were supposed to be inflated to 32 psi, and you drove the last 4,000 miles with your tires inflated to 29 psi, how many miles did you lose from each tire's life?

- a. Determine the percentage of under-inflation.

$$\frac{\frac{29 \text{ pounds}}{1 \text{ inch}^2}}{\frac{32 \text{ pounds}}{1 \text{ inch}^2}} = \frac{29 \text{ pounds}}{1 \text{ inch}^2} \cdot \frac{1 \text{ inch}^2}{32 \text{ pounds}} = 90.6\%$$

$$100\% - 90.6\% = 9.4\%$$

- b. Determine mileage lost due to under inflation.

2. Convert the numbers of miles lost over the life of the tire in #1 to kilometers. (1 mile = 1.61 kilometers)

3. Tire Temperature: Tires lose 1 psi for every 10° F (5.56° C) drop in temperature. If you travel from Phoenix (90° F) to Cleveland (30° F) and do not adjust your tire pressure, how much air pressure will your tires lose from the temperature change?

- a. Determine the decrease in temperature.

- b. To determine how much air pressure is lost, multiply the temperature difference by the ratio of air pressure loss (1 psi per 10 F°).

$$60 \text{ F}^\circ \cdot \frac{1 \text{ psi}}{10 \text{ F}^\circ} = 6 \text{ psi}$$

Worksheet 4 Continued

4. Gas Mileage: If your car gets 20 miles/gallon and you drive 1,000 miles with your tires under-inflated by 6 psi, how much extra fuel will you need? For this example, assume that if a tire is under-inflated by 6 psi, it will decrease gas mileage by 3%.

- a. Determine the amount of fuel needed under ideal conditions.

$$\frac{\boxed{} \text{ miles}}{\boxed{} \text{ miles}} = \frac{\boxed{} \text{ miles}}{1} \cdot \frac{1 \text{ gallon}}{\boxed{} \text{ miles}} = \boxed{}$$

- b. Determine the percentage of inefficiency.

- c. Determine the number of additional miles travelled due to inefficiency.

Divide the total mileage potential by the inefficiency percentage.

$$\frac{\boxed{} \text{ miles}}{0.97} = \boxed{} \text{ miles}$$

- d. Determine how many miles were lost due to under-inflation.

- e. Determine the additional number of gallons needed to drive 1000 miles on under-inflated tires.

$$\frac{\boxed{} \text{ miles}}{\frac{20 \text{ miles}}{1 \text{ gallon}}} = \frac{\boxed{} \text{ miles}}{1} \cdot \frac{1 \text{ gallon}}{20 \text{ miles}} = \boxed{} \text{ gallons}$$

$$1.50 \text{ gallons} - .50 \text{ gallons} = 1.5 \text{ gallons of extra fuel needed for this trip}$$

5. Assume gas costs \$3.00 per gallon. Determine how much extra you would pay to drive 1,000 miles on the under-inflated tires in #4.



Images

Img. 1 Tire Cross Sections



Img. 2 Tire Sidewall



Img. 3 Installing a main shuttle tire



(Photo courtesy of NASA – www.nasaimages.org)

Img. 4 The Space Shuttle at lift-off



MUSEUM IN A BOX - IMAGES

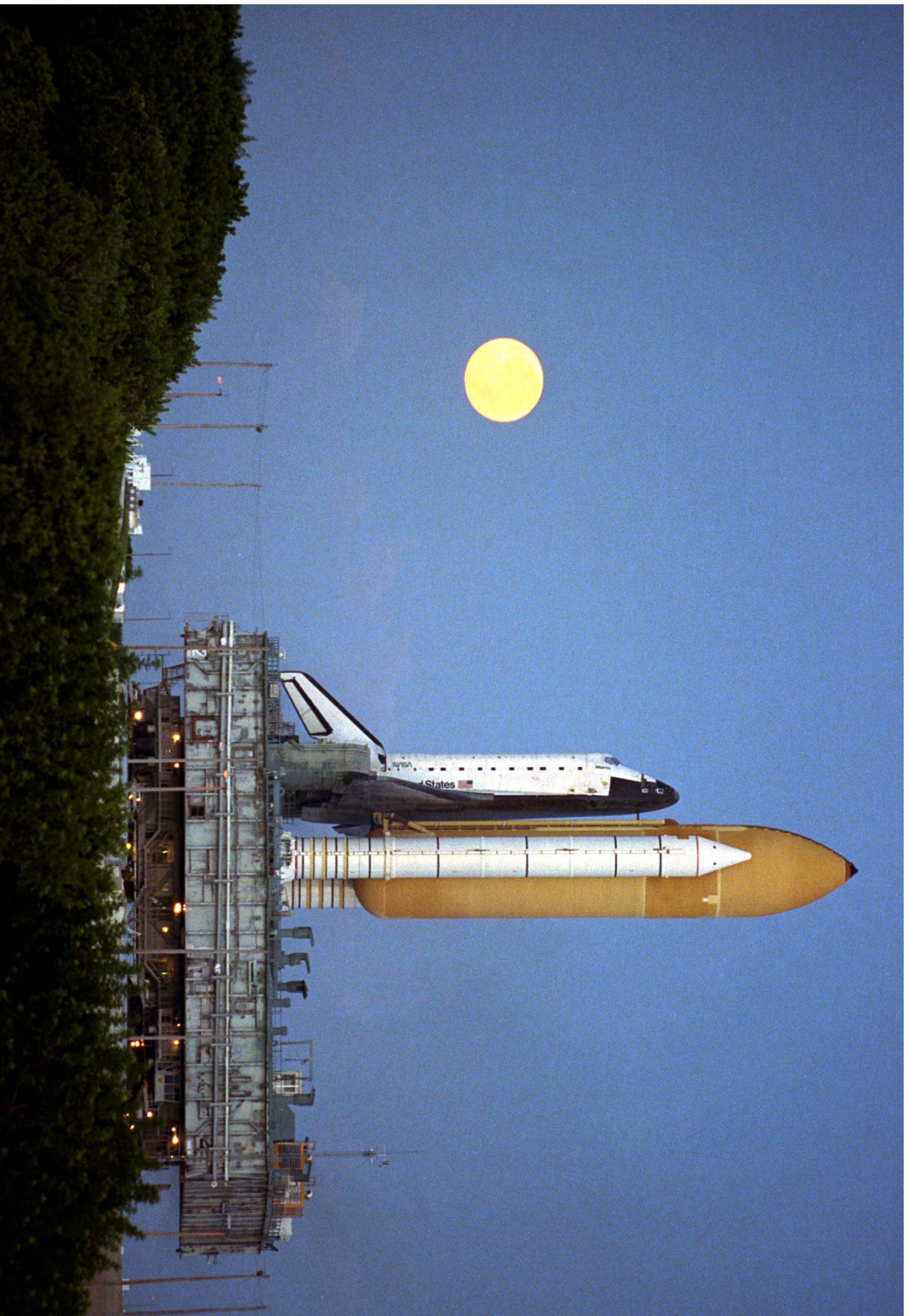
(Photo courtesy of NASA - www.nasaimages.org)

Img. 5 The Space Shuttle en-route to the launch pad



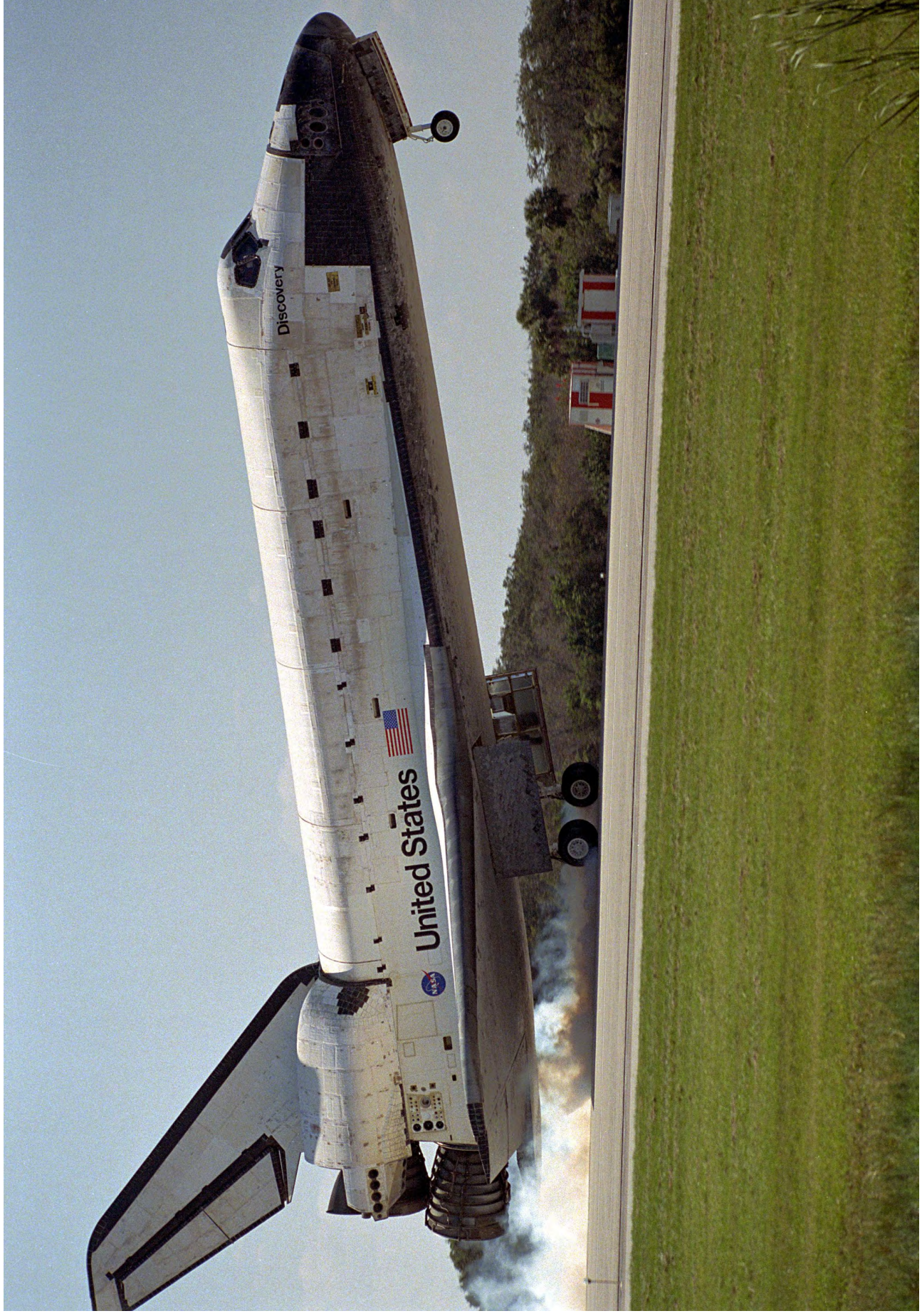
(Photo courtesy of NASA – www.nasaimages.org)

Img. 6 The Space Shuttle on the launch pad



(Photo courtesy of NASA – www.nasaimages.org)

Img. 7 The Shuttle Discovery landing at Kennedy Space Center



(Photo courtesy of NASA - www.nasaimages.org)

Img. 8 The Shuttle Endeavour landing at Kennedy Space Center



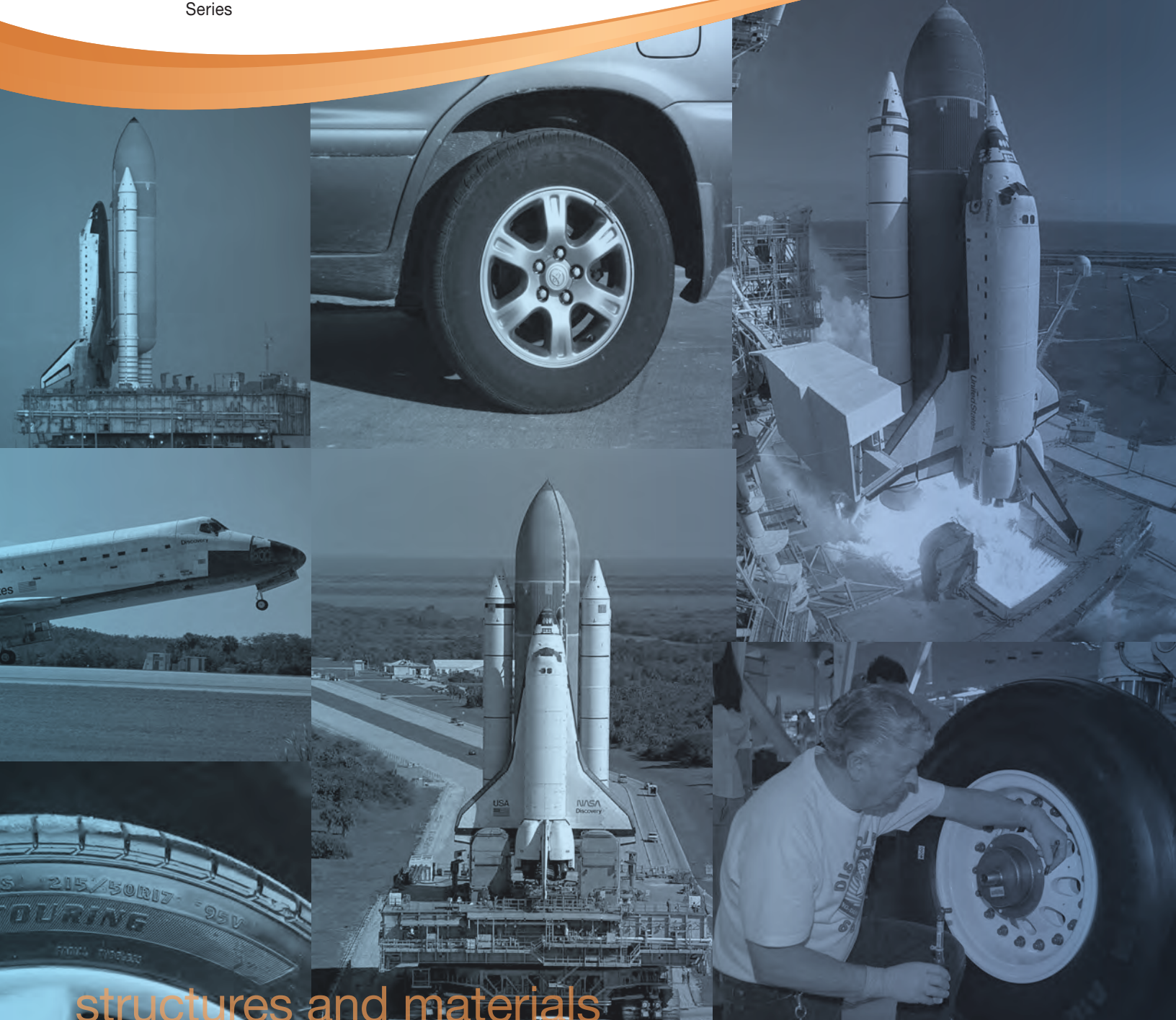
(Photo courtesy of NASA – www.nasaimages.org)

Img. 9 The Shuttle Columbia landing at Edwards Air Force Base

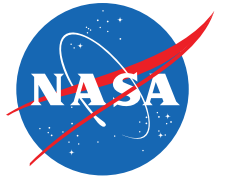


(Photo courtesy of NASA - www.nasaimages.org)

Aeronautics
Research
Mission
Directorate



structures and materials



GRADES **K-12**

Supplemental Space Shuttle Tire Lessons



structures and materials

Aeronautics
Research
Mission
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Supplemental Space Shuttle Tire Math Activity 1

Spare Parts for the Space Shuttle

GRADES

K-12

Background

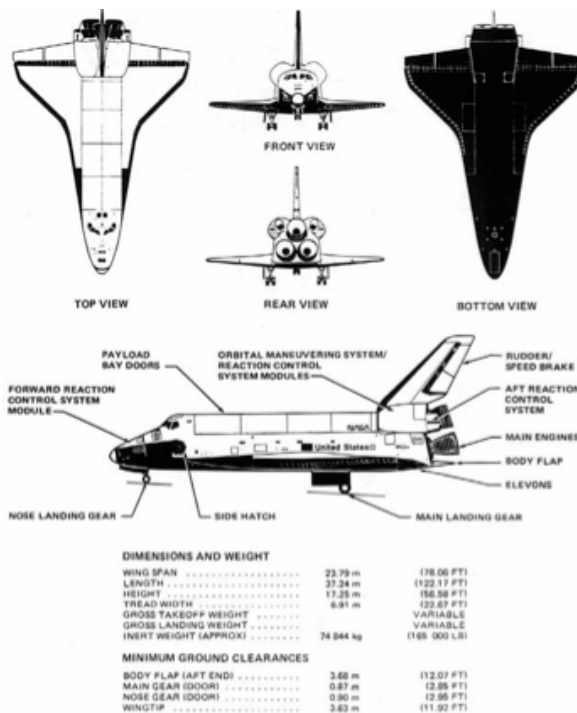
NASA's Space Shuttle has six tires used for landing. The four main landing gear tires are mounted in pairs on the rear wheel assemblies. These wheel assemblies are attached to the two main landing struts at the rear of the Shuttle. Each of the four main landing gear tires is used for one flight. The front two tires, again mounted as a pair, are attached to the nose landing gear strut and are used for two Shuttle landings. The four rear main landing gear tires hit the ground first, which causes them to wear out sooner. Because the main tires are on the ground longer than the front landing gear tires and because they take the brunt of the mass and force of the Space Shuttle landing (the Shuttle lands at speeds of up to 250 miles per hour [mph]), main and front tires have different needs. While both types of tires have very little tread to reduce the mass of the tires, these tires are also different sizes, since a larger tire is not needed in the front of the Shuttle.

This is similar to tire-size-ratio needs for other aircraft as well.



(photo from <http://www.nasaimages.org>)

(photo from <http://www.history.nasa.gov/SP-4225/diagrams/shuttle/shuttle-diagram-1.htm>)



Shuttle Tire Facts

Surprisingly, a Space Shuttle tire is not much larger than a truck tire, but a main landing gear tire can carry three times the load of a Boeing 747 tire or the entire starting lineup of a NASCAR race—40 race cars—all hitting the pavement at up to 250 miles per hour.

- Four main landing gear tires: 44.5 × 16.0-21, 34 ply, rated at 263 mph.
- Two nose landing gear tires: 32 × 8.8, 20 ply, rated at 250 mph.
- Space Shuttle tires are filled with nitrogen (as are most aircraft tires) due to its stability at different altitudes and temperatures. Due to extremely heavy loads, these bias ply tires are inflated to 340 pounds per square inch (psi) for the main landing gear and 300 psi for the nose landing gear.

- Shuttle tires go from in excess of -40 degrees Fahrenheit (-40 degrees Celsius) in space to $+130$ degrees Fahrenheit (54.4 degrees Celsius) on landing in a matter of minutes.
- Weight: Since weight is of extreme importance, the tires are made with a minimum amount of tread to conserve weight, allowing for larger payloads. A few pounds may not seem to make much difference, but when you add up all of the ways to decrease weight throughout the Shuttle, it can have a significant impact.

Size/Dimension	44.5 × 16.0-21 (main landing gear)
Outside Diameter	44.9 inches
Section Width	16 inches
Wheel Rim Diameter	21 inches
Approximate Weight	205 pounds (on Earth)
Max. Inflation Pressure	340 psi
Max. Operation Load	142,000 pounds (on Earth)
Max. Speed	259 mph
Load Per Pound of Tire	695 pounds

While most of us have focused on watching the Space Shuttle launch and land, a group of scientists and engineers have been responsible for determining how many spare parts had to be available to keep Shuttle missions running smoothly. In all, they had to think about 250,000 repairable and nonrepairable parts. This included making sure there were enough tires for each Shuttle flight.

Logistics engineers Seth Berkowitz, Randy Greeson, and Marcia Groh-Hammond at NASA's Kennedy Space Center explain a bit about their jobs:

There are certain things in life that we take for granted. For instance, we never give much thought to it, but we keep spares of basic household products. Most households contain spare paper towels, toilet paper, soap, shampoo, etc. How many and what types of items we buy to support our house is usually automatically calculated in our heads while going through the supermarket. We consider how often we consume an item, and how much it costs. Generally, the more expensive the item is the fewer spares we keep on hand. We are concerned about our budget. We know in most cases we can replenish that item when we need it; it is simply a matter of going to the store to pick it up. For instance, you are making a cake and run out of eggs. You go to the store and buy what you need. There is no waiting for the hen to lay the eggs and the eggs to be delivered from the farm. It's a short delay, a slight inconvenience.

Now imagine not being able to go to the corner grocery store and pick up what you need. On top of that, you have to wait weeks, months, maybe longer, once you decide you need it. The items you are buying cost \$1,000, \$10,000, \$100,000, or more than \$1,000,000. Deciding what you need and when to buy it is not as automatic as buying ordinary household items. This is the dilemma that faces the Space Shuttle Logistics Office.

One of the keys to successfully launching Shuttles on-time and within budget involves hardware availability. The availability of the hardware must not impose a constraint on the processing of the Shuttles. The Nation cannot afford to have an expensive national resource such as the Shuttle waiting on the launch pad for a part. The methods used to determine spare requirements for the Shuttle must be effective and efficient in terms of adequately identifying the required spares without incurring excessive program costs.

Procedure

In the following math problems, you are going to take on the role of a logistics engineer at NASA's Kennedy Space Center in Florida. Your job will be to make sure that you have enough Space Shuttle tires available for Shuttle flights. You should also plan on having an extra set of tires on hand in case of unexpected events, such as an additional flight and/or problems with a tire(s). Keep in mind that each tire costs over \$5,560, so you do not want to have too many tires. However, since it takes 9 months to have tires delivered from the time you order them from Michelin, a mistake of having too few tires would delay a Shuttle flight at least 9 months.

Tire information

Total number of tires per Space Shuttle: 6

Main landing gear tires per Shuttle: 4

Usage limit: 1 flight

Front landing gear tires per Shuttle: 2

Usage limit: 2 flights

Lead time on tire order: 9 months

Cost, per tire: \$5,560

Problem 1: How Many Tires?

In 2009, there are 5 planned Space Shuttle launches. Beginning in 2008, as logistics engineers, you have to place an order for Shuttle tires for 2009. However, you also have to account for existing, usable tires. The final Shuttle flight of 2008 used a completely new set of tires. Using the information above, calculate the number of tires needed for Space Shuttle flights in 2009. In addition, make sure to order one complete set of extra tires in case they are needed. Next, calculate the cost for the tires. Finally, decide when your order needs to be placed in order to ensure that tires are available for a February 2009 launch. (Show your work.)

Order Form:	Number of Tires	Cost of Tires	Total Cost
Existing inventory of usable main landing gear tires			
Main landing gear tires needed			
Spare main landing gear tires needed			
Existing inventory of usable front landing gear tires			
Front landing gear tires needed			
Spare front landing gear tires needed			
		TOTAL ORDER COST:	
		Last day to place order:	

Problem 2: Changing Your Order

NASA needs to get more parts to the International Space Station and needs to capture a failing satellite, so they add two more flights to their 2009 schedule. If they notify you of this change before you place your original order, what is your edited order? (Show your work.)

Order Form:	Number of Tires	Cost of Tires	Total Cost
Existing inventory of usable main landing gear tires			
Main landing gear tires needed			
Spare main landing gear tires needed			
Existing inventory of usable front landing gear tires			
Front landing gear tires needed			
Spare front landing gear tires needed			
		TOTAL ORDER COST:	
		Last day to place order:	

Problem 3: Changing Your Order, Part Two

In January of 2009, long after you placed your updated order, one front landing gear tire was punctured during preparation for a Shuttle launch. In addition, there is a need for an additional repair mission in May of 2009. (*The expanded 2009 Shuttle launch schedule is as follows: February 4, March 15, April 20, May 11, July 15, August 28, October 1, and November 16.) Based on the number of tires available, can this be done? Explain your answer.

*The actual launch schedule for 2009 included the following dates: March 15, May 11, July 15, August 28, and November 16. The additional dates were added for this activity only.

Adapted from "LTA 1: Kennedy Space Center: Spare Parts for the Space Shuttle," NASA-AMATYC-NSF Project Coalition, <http://cctc.commnet.edu/lta/lta1/index.pdf>.

Supplemental Space Shuttle Tire Math Activity 1

Spare Parts for the Space Shuttle

GRADES **5-12** Answer Key

Procedure

In the following math problems, you are going to take on the role of a logistics engineer at NASA's Kennedy Space Center in Florida. Your job will be to make sure that you have enough Space Shuttle tires available for Shuttle flights. You should also plan on having an extra set of tires on hand in case of unexpected events, such as an additional flight and/or problems with a tire(s). Keep in mind that each tire costs over \$5,560, so you do not want to have too many tires. However, since it takes 9 months to have tires delivered from the time you order them from Michelin, a mistake of having too few tires would delay a Shuttle flight at least 9 months.

Tire information

Total number of tires per Space Shuttle: 6

Main landing gear tires per Shuttle: 4

Usage limit: 1 flight

Front landing gear tires per Shuttle: 2

Usage limit: 2 flights

Lead time on tire order: 9 months

Cost, per tire: \$5,560

Problem 1: How Many Tires?

In 2009, there are 5 planned Space Shuttle launches. Beginning in 2008, as logistics engineers, you have to place an order for Shuttle tires for 2009. However, you also have to account for existing, usable tires. The final Shuttle flight of 2008 used a completely new set of tires. Using the information above, calculate the number of tires needed for Space Shuttle flights in 2009. In addition, make sure to order one complete set of extra tires in case they are needed. Next, calculate the cost for the tires. Finally, decide when your order needs to be placed in order to ensure that tires are available for a February 2009 launch. (Show your work.)

Order Form:	Number of Tires	Cost of Tires	Total Cost
Existing inventory of usable main landing gear tires	0	n/a	n/a
Main landing gear tires needed	20 (5 sets of 4 tires)	\$5,560	\$111,200
Spare main landing gear tires needed	4 (one set)	\$5,560	\$22,240
Existing inventory of usable front landing gear tires	2 (one more use)	\$5,560	n/a
Front landing gear tires needed	4 (2 sets)	\$5,560	\$22,240
Spare front landing gear tires needed	2 (one set)	\$5,560	\$11,120
		TOTAL ORDER COST:	\$166,800
		Last day to place order:	April 30, 2008

Problem 2: Changing Your Order

NASA needs to get more parts to the International Space Station and needs to capture a failing satellite, so they add two more flights to their 2009 schedule. If they notify you of this change before you place your original order, what is your edited order? (Show your work.)

Order Form:	Number of Tires	Cost of Tires	Total Cost
Existing inventory of usable main landing gear tires	0	n/a	n/a
Main landing gear tires needed	28 (7 sets)	\$5,560	\$155,680
Spare main landing gear tires needed	4 (one set)	\$5,560	\$22,240
Existing inventory of usable front landing gear tires	2 (one more use)	\$5,560	n/a
Front landing gear tires needed	6 (3 sets)	\$5,560	\$33,360
Spare front landing gear tires needed	2 (one set)	\$5,560	\$11,120
		TOTAL ORDER COST:	\$222,400
		Last day to place order:	April 30, 2008

Problem 3: Changing Your Order, Part Two

In January of 2009, long after you placed your updated order, one front landing gear tire was punctured during preparation for a Shuttle launch. In addition, there is a need for an additional repair mission in May of 2009. (*The expanded 2009 Shuttle launch schedule is as follows: February 4, March 15, April 20, May 11, July 15, August 28, October 1, and November 16.) Based on the number of tires available, can this be done? Explain your answer.

Answers will vary, but this could be done if the spare tires were used and there were no more tire punctures. New tires would have to be ordered in January 2009 to replace the spare tires and the punctured tire, as well as for the additional mission. (The repair mission for April 20 would use a set of tires scheduled to be used later in the year. As long as replacement tires arrived before the November 16 launch, the addition would be feasible.)

*The actual launch schedule for 2009 included the following dates: March 15, May 11, July 15, August 28, and November 16. The additional dates were added for this activity only.

Adapted from "LTA 1: Kennedy Space Center: Spare Parts for the Space Shuttle," NASA-AMATYC-NSF Project Coalition, <http://cctc.commnet.edu/lta/lta1/index.pdf>.

Supplemental Space Shuttle Tire Math Activity 2

Space Shuttle Tire Lessons

GRADES

5-12

Background

Surprisingly, a Space Shuttle tire is not much larger than a truck tire, but a main landing gear tire can carry three times the load of a Boeing 747 tire or the entire starting lineup of a NASCAR race—40 race cars—all hitting the pavement at up to 250 miles per hour. So how can a Shuttle tire accomplish that? The following math problems may help you compare the Space Shuttle tire to other tires.

Surface Area and Ratios

In this math problem, you are going to calculate the surface area of the sidewall of a bicycle tire, a car tire, and a Space Shuttle tire. If you have the tire sections from the “Museum in a Box” kit, you can try to make calculations based on your own measurements from those tire sections. However, exact measurements are difficult because the tire sections are small and the surfaces are curved. To help simplify measurements, the chart below lists a standard set of measurements that can be used (making the assumption, for this problem, that the tire sidewall surfaces are flat). Notice that certain measurements are given to you in millimeters (mm), some in centimeters (cm), and others in inches (in). Unfortunately, when tire specifications are given, both millimeters and inches are used, which means you will have to convert these numbers for your needs. If you need help determining diameters based on the tire specifications listed, refer to the main “Space Shuttle Tire” lessons, where a “Tire Basics” section can be found.

Tire Type	O.D. (outside diameter, in inches)	I.D. (inside diameter, in inches)	Inside Radius (in inches) $r = D/2$	Total Radius (inside radius + sidewall height, in inches)	Total Tire Area (in inches ²)	Inside Tire Area (in inches ²)	Tire Sidewall Area (in inches ²)
Bicycle (26 × 13/8)							
Car (P185/70R14)							
Space Shuttle (main landing gear tire: 44.5 × 16.0-21)	44.9 inches	21 inches					

Hint: to calculate sidewall area, you are basically calculating the area of a donut (subtracting the area inside the circle from the outer area of the circle).

Diameter: $D = 2r$ Radius: $r = D/2$

Area of a circle: $A = \pi r^2$

To convert from inches to millimeters: multiply the number of inches by 25.4

To convert from millimeters to inches: divide the number of millimeters by 25.4

Step one: Find the inside and outside diameters of each tire (in inches). For a bicycle tire, the first number listed on the tire specifications is the outside tire diameter (in inches). For a car tire, the number after the tire construction (in this case, the “R” refers to a *radial* tire) is the inside diameter (in inches). The Space Shuttle tire numbering is slightly different, so it is given to you on the chart (in inches).

The second piece of information you need for this problem is the *aspect ratio*, or the height of the sidewall as a percentage of the *section width*. For a car tire, the aspect ratio is the number found after the “/” (the number 70 in this case). The section width is the first number after the tire class designation (the “P” for this tire, which refers to “passenger car” class). Section width is given in mm. The sidewall height for this tire is 70 percent of the section width. For a bike tire, the sidewall height (given in inches), is the second number in the tire specifications (for the bike tire above, the sidewall height is $1\frac{3}{8}$ ”).

Show your work, including a labeled drawing that shows the numbers you are using for each component of the problem.

Step two: Find the areas of the circle inside each tire and the total area of each tire. Refer to the formulas above for help in calculating the areas of each circle. Give measurements in inches². Again, show all work.

Step three: Find the area of each tire’s sidewall. Subtract the inner tire area from the total tire area to find our answer. Give measurements in inches² and show all work.

Once you have the total contact area of each tire, write the ratio of sidewall areas, from bicycle tire to car tire to Space Shuttle tire. Using only the sidewall surface area of the tires, explain why Space Shuttle tires are able to safely land the Space Shuttle.

Supplemental Space Shuttle Tire Math Activity 2

Space Shuttle Tire Lessons

GRADES **5-12** Answer Key

Surface Area and Ratios

In this math problem, you are going to calculate the surface area of the sidewall of a bicycle tire, a car tire, and a Space Shuttle tire. If you have the tire sections from the “Museum in a Box” kit, you can try to make calculations based on your own measurements from those tire sections. However, exact measurements are difficult because the tire sections are small and the surfaces are curved. To help simplify measurements, the chart below lists a standard set of measurements that can be used (making the assumption, for this problem, that the tire sidewall surfaces are flat). Notice that certain measurements are given to you in millimeters (mm), some in centimeters (cm), and others in inches (in). Unfortunately, when tire specifications are given, both millimeters and inches are used, which means you will have to convert these numbers for your needs. If you need help determining diameters based on the tire specifications listed, refer to the main “Space Shuttle Tire” lessons, where a “Tire Basics” section can be found.

Tire Type	O.D. (outside diameter, in inches)	I.D. (inside diameter, in inches)	Inside Radius (in inches) $r = D/2$	Total Radius (inside radius + sidewall height, in inches)	Total Tire Area (in inches ²)	Inside Tire Area (in inches ²)	Tire Sidewall Area (in inches ²)
Bicycle (26 × 13/8)	26 inches (found in tire specifications)	23.25 inches	11.6 inches	13 inches	530.7 inches ²	514.5 inches ²	32.6 inches ²
Car (P185/70R14)	24.2 inches	14 inches	7 inches	12.1 inches	459.7 inches ²	153.9 inches ²	305.8 inches ²
Space Shuttle (main landing gear tire: 44.5 × 16.0-21)	44.9 inches	21 inches	10.5 inches	22.5 inches	6,330.3 inches ²	346.2 inches ²	5,983.8 inches ²

Hint: to calculate sidewall area, you are basically calculating the area of a donut (subtracting the area inside the circle from the outer area of the circle).

Answer Key

Diameter: $D = 2r$ Radius: $r = D/2$

Area of a circle: $A = \pi r^2$

To convert from inches to millimeters: multiply the number of inches by 25.4

To convert from millimeters to inches: divide the number of millimeters by 25.4

Step one: Find the inside and outside diameters of each tire (in inches). For a bicycle tire, the first number listed on the tire specifications is the outside tire diameter (in inches). For a car tire, the number after the tire construction (in this case, the “R” refers to a *radial* tire) is the inside diameter (in inches). The Space Shuttle tire numbering is slightly different, so it is given to you on the chart (in inches).

The second piece of information you need for this problem is the *aspect ratio*, or the height of the sidewall as a percentage of the *section width*. For a car tire, the aspect ratio is the number found after the “/” (the number 70 in this case). The section width is the first number after the tire class designation (the “P” for this tire, which refers to “passenger car” class). Section width is given in mm. The sidewall height for this tire is 70 percent of the section width. For a bike tire, the sidewall height (given in inches), is the second number in the tire specifications (for the bike tire above, the sidewall height is $1\frac{3}{8}$ ”).

Show your work, including a labeled drawing that shows the numbers you are using for each component of the problem.

Inside diameter of bicycle tire: $26 - 1.375$ ($\frac{3}{8}$ converted) $- 1.375 = 23.25$ inches (when finding the inside diameter, remember that there are two sidewalls to figure into this)

Inside radius of bicycle tire: $23.25 \div 2 = 11.6$ inches

Total bicycle tire radius: $26 \div 2 = 13$ inches

Inside radius of car tire: $14 \div 2 = 7$ inches

Outside diameter of car tire: sidewall height = 70% of section width (185 mm) = $185 \times 0.70 = 130$ mm

$130 \text{ mm} \div 25.4$ (mm to inch conversion) = 5.1 inches

7 inches (inside radius) + 5.1 inches (sidewall height) = 12.1 inches (total radius) $\times 2$ (to find diameter) = 24.2 inches

Shuttle tire sidewall height: $44.9 \text{ inches} - 21 \text{ inches} = 23.9 \text{ inches} \div 2$ (two sidewalls in total diameter) = 12 inches

Total Shuttle tire radius: $44.9 \div 2 = 22.5$ inches

Step two: Find the areas of the circle inside each tire and the total area of each tire. Refer to the formulas above for help in calculating the areas of each circle. Give measurements in inches². Again, show all work.

Total bicycle tire area: $13^2 \times 3.14$ (π) = 530.7 inches²

Inside bicycle tire area: $11.6^2 \times 3.14$ (π) = 422.5 inches²

Total car tire area: $12.1^2 \times 3.14$ (π) = 459.7 inches²

Inside car tire area: $7^2 \times 3.14$ (π) = 153.9 inches²

Total Shuttle tire area: $44.9^2 \times 3.14$ (π) = 6,330.3 inches²

Inside Shuttle tire area: $10.5^2 \times 3.14$ (π) = 346.2 inches²

Supplemental Space Shuttle Tire Math Activity 2

Answer Key

Step three: Find the area of each tire's sidewall. Subtract the inner tire area from the total tire area to find our answer. Give measurements in inches² and show all work.

Bicycle tire sidewall area: $530.7 - 422.5 = 108.2$ inches²

Car tire sidewall area: $459.7 - 153.9 = 305.8$ inches²

Space Shuttle tire sidewall area: $6,330 - 346.2 = 5,983.8$ inches²

Once you have the total contact area of each tire, write the ratio of sidewall areas, from bicycle tire to car tire to Space Shuttle tire. Using only the sidewall surface area of the tires, explain why Space Shuttle tires are able to safely land the Space Shuttle.

$32.6 : 305.8 : 5,983.8$

Answers will vary on the explanation, but looking at the ratios of sidewall area, students should be able to point out that car tires are almost 10 times the surface area of the bike tires, which helps car tires carry more weight. Likewise, Shuttle tire sidewall area is more than 19 times the car tire sidewall area, making Shuttle tires that much stronger.

SPACE SHUTTLE TIRES LESSONS: NATIONAL SCIENCE STANDARDS K–12

SCIENCE AS INQUIRY

All students should develop

- Abilities necessary to do scientific inquiry

PHYSICAL SCIENCE

All students should develop an understanding of

- Properties of objects and materials

SCIENCE AND TECHNOLOGY

All students should develop

- Abilities of technological design
- Understandings about science and technology

HISTORY OF NATURE AND SCIENCE

All students should develop an understanding of

- Science as a human endeavor

5–8

SCIENCE AS INQUIRY

All students should develop

- Abilities necessary to do scientific inquiry

PHYSICAL SCIENCE

All students should develop an understanding of

- Properties and changes of properties in matter
- Motions and forces

SCIENCE AND TECHNOLOGY

All students should develop

- Abilities of technological design
- Understandings about science and technology

PERSONAL AND SOCIAL PERSPECTIVES

All students should develop an understanding of

- Science and technology in society

HISTORY AND NATURE OF SCIENCE

All students should develop an understanding of

- Science as a human endeavor

9–12

UNIFYING CONCEPTS AND PROCESSES

All students should develop an understanding of

- Systems, order, and organization

SCIENCE AND TECHNOLOGY

All students should develop

- Understandings about science and technology

PERSONAL AND SOCIAL PERSPECTIVES

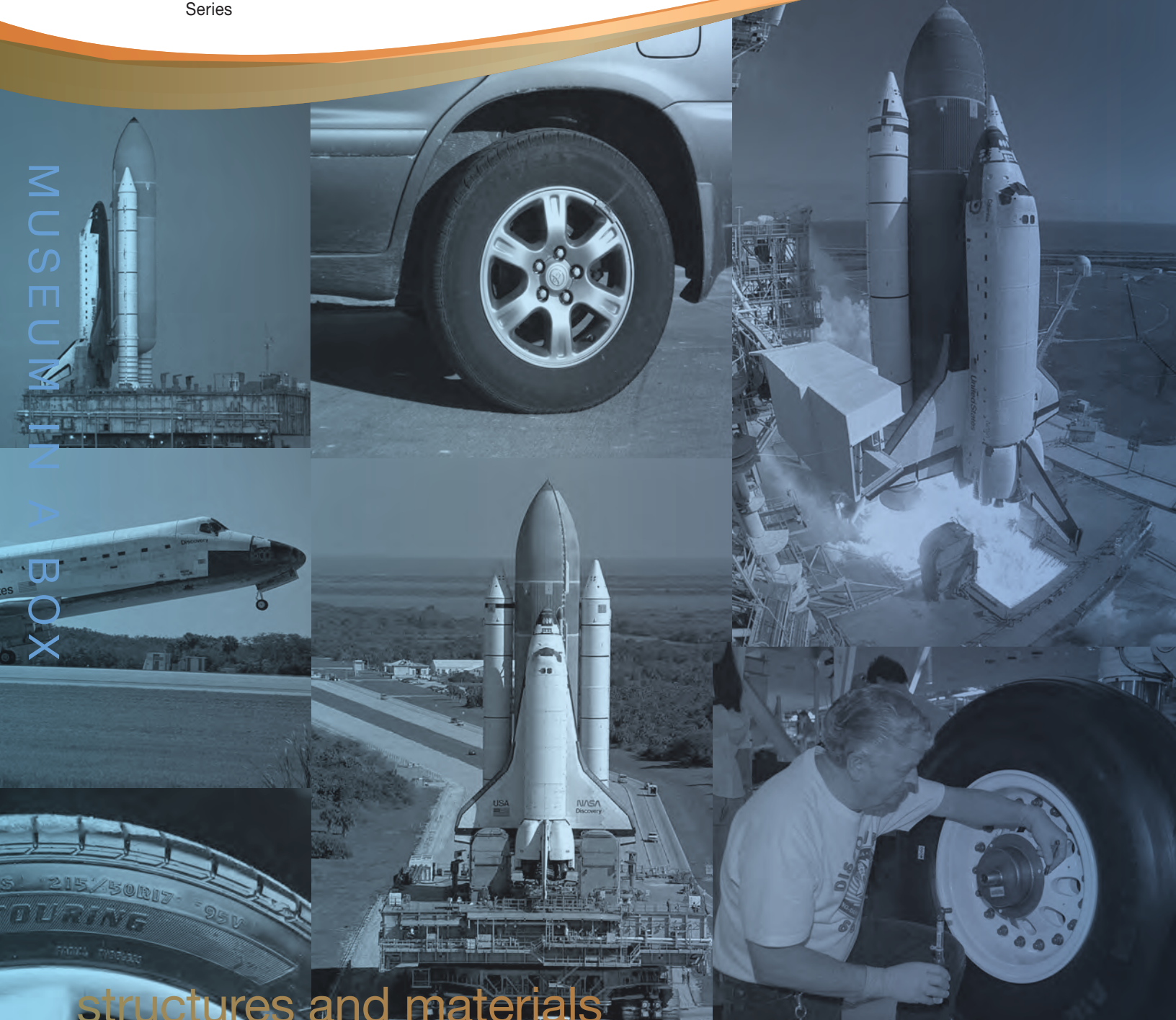
All students should develop an understanding of

- Science and technology in local, national, and global challenges
- Science as a human endeavor

Aeronautics
Research
Mission
Directorate



MUSEUM IN A BOX



structures and materials

Supplemental Space Shuttle Tire Activity

Tire Permeability and Nitrogen-Filled Tires

GRADES**K-8****5-12**

Lesson Objective

Students will learn about the structure and properties of matter by identifying different scents that diffuse through a semipermeable balloon membrane. Students will be able to identify abilities of technological design as they compare differing balloon membranes with Space Shuttle tires, which are also membranes.

Lesson Description

Students will try to identify the different extracts in each balloon. Since latex is more permeable than Mylar, students should be able to identify the extract scent that will escape from the latex balloons but should not be able to smell any of the extract within the Mylar balloons. Connections can then be made about some of the reasons NASA uses nitrogen, a larger gas molecule than other atmospheric gases, inside their Space Shuttle tires.

Materials

Several latex balloons and Mylar balloons (one of each balloon for each scent extract you have)

Scent extracts (can include vanilla extract, lemon extract, strawberry extract, etc.)

Plastic pipettes or eyedroppers (one per extract)

Air pump for balloons (optional)

Introduction

The background information above will provide information about how and why NASA has used nitrogen to inflate its Space Shuttle tires. This activity will show students how smaller-sized molecules such as scented extract can make their way through a porous solid. Latex, which is a liquid rubber, is much like the rubber used in Shuttle tires, car tires, and aircraft tires. Rubber is somewhat porous, which allows smaller molecules to make their way through the walls of that material. Since both pressurized tires and balloons have a higher internal than external pressure, gases within tires and balloons will try to reach equilibrium with outside gas pressure, causing diffusion to occur, if possible. There are several ways to prevent diffusion from occurring, and the objective of this lesson is to show students how that can be done. First, if gas molecules are too large to squeeze through the pores of the material membrane, then the gases will remain inside a balloon or tire. Nitrogen, for example, is a larger molecule than oxygen and other atmospheric gases including water vapor, so it doesn't make its way out of pressurized tires as easily. Another way to keep gases inside a membrane is to choose a material that has smaller pore sizes. Mylar balloons have much smaller pores than latex balloons, so this component of the activity shows that even tiny molecules such as vaporized extracts (or helium, as Mylar balloons are often used for), have trouble escaping. Mylar, in comparison to latex, is made from nylon sheeting that is coated with plastic and metallic materials. These different layers and materials make Mylar much less porous than latex.

Safety note: since latex balloons are used for this activity, warn students about the presence of latex, since some people are allergic to rubber and latex.

Procedure

Note: This lab needs to be set up before students enter the room so students cannot smell the extract scents before the activity.

Setup:

1. Using a plastic pipette or an eyedropper, add several drops of extract as deep into the balloon as possible (try not to get any of the extract on the balloon opening since even the smallest amount of extract is easy to smell).
2. Inflate and tie the balloon, again being careful not to get extract on your mouth or on the balloon pump.
3. Repeat steps one and two, using one latex balloon and one Mylar balloon for each scent. (To help you keep track of your balloons, you could use different colors for each scent. However, try not to be too obvious to students—don't use white or yellow for vanilla, red for strawberry, etc.)
4. Shake each balloon several times to help the extract vaporize within the balloon.

Activity

1. Introduce lesson background and discuss Shuttle tires and molecule size with students.
2. Explain that the balloons for this activity represent tires.
3. Ask students to complete the first part of their activity, which is to compare and contrast tires with both the latex balloons and the Mylar balloons (you may want to have an uninflated latex balloon and Mylar balloon for students to see and touch).
4. For the second part of the activity, have students move from balloon to balloon and try to identify each scent. It might be helpful to write a list of scents on the board before they begin.
5. When students have finished, discuss why the extract was able to diffuse through the latex balloon and not the Mylar balloon.
6. Review why Shuttle tires are inflated with nitrogen gas instead of regular air.

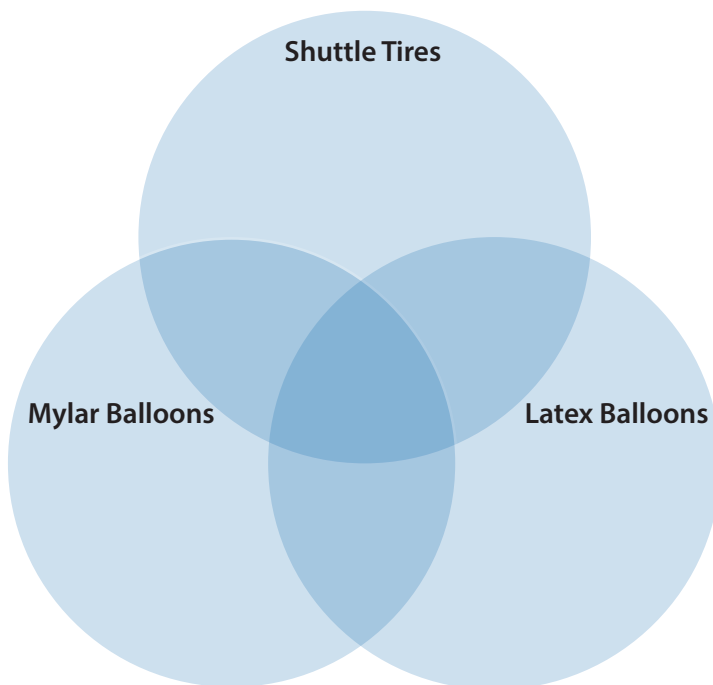
Supplemental Space Shuttle Tire Activity

Tire Permeability and Nitrogen-Filled Tires

GRADES **K-8** **5-12**

Pre-Lab Activity

Using the Venn diagram below, come up with at least two similarities and two differences between Shuttle tires, latex balloons, and Mylar balloons.



Activity

Each balloon has been filled with a different scent extract. Extracts, such as vanilla extract, are made of that specific scent and an alcohol, which vaporizes easily. The extract has vaporized inside the balloon, and if you are able to smell the extract, then the molecules of the extract vapor have been able to make their way through the pores of the balloon and to your nose.

Try to identify each of the extracts in the balloons (add more lines if necessary).

Balloon Color	Type of Balloon	Scent

Followup Questions

1. In your own words, explain why you were able to smell the extract that diffused through some of the balloons.

2. For the next question, draw pictures to explain what is happening:

<p>Extract in a latex balloon:</p>	<p>Extract in a Mylar balloon:</p>
<p>Air inside an inflated Space Shuttle tire:</p>	<p>Nitrogen inside an inflated Space Shuttle tire:</p>

3. What would be a benefit of having nitrogen in your car's tires?

4. Looking at the Mylar balloon, why do you think that Space Shuttle tires are not made of Mylar?

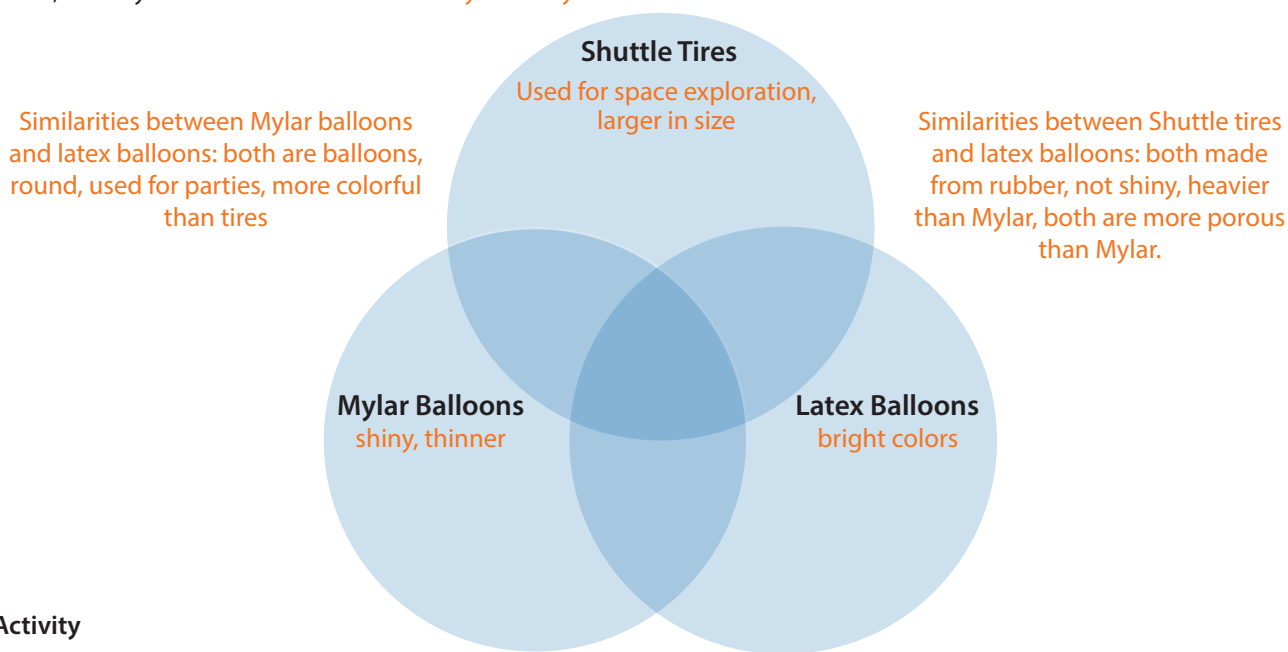
Supplemental Space Shuttle Tire Activity

Tire Permeability and Nitrogen-Filled Tires

GRADES **K-8** **5-12** Answer Key

Pre-Lab Activity

Using the Venn diagram below, come up with at least two similarities and two differences between Shuttle tires, latex balloons, and Mylar balloons. Answers will vary but may include:



Activity

Each balloon has been filled with a different scent extract. Extracts, such as vanilla extract, are made of that specific scent and an alcohol, which vaporizes easily. The extract has vaporized inside the balloon, and if you are able to smell the extract, then the molecules of the extract vapor have been able to make their way through the pores of the balloon and to your nose.

Try to identify each of the extracts in the balloons (add more lines if necessary).

Balloon Color	Type of Balloon	Scent
This chart will depend on your choices.		

Followup Questions

1. In your own words, explain why you were able to smell the extract that diffused through some of the balloons.

Scented extract is made of tiny aromatic molecules that have been diffused in alcohol. Alcohol quickly vaporizes at room temperature, which allows the aromatics and vaporized alcohol to easily escape through the pores of a latex balloon.

2. For the next question, draw pictures to explain what is happening:

<p>Extract in a latex balloon:</p> <p>Picture should show molecules escaping the balloon.</p>	<p>Extract in a Mylar balloon:</p> <p>Picture should show molecules staying inside the balloon.</p>
<p>Air inside an inflated Space Shuttle tire:</p> <p>Picture should show some molecules escaping the tire.</p>	<p>Nitrogen inside an inflated Space Shuttle tire:</p> <p>Picture should show molecules inside the tire.</p>

3. What would be a benefit of having nitrogen in your car's tires?

Answers will vary but could include better gas mileage (since tires are properly inflated), longer tire life, greater safety since nitrogen is nonflammable.

4. Looking at the Mylar balloon, why do you think that Space Shuttle tires are not made of Mylar?

Answers will vary but could include that Mylar is too thin to make a strong enough tire.

SPACE SHUTTLE TIRES LESSONS: NATIONAL SCIENCE STANDARDS

K–12

SCIENCE AS INQUIRY

All students should develop

- Abilities necessary to do scientific inquiry

PHYSICAL SCIENCE

All students should develop an understanding of

- Properties of objects and materials

SCIENCE AND TECHNOLOGY

All students should develop

- Abilities of technological design
- Understandings about science and technology

HISTORY OF NATURE AND SCIENCE

All students should develop an understanding of

- Science as a human endeavor

5–8

SCIENCE AS INQUIRY

All students should develop

- Abilities necessary to do scientific inquiry

PHYSICAL SCIENCE

All students should develop an understanding of

- Properties and changes of properties in matter
- Motions and forces

SCIENCE AND TECHNOLOGY

All students should develop

- Abilities of technological design
- Understandings about science and technology

PERSONAL AND SOCIAL PERSPECTIVES

All students should develop an understanding of

- Science and technology in society

HISTORY AND NATURE OF SCIENCE

All students should develop an understanding of

- Science as a human endeavor

9–12

UNIFYING CONCEPTS AND PROCESSES

All students should develop an understanding of

- Systems, order, and organization

SCIENCE AND TECHNOLOGY

All students should develop

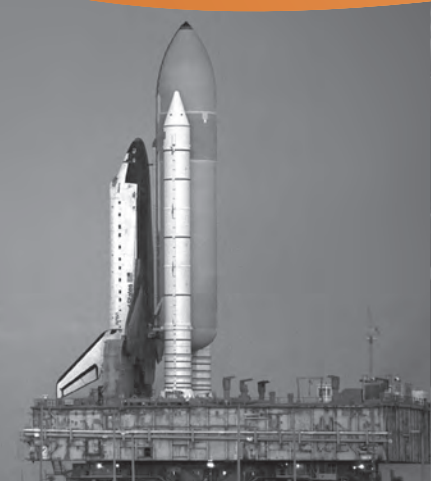
- Understandings about science and technology

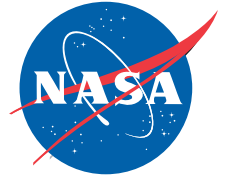
PERSONAL AND SOCIAL PERSPECTIVES

All students should develop an understanding of

- Science and technology in local, national, and global challenges
- Science as a human endeavor

Aeronautics
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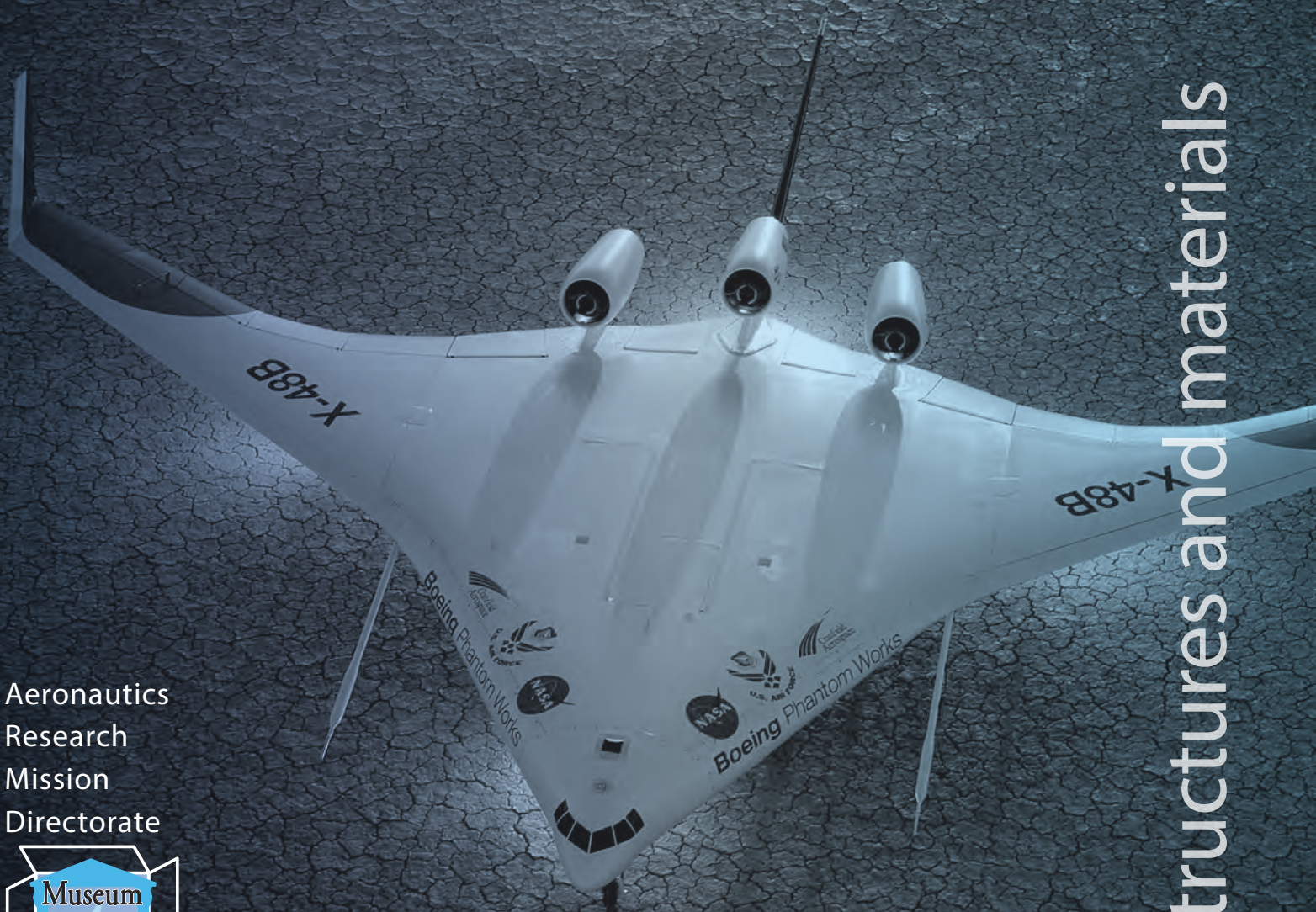




GRADES

K-12

Composites



structures and materials

Aeronautics
Research
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Directorate



Composites

Lesson Overview

In this lesson, students will examine some of the materials used in the field of aerospace. Through demonstration and experimentation, students will learn how modern technologies have allowed us to fly faster and travel deeper into our solar system.



(Photo courtesy of the NASA Dryden Flight Research Center Photo Collection)

X-48B Blended wing body during its first flight on July 20, 2007

Objectives

Students will:

1. Learn that the materials used in airplane construction have changed over time.
2. Discover that a material's density does not correspond to its strength.
3. Experiment with Shape Memory Alloys and discover their properties.
4. Compare the densities of a variety of metals and learn how material selection affects the cost of flight.

SAFETY STATEMENT:

Do not attempt to cut any of the carbon fiber materials!

Caution: Handle the balance carefully. The capacity is 210 grams, which is less than half a pound. Anything heavier, including pushing on the balance, can damage this delicate apparatus.

Note: Testing has shown that there is a strong urge for students to push down on the balance!

Materials:

Included in MIB

Carbon fiber samples
 Balance
 Carbon fiber strip
 Spruce wood strip
 The Memory Metal book (pink cover)
 and Nitinol sample (inside the book's front cover)
 Density Cubes
 Balance

Provided by the User:

Ruler
 Large glass of hot water
 Paperclip

GRADES

K-12

Time Requirements: 1 hour 25 minutes minimum

Background

Materials in Aerospace

Ever since the Wright brothers built their Flyer back in 1903 (Img. 1), the materials used in airplane design have been constantly evolving. The original Wright Flyer was comprised primarily of spruce and ash wood with muslin covering the wings, while today's airliners are made mostly of aluminum with some structure made from steel.

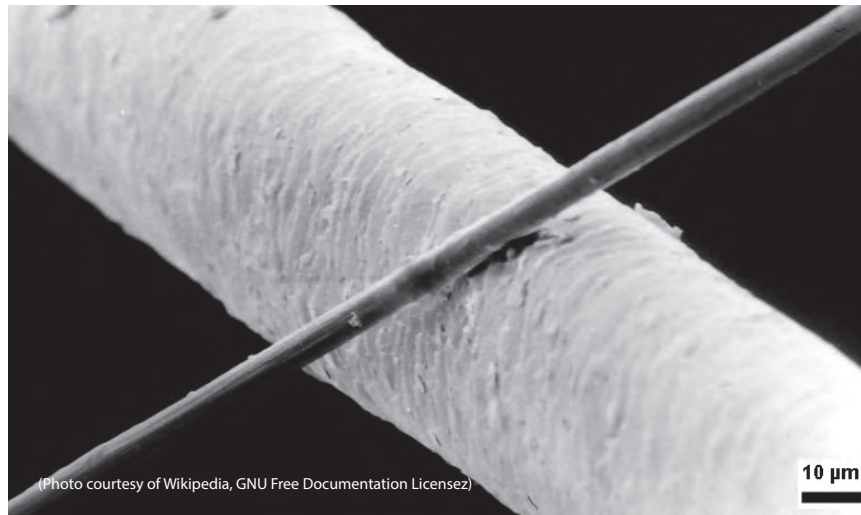
In the mid 1960's, scientists and engineers began working on a new breed of aerospace materials called composites. A composite is an engineered material made from two or more ingredients with significantly differing properties, either physical or chemical. While no longer used today, an early example of a composite material was a mix of mud and straw that was used to make bricks. Composites have two significant advantages over some of the more traditional materials: greater strength and lighter weight.

One of the most common forms of composite in use today is carbon fiber. It is made by heating lengths of rayon, pitch or other types of fiber to extremely high temperatures (~2000°C) in an oxygen-deprived oven. This heat, combined with the lack of oxygen, means that instead of combusting or burning completely, the rayon strands turn into strands of pure carbon atoms approximately 6µm (six micrometers) in diameter (Img. 2). These strands are spun into a thread, then woven into sheets and mixed with hardening resins to form the various components needed.



(Photo courtesy of Wikipedia, GNU Free Documentation License)

Img. 1 The Wright Brothers' First Flight – December 17th, 1903



Img. 2 A 6 µm diameter carbon filament (running from bottom left to top right) compared to a human hair



(Photo courtesy of Boeing)

Img. 3 The Boeing 787 takes off on its maiden flight

Carbon fiber had a difficult start in the aviation industry. In 1968 Rolls Royce attempted to make the blades of a turbine engine out of carbon fiber. Unfortunately, it was determined that while they were incredibly lightweight and strong, they were unable to tolerate an impact from a bird and shattered instantly. While the US military has made a few aircraft from predominately carbon fiber, it wasn't until January 2003 that Boeing announced they intended to build a passenger aircraft predominately out of composite materials. This aircraft, the Boeing 787 (Img. 3), took flight for the first time on the 15th of December, 2009 and is scheduled to enter passenger service in late 2011.

It isn't just composites that have been advancing technologically. Metals have also seen major improvements in strength, structure and durability, which is focused on in this lesson. Nitinol is a composite of two metals, known as an alloy, of Nickel and Titanium. It was discovered in 1962 by William Buehler of the Naval Ordinance Laboratory. Nitinol (Ni [nickel] Ti [titanium] Naval Ordinance Laboratory) is one of just a few alloys that are known as Shape Memory Alloys, or SMAs. An SMA, sometimes referred to as Smart Metal, Memory Alloy or Muscle Wire, can return to its original shape after being deformed. It has many uses in the medical field as well as in aerospace, where it is used in hydraulic hose clamps, and to reduce engine noise by using the heat of the engine to control exhaust emissions.

An SMA works by having the desired shape 'set' using extremely high temperatures, usually while in a vacuum. After it has cooled, the SMA can be stretched, bent, crushed or twisted. Then by applying heat, or an electrical current which through resistance causes the wire to heat, the SMA quickly returns to its preset shape. One of the most recent breakthroughs with SMAs are the creation of shape-changing heart stents. The stent is flattened before being placed into the artery and uses the body's own heat to return it to a cylindrical form. This means that the incision needed to insert the stent can be much smaller, leading to a reduced recovery time for the patient.

Activity 1

Materials Past and Present

GRADES **K-12**
Materials:In the Box

Carbon fiber samples

WorksheetsMaterial Comparison
(Worksheet 1)Reference Materials

None

Key Terms:

Carbon fiber

Time Requirement: 30 minutes**Objective:**

Students will learn through discussion how the materials used in airplane construction have changed over time.

Activity Overview:

By using the photos supplied in the **Images** section, you will lead a discussion with the students on how the materials used in the manufacture of aircraft have changed over time and why. A worksheet is provided for the students to record and compare their answers.

Activity:

1. Examine the Wright Flyer using the photos provided in the **Images section (Imgs. 1, 4 and 5).** As a group, ask the students to list the materials used in the airplane's construction on their worksheet.

Wood (spruce), steel, cloth (muslin), aluminum

2. Ask the students why they think the Wright brothers chose those materials. Points to consider are the material's availability, strength, elasticity, weight, cost, hardness and resistance to corrosion.

Wood – Used in the wings. It is light, flexible and easy to shape into parts. They originally chose pine instead of spruce, but it cracked easily under pressure. Spruce was far more flexible which was especially important to consider when landing. Wood is also cheap and readily available.

Steel – Used in numerous locations to hold parts together. Steel is easy to shape, very hard and is well suited for making bolts. It does however rust easily if untreated.

Cloth – Used to cover the wings. It is extremely light and easy to shape but very easy to tear.

Aluminum – Used to make the engine. Aluminum can be heated and molded easily which still today makes it popular for engine construction.

3. Examine the Boeing VC-137C (Boeing 707) using the photo provided in the **Images** section (Imgs. 6 and 7). Once again, have the students list the materials in the airplane's construction along with their respective properties.

Aluminum, Steel, Plastic / Glass

4. Ask the students why they think the VC-137C was made using different materials to the Wright Flyer. What made these materials better?

Aluminum – Used to cover the wings and fuselage. Heavier than cloth, but much stronger and can withstand many years of flying. It also enables aircraft to be pressurized which allows it to fly much higher, which in turn saves fuel.

Steel – Still used in many components today, although the newer steel alloys are much lighter and more corrosion resistant. The parts can also be made thinner as the aluminum skin provides the rigidity and strength that the cloth could not.

Plastic/Glass – Used in the windows, as well as in some places of the outer skin where strength isn't needed. While plastic was invented in 1862, well before the Wright Flyer was made, it wasn't readily available until the 1920s.

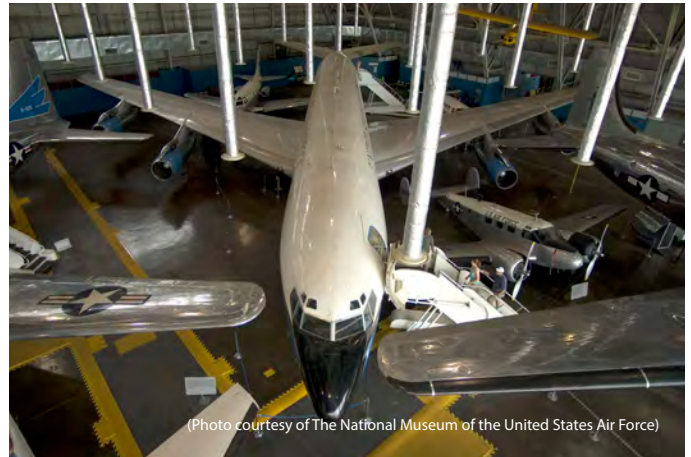
5. Lastly, show the students the picture of the Boeing 787 (Img. 3). Explain that while this aircraft still uses metals and plastic, it is made predominately of a material called carbon fiber. Hand out the samples of carbon fiber and ask them to describe it in comparison to the other materials.

Students should discover that carbon fiber is extremely light but very strong. They are unable to bend it or stretch it which makes it as strong as metal, without the associated weight.



(Photo courtesy of The National Museum of the United States Air Force)

Img. 6 SAM 26000, a Boeing VC-137C landing at the National Museum of the United States Air Force in Dayton, OH



(Photo courtesy of The National Museum of the United States Air Force)

Img. 7 SAM 26000 on display at the National Museum of the United States Air Force in Dayton, OH

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Properties and changes of properties in matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Structure and properties of matter
- Interactions of energy and matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

Activity 2

Material Comparisons

GRADES K-12**Time Requirements:** 20 minutes**Materials:**In the Box

Balance
Carbon fiber strip
Spruce wood strip

Provided by User

Ruler

Worksheets

Material Density
(Worksheet 2)

Reference Materials

None

Key Terms:

Density
Carbon fiber

Objective:

By calculating the samples' densities, students will discover that a material's density does not correspond to its strength.

Activity Overview:

In this activity, students will determine the mass, volume and density of two samples, spruce and carbon fiber. Students should discover that although the carbon fiber is less dense, it is clearly a stronger material than the spruce wood.

Prior to beginning this activity, set up the balance at the front of the classroom. If necessary, remove the cardboard protector from underneath the balance and remove the carbon fiber strip from its plastic packaging.

Activity:

1. Pass the spruce and carbon fiber strips around the classroom. Ask the students to GENTLY flex each strip, comparing how easily each one bends. Ask them to guess which one is heavier, or has more mass. Based on their answers, ask them to predict which one is more dense. (If needed, explain the definition of density: a measurement of the compactness of a material, measured in terms of mass per unit of volume.)

CAUTION: *The spruce strip WILL snap if over flexed. The idea is to demonstrate that spruce bends easier than carbon fiber, not to see how far both can bend!*

The students should discover that the spruce strip is more flexible and feels heavier than the carbon fiber.

2. Ask a student to find the mass of one of the strips by placing it on the balance. Have the

students record the answer on their worksheets. Repeat the process with the other strip.

Answers will vary by material sample.



3. Next, ask additional students to measure the length, width and thickness of the samples, again having the entire class record the data on their worksheets.

Answers will vary by material sample.

4. Using the following equations, have the students calculate the density of the samples.

$$\text{Length (mm)} \cdot \text{Width (mm)} \cdot \text{Thickness (mm)} = \text{Volume (mm}^3\text{)}$$

$$\frac{\text{Mass (g)}}{\text{Volume (mm}^3\text{)}} = \text{Density (g/mm}^3\text{)}$$

Answers will vary by material sample.

Example (Carbon fiber):

$$610\text{mm} \cdot 11\text{mm} \cdot 1.8\text{mm} = 12,078\text{mm}^3$$

$$\frac{19\text{g}}{12,078\text{mm}^3} = 0.00157\text{g/mm}^3$$

5. Summarize this activity by pointing out that while the spruce is more dense, the carbon fiber is the stronger material, as demonstrated when flexed.

The connection should be made that just because a material is dense, it does not necessarily make it strong. In this case, the carbon fiber is clearly a stronger material, despite being less dense.

Discussion Points:

1. Ask the students to name other materials they are familiar with that are very light but strong.

Some items they may suggest are Kevlar, foam, plastic, glass, fiberglass.

2. Ask the students to name everyday items that are made from the materials they identified in

Discussion Point 1.

Some examples of this might be plastic drinking cups, bulletproof vests and aquariums.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Properties and changes of properties in matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Structure and properties of matter
- Interactions of energy and matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL MATH STANDARDS K-12

NUMBER AND OPERATIONS

- Understand numbers, ways of representing numbers, relationships among numbers, and number systems
- Understand meanings of operations and how they relate to one another
- Compute fluently and make reasonable estimates

ALGEBRA

- Represent and analyze mathematical situations and structures using algebraic symbols
- Use mathematical models to represent and understand quantitative relationships

MEASUREMENT

- Understand measurable attributes of objects and the units, systems, and processes of measurement
- Apply appropriate techniques, tools, and formulas to determine measurements.

DATA ANALYSIS AND PROBABILITY

- Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them

PROCESS

- Problem Solving
- Communication
- Connections
- Representation

Activity 3

Shape Memory Alloys (SMAs)

GRADES K-12**Materials:**In the Box

The Memory Metal book (pink cover) and Nitinol sample (inside the book's front cover)

Provided by User

Large glass of hot water
Paperclip

Worksheets

None

Reference Materials

None

Key Terms:

Shape Memory Alloy (SMA)
Nitinol

Time Requirements:

5 minutes per student or group of students

Objective:

Through experimentation, students will learn how a Shape Memory Alloy reacts to heat in order to regain its shape.

Activity Overview:

By stretching the nitinol sample and then immersing it in hot water, students will see how the sample reacts. This can be repeated as many times as necessary with each student or group of students.

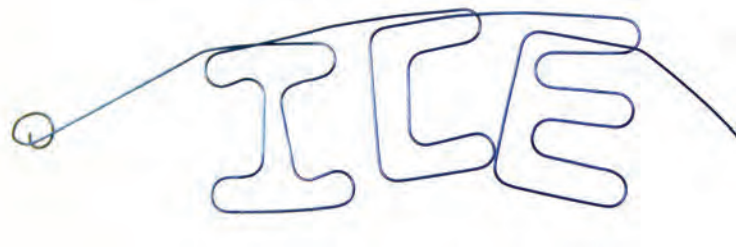
Before starting this lesson, fill a large glass with hot water and have it available. Water from the hot tap is sufficiently hot, do NOT use boiling water!

Activity:

1. **Start this demonstration by holding up a paperclip and showing it to the class.** It should be made clear to them that it is a normal paperclip.
2. **Bend the paperclip out of shape in such a fashion that it can no longer be used as a paperclip.** Ask the students what will happen to the clip if you immerse it in the hot water. Once the students have had a chance to answer, place the paperclip in the water.

While you may receive different answers, the correct answer is that nothing will happen except the paperclip will become warmer to the touch.

3. **Remove the nitinol sample from the envelope.** Pass the sample carefully around the class. Have the students note that it spells the word ICE.



At this point, ensure that the students do not deform the sample so that they all clearly see it spells the word ICE.

4. After each student has examined the sample, stretch the sample so that the word ICE is no longer discernible.

Caution: Do not try to remove all the small curves and kinks. Overstretching the wire will damage it and prevent it from remembering its shape.

5. Ask the students what they think will happen when it is immersed into the hot water.

At this point, it will likely be assumed that the sample will react the same as the paperclip in that nothing will happen. For now, there is no need to correct their assumptions.

6. Slowly lower the sample into the glass of hot water. Students will see that as the sample heats up, it returns to its original shape. Ask them why they think that happened.

7. Using the **Background Information** as a guide, explain to the students what a Shape Memory Alloy is and why the word ICE returned when it was immersed into hot water.

It is important to point out during your discussion that the paperclip was made of regular steel, which is why it failed to return to its original shape, unlike the SMA, which is made of nitinol.

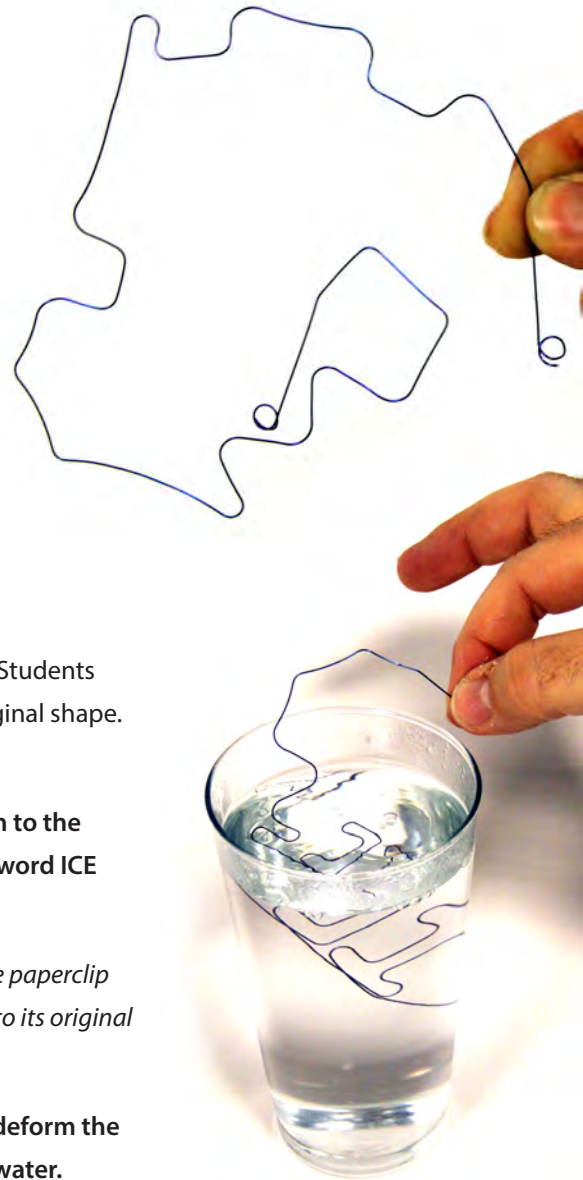
8. Either individually or in small groups, have students deform the nitinol sample themselves and immerse it in the hot water.

This can be repeated as many times as required without damage to the sample, provided that it is not overstretched.

Discussion Points:

1. Ask the students to suggest places where Shape Memory Alloy's might be used. Point out that only a temperature change is needed to return the metal to its original shape; it does not need to be immersed in water.

Answers might include: flexible eye-glass frames, orthodontic braces, heart stents.



NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Properties and changes of properties in matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Structure and properties of matter
- Interactions of energy and matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

Activity 4

Density Cubes

GRADES **K-12****Time Requirements:** 30 minutesIn the BoxDensity Cubes
(4 sets)

Balance

Provided by User

Ruler

WorksheetsDensity Cubes
(Worksheet 3)Reference Materials

None

Key Terms:

Density

Objective:

To determine the density of different metals.

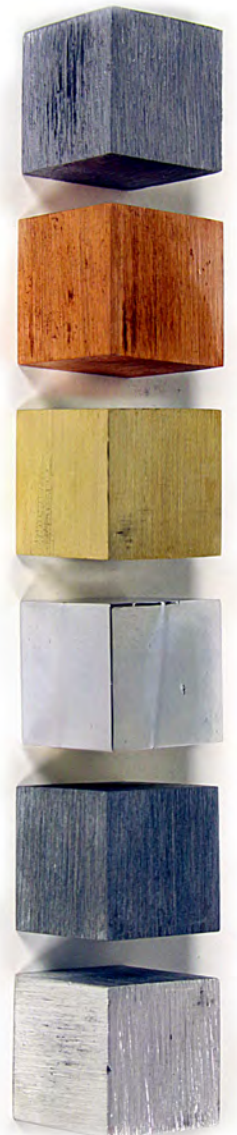
Activity Overview:

Using mathematics, students will determine the density of differing metals by first calculating each one's mass and size, then solving as required.

The sample cubes are not marked. As such, here is how to determine which cube is which:

*Lead – The heaviest of the 4 silver cubes**Copper – The bright orange cube**Brass – The yellow cube**Iron – Has a bright, silver-colored mirrored finish (the finish is a chrome plating to prevent the cube from rusting)**Zinc – The darkest of the silver colored cubes**Aluminum – The lightest (in weight) of the silver-colored cubes***Activity:**

1. **Divide the class into 4 groups and provide each group with a set of density cubes.** Ask the students to order them on their worksheets according to their mass (from most to least) just by judging how heavy they feel.
2. **Using the balance, have the students determine the mass of each cube and record the answer on their worksheets.**

*This can be done individually or in groups depending on class size and time available.**Answers will vary by sample.*

- Have the students list the cubes in order by mass (from most to least) based upon their measurements.
- Using a ruler, have each student, or group of students, measure the size of each cube in millimeters and record the height, length and width on their worksheets.
- Using the following formulas, calculate the density of each cube on the data sheet.

$$\text{Length (mm)} \cdot \text{Width (mm)} \cdot \text{Thickness (mm)} = \text{Volume (mm}^3\text{)}$$

$$\frac{\text{Mass (g)}}{\text{Volume (mm}^3\text{)}} = \text{Density (g/mm}^3\text{)}$$

- Compare the students' answers with those in the table below. Their answers should be very close to those shown here:

Sample Density g/ mm ³	
Lead	0.0113
Copper	0.0089
Brass	0.0086
Iron	0.0079
Zinc	0.0071
Aluminum	0.0027

If there are slight differences in the results, this is due to the impurities in the samples provided. The numbers above are for the pure metals. For example, the zinc sample does contain small traces of aluminum which may cause your sample to be less dense.

If the students have completed **Activity 2 – Material Comparisons**, use their calculations of the density of carbon fiber or the remainder of this activity. If not, use a density of 0.00158 g/mm³. Note: In our calculations, we used the pure metal densities shown in the preceding table; your students' results may differ.

- Compare the density of aluminum to that of carbon fiber by determining the ratio of the density of carbon fiber to the density of aluminum. Express this ratio as a percentage.

$$\frac{\text{Density of Carbon Fiber}}{\text{Density of Aluminum}} = \text{Density Ratio}$$

$$\frac{0.00158 \text{ g/mm}^3}{0.0027 \text{ g/mm}^3} = 0.5852$$

$$0.5852 \cdot 100 = 58.52\%$$

Carbon fiber is only 58.52% as dense as aluminum

8. A Boeing 747-400ER is made predominantly of aluminum and has a mass of 184,000kg.

(For the purpose of this activity, assume that the non-aluminum components are of a negligible mass.)

a. If Boeing replaced 10% of the aluminum with carbon fiber, what would its new mass be?

First, determine how much mass equates to 10% of the plane's total mass.

$$184,000\text{kg} \cdot 10\% = 18,400\text{kg}$$

To find the mass of the portion of the plane that will be made of carbon fiber, multiply the difference by the density ratio found in the previous problem.

$$18,400\text{kg} \cdot 0.5852 = 10,767.68\text{kg} \text{ would be made of carbon fiber}$$

Now, determine how much of the plane is still made of aluminum.

$$\text{Airplane's Original Mass} - \text{Amount Changed to Carbon Fiber} = \text{Total Aluminum Remaining}$$

$$184,000\text{kg} - 18,400\text{kg} = 165,600\text{kg}$$

Add the aluminum and carbon fiber components to determine the plane's new mass.

$$165,600\text{kg} + 10,767.68\text{kg} = 176,367.68\text{kg}$$

b. As a percentage, how much lighter is the new aircraft?

$$\frac{\text{New Mass}}{\text{Original Mass}} \cdot 100 = \text{Percentage of Original Mass}$$

$$\frac{176,367.68\text{kg}}{184,000\text{kg}} \cdot 100 = 95.85\%$$

$$100\% - 95.85\% = 4.15\%$$

The aircraft is 4.15% lighter

9. The airplane burns approximately 3,600 gallons of fuel every hour. Assuming that the mass

(and therefore the weight) of the aircraft is directly proportional to its fuel consumption, how many gallons per hour would an airline save if it replaced 10% of the aluminum materials in the plane with carbon fiber?

$$\text{Fuel Consumption (gal/hr)} \cdot \text{Percentage Savings} = \text{Gallons Saved per Hour}$$

$$3,600 \text{ gal/hr} \cdot 4.15\% = 149.4 \text{ gal/hr}$$

10. If the fuel costs \$4/gallon, how much money would an airline save on one 16 hour flight from London to Sydney?

$$\text{Fuel Savings} \cdot \text{Length of Flight} \cdot \text{Cost of Fuel} = \text{Money Saved}$$
$$149.4 \text{ gal/hr} \cdot 16 \text{ hrs} \cdot \$4/\text{gal} = \$9,561.60$$

Discussion Points:

1. What are some benefits of using carbon fiber and other composite materials over traditional materials (wood, metal, glass, etc.) in the aviation industry?

The airplane will burn less fuel as the plane will be lighter.

Composite materials can cope with the stresses of continual heating and cooling better than traditional metal components.

Composites are usually easier to work with in manufacturing facilities. It takes less energy to form components made from composites.

2. What are some of the challenges in designing new materials to replace existing ones, in ANY industry?

The new materials must retain all of the desirable qualities that the old materials had, such as impact-resistance and strength.

They must also be cost-effective to produce.

There are long term effects that have not had time to surface. For example, asbestos was used for decades until its health implications were discovered.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 5-8

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NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

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- Understandings about scientific inquiry

PHYSICAL SCIENCE

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- Interactions of energy and matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL MATH STANDARDS K-12

NUMBER AND OPERATIONS

- Understand numbers, ways of representing numbers, relationships among numbers, and number systems
- Understand meanings of operations and how they relate to one another
- Compute fluently and make reasonable estimates

ALGEBRA

- Represent and analyze mathematical situations and structures using algebraic symbols
- Use mathematical models to represent and understand quantitative relationships

MEASUREMENT

- Understand measurable attributes of objects and the units, systems, and processes of measurement
- Apply appropriate techniques, tools, and formulas to determine measurements.

DATA ANALYSIS AND PROBABILITY

- Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them

PROCESS

- Problem Solving
- Communication
- Connections
- Representation



Reference Materials

Glossary

Carbon fiber:

An extremely strong fiber, consisting of long, chain-like molecules of nearly pure carbon that are made by burning fibers such as rayon in the absence of oxygen

Density:

A measurement of the compactness of a material, measured in terms of mass per unit of volume

Shape Memory Alloy (SMA):

An alloy that via a process of extensive heating “remembers” an assigned shape

Nitinol:

An example of a Shape Memory Alloy



Student Worksheets

	1903 Wright Flyer	Boeing VC-137C	Boeing 787
Materials			Carbon fiber Steel Aluminum
Properties			Carbon fiber <ul style="list-style-type: none"> • lighter than metals • easier to shape than metals • very strong Steel <ul style="list-style-type: none"> • easy to shape • very hard and rigid • can rust Aluminum <ul style="list-style-type: none"> • strong • lighter than steel, heavier than cloth • rigid

1. Examine the photos of the Wright Flyer and list the materials they used in the chart above.

2. Why did the Wright brothers choose these materials?

3. Examine the photos of the Boeing VC-137C (Boeing 707) and list the materials they used in the chart above.

4. Why was the Boeing VC-137C (Boeing 707) made using different materials to the Wright Flyer?

Worksheet 2

Material Density

	Mass (g)	Length (mm)	Width (mm)	Thickness (mm)	Volume (mm ³)	Density (g/mm ³)
Spruce						
Carbon fiber						

1. Using the balance, determine the mass of the strips of spruce and carbon fiber . Record your results in the table above.
2. Measure the length, width and thickness of the strips of spruce and carbon fiber . Record your results in the table above.
3. Using the formulae below, calculate the density of the strips. Record your results in the table above.

$$\text{Length (mm)} \cdot \text{Width (mm)} \cdot \text{Thickness (mm)} = \text{Volume (mm}^3\text{)}$$

$$\frac{\text{Mass (g)}}{\text{Volume (mm}^3\text{)}} = \text{Density (g/mm}^3\text{)}$$

Worksheet 3 Density Cubes

1. Predicted order of cubes by mass, from least to most, judged by feeling of heaviness:

- 1.
- 2.
- 3.
- 4.
- 5.
- 6.

2. Actual order of cube by mass, from least to most:

- 1.
- 2.
- 3.
- 4.
- 5.
- 6.

3. Measure each cube, then calculate its volume and density. Record your measurements and results in the table below.

	Mass (g)	Length (mm)	Width (mm)	Height (mm)	Volume (mm ³)	Density (g/mm ³)
Lead						
Copper						
Iron						
Brass						
Aluminum						
Zinc						

$$\text{Length (mm)} \cdot \text{Width (mm)} \cdot \text{Thickness (mm)} = \text{Volume (mm}^3\text{)}$$

$$\frac{\text{Mass (g)}}{\text{Volume (mm}^3\text{)}} = \text{Density (g/mm}^3\text{)}$$

Worksheet 3 Continued

4. Compare the density of aluminum to that of carbon fiber by determining the ratio of the density of carbon fiber to the density of aluminum. Express this ratio as a percentage.

Density of Carbon Fiber \div Density of Aluminum = Density Ratio

$$\frac{\text{ } \text{g/mm}^3}{\text{ } \text{g/mm}^3} = \text{ }$$

$$\text{ } \cdot 100 = \text{ } \%$$

Answer: Carbon fiber is only $\text{ } \%$ as dense as aluminum

5. A Boeing 747-400ER is made predominantly of aluminum and has a mass of 184,000kg. (For the purpose of this activity, assume that the non-aluminum components are of a negligible mass.)

- a. If Boeing replaced 10% of the aluminum with carbon fiber, what would its new mass be?

First, determine how much mass equates to 10% of the plane's total mass.

$$\text{ } \text{kg} \cdot 10\% = \text{ } \text{kg}$$

To find the mass of the portion of the plane that will be made of carbon fiber, multiply the difference by the density ratio found in the previous problem.

$$\text{ } \text{kg} \cdot \text{ } = \text{ } \text{kg} \text{ would be made of carbon fiber}$$

Worksheet 3 Continued

Now, determine how much of the plane is still made of aluminum.

Airplane's Original Mass – Amount Changed to Carbon Fiber = Total Aluminum Remaining

$$\text{[] kg} - \text{[] kg} = \text{[] kg} \text{ would remain aluminum}$$

Add the aluminum and carbon fiber components to determine the plane's new mass.

$$\text{[] kg} + \text{[] kg} = \text{[] kg}$$

b. As a percentage, how much lighter is the new aircraft?

$$\frac{\text{New Mass}}{\text{Original Mass}} \cdot 100 = \text{Percentage of Original Mass}$$

$$\frac{\text{[] kg}}{\text{[] kg}} \cdot 100 = \text{[] \%}$$

$$100\% - \text{[] \%} = \text{[] \%}$$

The aircraft is [] % lighter.

6. The airplane burns approximately 3,600 gallons of fuel every hour. Assuming that the mass (and therefore the weight) of the aircraft is directly proportional to its fuel consumption, how many gallons per hour would an airline save if it replaced 10% of the aluminum materials in the plane with carbon fiber?

Fuel Consumption (gal/hr) • Percentage Savings = Gallons Saved per Hour

$$\text{[] gal/hr} \cdot \text{[] \%} = \text{[] gal/hr}$$

Worksheet 3 Continued

7. If the fuel costs \$4/gallon, how much money would an airline save on one 16 hour flight from London to Sydney?

Fuel Savings • Length of Flight • Cost of Fuel = Money Saved

$$\boxed{} \text{ gal/hr} \cdot \boxed{} \text{ hrs} \cdot \$ \boxed{} / \text{gal} = \$ \boxed{}$$



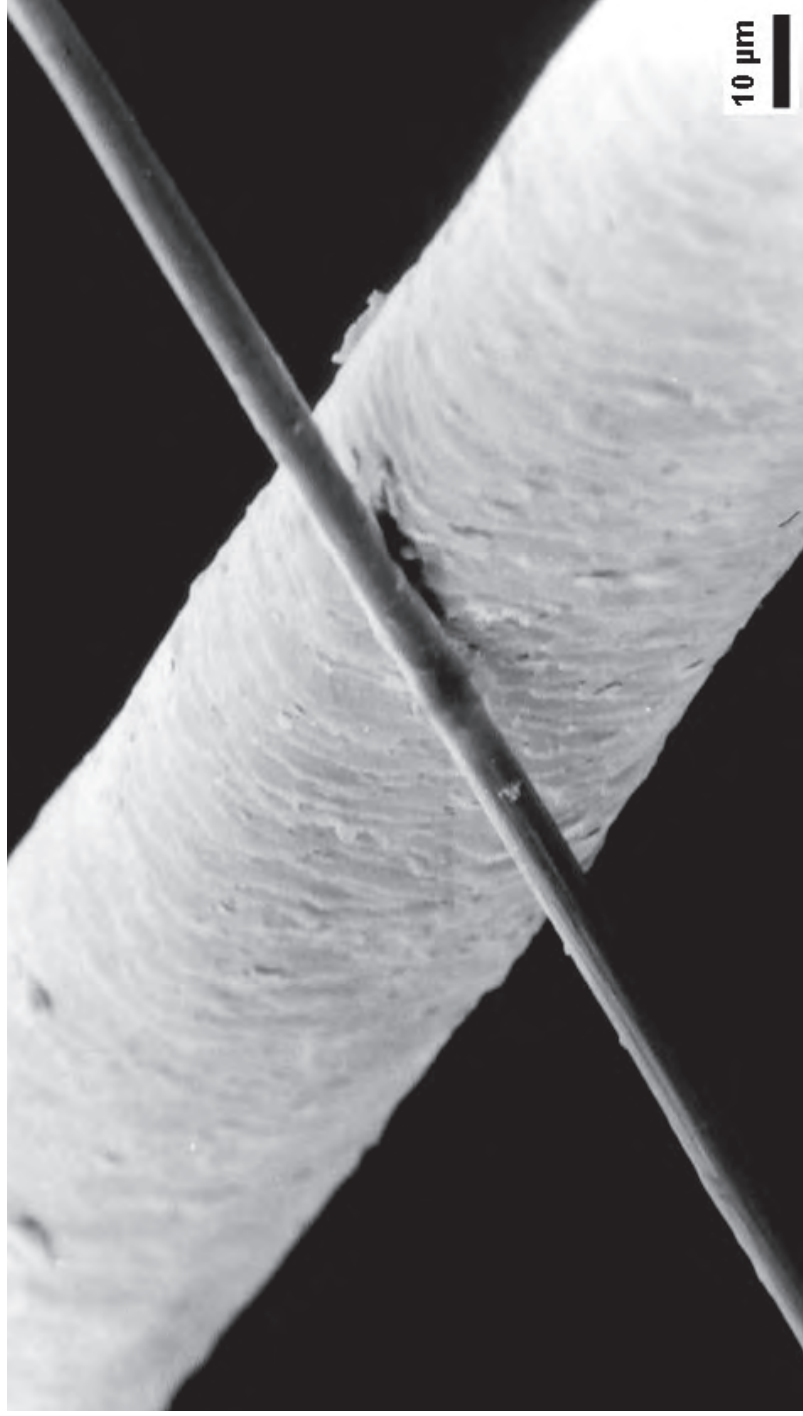
Images

Img. 1 The Wright Brothers' First Flight – December 17th, 1903



(Photo courtesy of Wikipedia, GNU Free Documentation License)

Img. 2 A 6 μm diameter carbon filament (running from bottom left to top right) compared to a human hair



(Photo courtesy of Wikipedia, GNU Free Documentation License.)

Img. 3 The Boeing 787 takes off on its maiden flight



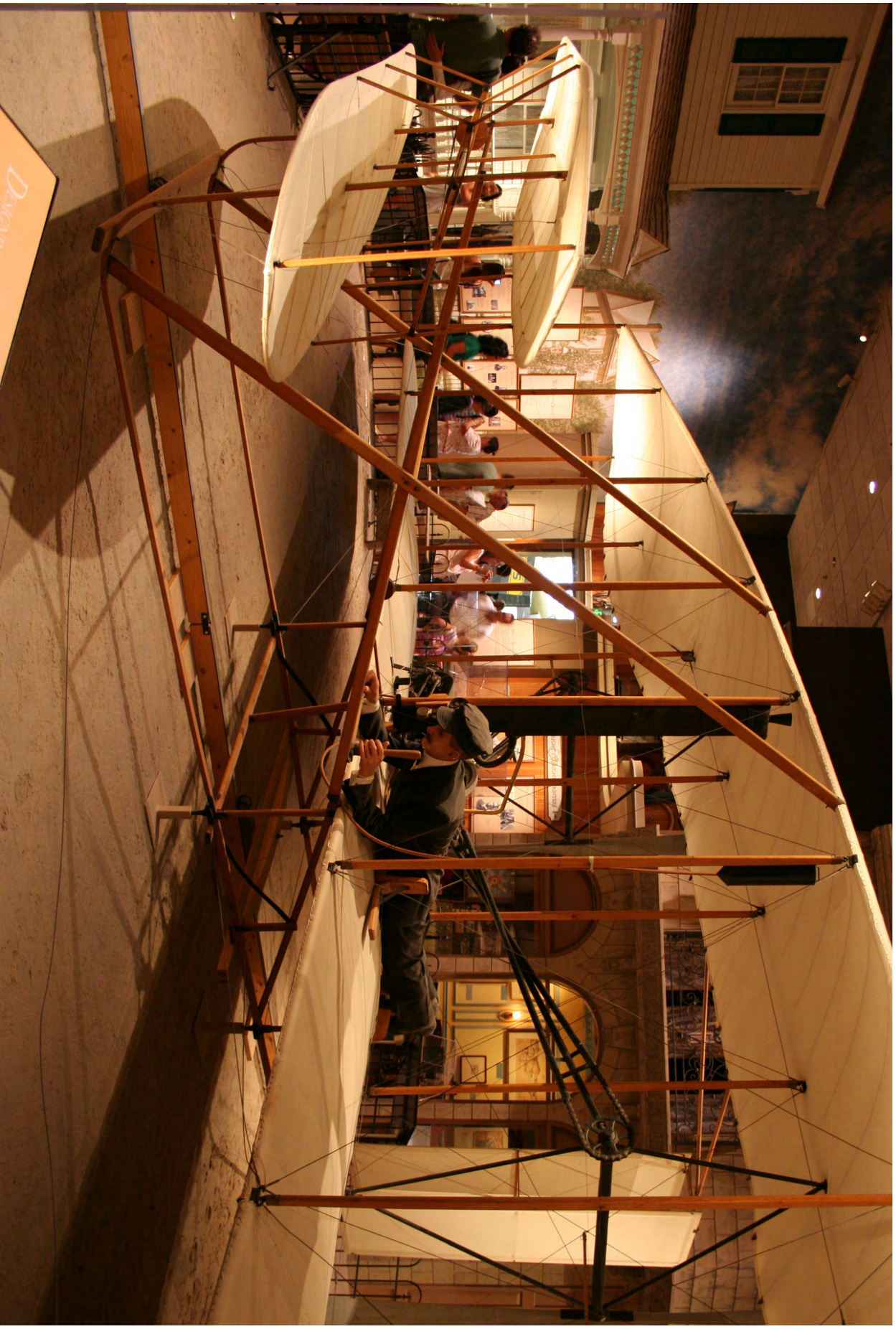
(Photo courtesy of Boeing)

Img. 4 The Wright Brothers' 1903 aircraft, the Wright Flyer, in the Smithsonian National Air and Space Museum



(Photo courtesy of Smithsonian National Air and Space Museum)

Img. 5 The Wright Brothers' 1903 aircraft, the Wright Flyer, in the Smithsonian National Air and Space Museum



(Photo courtesy of Wikipedia, GNU Free Documentation License)

Img. 6 SAM 26000, a Boeing VC-137C, landing at the National Museum of the United States Air Force in Dayton, OH



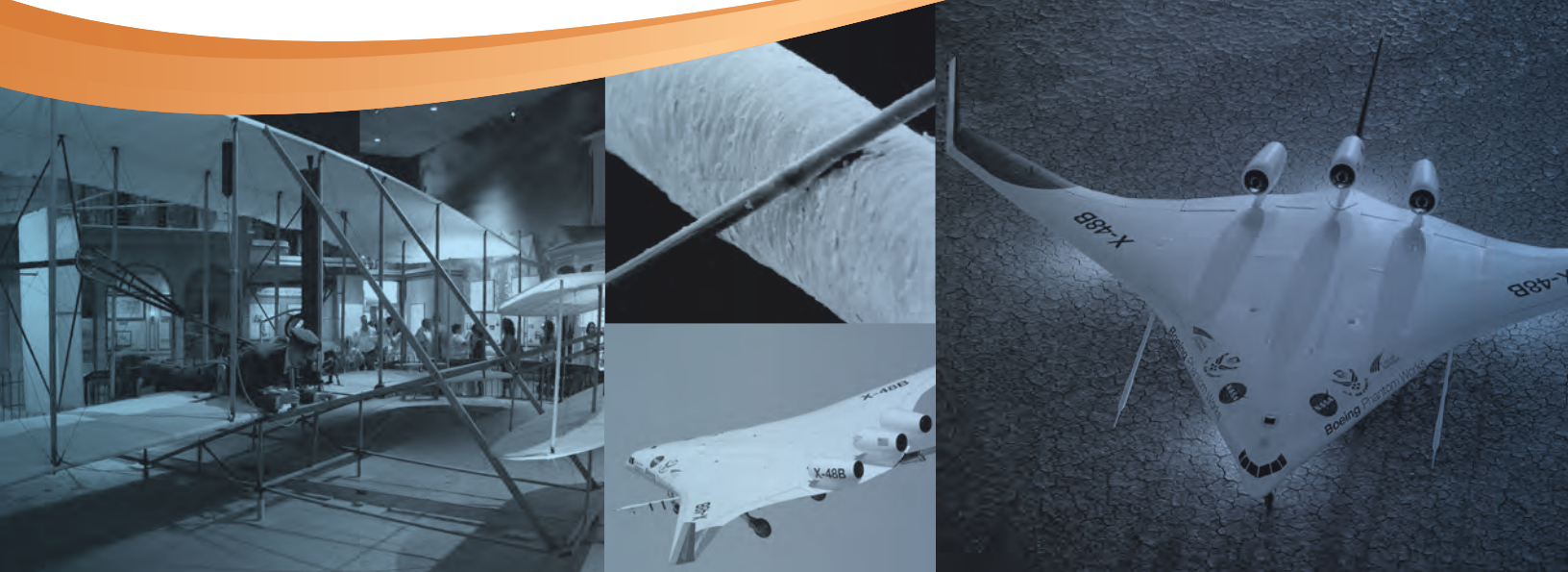
(Photo courtesy of The National Museum of the United States Air Force)

Img.7 SAM 26000 on display at the National Museum of the United States Air Force in Dayton, OH

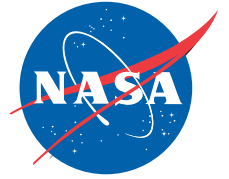


(Photo courtesy of The National Museum of the United States Air Force)

Aeronautics
Research
Mission
Directorate



structures and materials



GRADES

2-4

Space Shuttle Tiles

structures and materials

Aeronautics
Research
Mission
Directorate





(Photo courtesy of NASA - www.nasaimages.org)

Space Shuttle Tiles

Img. 1 The Space Shuttle Atlantis in orbit.

Lesson Overview

In this activity, students will calculate the number of tiles to cover an area of the shuttle (15 feet by 22 feet) as well as the weight of these tiles based on the shuttle tile included in the MIB. The students then determine the launch costs for the weight of the tiles determined.

SAFETY NOTE FOR SHUTTLE TILE:

The silica material in shuttle tiles is not classified as hazardous either by Federal SARA or CERCLA standards. However, material from the silica fiber layer can cause temporary irritation of the throat and/or itching of the eyes and skin so that touching a bare tile should be avoided. For your convenience, the tile is sealed in a protective plastic wrapping. The plastic wrap should not be removed. Never touch the shuttle tile. More information is available through MSDS (www.MSDS.gov).

Objectives

1. Calculate number and weight of materials, the same way scientists and engineers do.
2. Learn about cost measuring, using simple math operations.

Materials:

Included in MIB

Space Shuttle tile
Food scale

Provided by User

None

GRADES

2-4

Time Requirements: 30 minutes

Background

Shuttle Tiles

A key to a successful thermal protection system for the Space Shuttle depends on two things—light weight and the ability to withstand the high temperatures of reentry.

When the space shuttle de-orbits and begins to return to Earth, it faces a serious problem due

to frictional heating. Protecting the shuttle and the crew from such heat is very important. When the shuttle reenters Earth's atmosphere at about 400,000 feet or about 122 km, it is traveling at about 25 times the speed of sound (Mach 25). It uses the friction of reentry to slow the shuttle down, but in doing so it pays a price in the form of frictional heating. Temperatures on the shuttle reach several thousand degrees. If the shuttle had a metal exterior like an airplane, it would be burn up due to the heat produced by the friction.

The tiles on the shuttle provide a means for thermal protection.

There are some 24,300 tiles that measure about six inches long on each side (15.25cm) and vary in thickness from 1 to 5 inches (2.54 to 12.7 cm) depending on where they are attached. They are made up of what is called a porous silicon material that is very light and extremely heat resistant. There are two main types of tiles, one a black-coated tile called HRSI for High-Temperature Reusable Surface Insulation tile. These tiles can withstand up to 2,300 degrees F (1,260 degrees C). They cover the bottom of the shuttle, areas around the forward windows, and several other key areas. The densities of these tiles range from 9-22 pounds per cubic foot.



Img. 2 A close-up of the underside of the orbiter.



The second type are white-coated tiles and are Low Temperature Reusable Surface Insulation (LRSI). They are made to insulate the shuttle up to 1,200 degrees F (650 degrees C). These tiles are usually larger and thinner, 8 inches long on each side (20.3cm) and from less than a half inch (1 cm) thick up to 1 inch (2.54 cm) in thickness. The densities range from 9 to 12 pounds per cubic foot.

The making of tiles begins with pure silica that comes from refined sand. This material is formed in fibers and mixed with pure water and other chemicals and then poured into a mold where the excess water is squeezed out.



(Photo courtesy of NASA - www.nasaimages.org)

Img 5. A close-up of the tile numbering system.

This is then taken to the largest microwave oven in America located at the Lockheed Space Operations plant in Sunnyvale, California. After this they are treated in an oven at a temperature of 2,350 F (1,288 C). This process fuses the fibers without actually melting them.

The two types of tiles are essentially the same except for the coatings and cut. No two tiles are exactly alike. They fit by being trimmed to an exact size depending on its location on the shuttle. The tiles form the ultimate “jigsaw puzzle”, only in this case, each piece is numbered so its location is easy to find.

Activity 1

Analyzing Tiles

GRADES

2-4

Time Requirement: 30 minutes

Materials:In the Box

Space Shuttle tile
Food scale

Supplied by user

None

Worksheets

Cost of Launching the
Space Shuttle Tiles
(Worksheet 1)

Reference Materials

None

Key Terms:

Friction



Img. 3 Replacing a shuttle tile.

Objective:

In this activity, students will learn how friction affects the space shuttle.

Activity:

- Show students the picture of the space shuttle from the **Images** section at the end of this document. Ask the students to observe the tiles in the picture. Where have they seen tiles before? What are some uses for tiles? Ask the students to turn to a partner and discuss:
 - Describe the tiles (What is their shape? Color? Are they all the same?)
 - What do you think is the purpose of the tiles?
- Ask the students to rub their hands together. What do they feel? (Students should observe that their hands become warm.) Explain that when objects rub against one another, the force of friction opposes the objects' motion. Friction causes heat. Ask the students to imagine the space shuttle returning to the Earth from the International Space Station. What does the space shuttle rub against as it enters the Earth's atmosphere? (This may take a bit of coaching, but the students should be able to arrive at the conclusion that the shuttle encounters friction due to the air.) Discuss how the friction between the shuttle and the air creates heat.

3. Ask the students what protects the shuttle (and thus the astronauts inside) from the heat? (The tiles.) Can they think of anything that people might use on earth to protect them from heat? (Examples may be pot holders, firefighters wear special suits, or insulating material in your house.)
4. Ask the students to describe common characteristics of heat insulating materials. Lead the students to infer that heat insulating materials are often (but not always) bulky and heavy.
5. Pass around the shuttle tile. The tile is very fragile and students should be instructed on how to handle the tile carefully. *****CAUTION: The tile must stay in the plastic bag!***** Ask the students to describe the tile to their partner as they are observing it. What do they notice? Is it heavy or light? Is its light weight surprising?
6. Ask the students to explain why a low tile weight would be advantageous for the space shuttle. (The greater the weight of the shuttle, the more energy and thus more money it takes to launch.)
7. Now we will calculate the cost to launch the shuttle tile into space!

**Note: Numbers in the following calculations are for example only. Class calculation will vary by individual tile.*

- a. Determine the weight (in pounds) of the shuttle tile with a small scale that might be used to weigh foods.

Tile weight: 0.8 lb

- b. Determine the area of the shuttle tile.

1. Multiply the length times the width of the shuttle tile.

$$\text{Length} \cdot \text{Width} = \text{Area}$$

$$6 \text{ in} \cdot 6 \text{ in} = 36 \text{ in}^2$$

2. Divide the area (in square inches) by the number of square inches in a square foot (144) to determine the size of the area in square feet.

$$\frac{\text{Area in in}^2}{144 \text{ in}^2/\text{ft}^2} = \text{Area in ft}^2$$

$$\frac{36 \text{ in}^2}{144 \text{ in}^2/\text{ft}^2} = 0.25 \text{ ft}^2$$

- c. Assume the tiled surface area of the Space Shuttle is 15x22 feet. Determine the number of square feet in this area.

$$15 \text{ ft} \cdot 22 \text{ ft} = 330 \text{ ft}^2$$

- d. Calculate the number of tiles in this area by dividing the number of square feet in the area by the area of the shuttle tile (in square feet).

$$\frac{\text{Tiled area of shuttle}}{\text{Area of one tile}} = \text{number of tiles}$$

$$\frac{330 \text{ ft}^2}{0.25 \text{ ft}^2/\text{tile}} = 1320 \text{ tiles}$$

- e. Determine the total weight in pounds for the number of tiles identified above.

$$\text{Number of tiles} \cdot \text{weight of one tile} = \text{total weight}$$

$$1320 \text{ tiles} \cdot 0.8 \text{ lbs/tile} = 1056 \text{ lbs}$$

- f. It costs about \$10,000 per pound to launch the shuttle into space. Determine the cost to launch the weight of the tiles into space.

$$\text{Total weight} \cdot \$10,000/\text{lb} = \text{cost}$$

$$1056 \text{ lbs} \cdot \$10,000/\text{lb} = \$10,560,000$$

Discussion Points:

Have the students explain why a thermal protection system is so important for human space flight.

1. Have the students explain why it is important to create a thermal protection system with the least weight possible.
2. Have the students discuss why it is so expensive to launch an object into orbit.
3. Have the students identify thermal protection systems in their homes or school used to keep the structure warm in the winter and cool in the summer. Have the students discuss what kind of costs they are saving with these systems.
4. Discuss ways to reduce friction. Have students look around the classroom and home and identify ways to reduce friction, such as oiling the hinges on doors, waxing skis, etc.
5. Invite a local firefighter to visit your classroom to demonstrate and discuss how he or she uses thermal protection gear.

NATIONAL SCIENCE STANDARDS 2-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Motions and Forces

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES

- Science and technology in society

NATIONAL MATH STANDARDS K-12

NUMBER AND OPERATIONS

- Understand numbers, ways of representing numbers, relationships among numbers, and number systems
- Understand meanings of operations and how they relate to one another
- Compute fluently and make reasonable estimates

ALGEBRA

- Represent and analyze mathematical situations and structures using algebraic symbols
- Use mathematical models to represent and understand quantitative relationships

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- Problem Solving
- Communication
- Connections
- Representation

Glossary

Acceleration:

is the rate of change of velocity. An object is accelerating if it is changing its velocity.

Energy:

is the capacity for doing work. You must have energy to accomplish work - it is like the "currency" for performing work. To do 1000 Joules of work, you must expend 1000 Joules of energy.

Friction:

is the surface resistance to relative motion, as of a body sliding or rolling.

Joule:

is the unit of energy equal to the energy exerted by a force of one Newton acting to move an object through a distance of one meter.

Kinetic Energy:

is the energy of motion

Mass:

is a measurement of how much matter there is in a body.

Newton:

is the unit of force equal to the force required to cause a mass of one kilogram to accelerate at a rate of one meter per second squared.

Power:

is the rate of doing work or the rate of using energy, which are numerically the same. If you do 100 Joules of work in one second (using 100 Joules of energy), the power is 100 Watts.

Work:

refers to an activity involving a force and movement in the direction of the force. A force of 20 Newtons pushing an object 5 meters in the direction of the force does 100 Joules of work.

MUSEUM IN A BOX

Student Worksheets

Worksheet 1 Cost of Launching the Space Shuttle Tiles

1. Determine the weight (in pounds) of the shuttle tile with a small scale that might be used to weigh foods.

Tile weight: lb

2. Determine the area of the shuttle tile.

1. Multiply the length times the width of the shuttle tile.

Length • Width = Area

$$\text{in} \cdot \text{in} = \text{in}^2$$

2. Divide the area (in square inches) by the number of square inches in a square foot (144) to determine the size of the area in square feet.

$$\frac{\text{Area in in}^2}{144 \text{ in}^2/\text{ft}^2} = \text{Area in ft}^2$$

$$\frac{\text{in}^2}{144 \text{ in}^2/\text{ft}^2} = \text{ft}^2$$

- c. Assume the tiled surface area of the Space Shuttle is 15x22 feet. Determine the number of square feet in an area.

$$15 \text{ ft} \cdot 22 \text{ ft} = \text{ft}^2$$

- d. Calculate the number of tiles in this area by dividing the number of square feet in the area by the area of the shuttle tile (in square feet).

$$\frac{\text{Tiled area of shuttle}}{\text{Area of one tile}} = \text{number of tiles}$$

$$\frac{\text{ft}^2}{\text{ft}^2/\text{tile}} = \text{tiles}$$

- e. Determine the total weight in pounds for the number of tiles identified in ab ve.

Number of tiles • weight of one tile = total weight

$$\text{tiles} \cdot \text{lbs/tile} = \text{lbs}$$

- f. It costs about \$10,000 per pound to launch the shuttle into space. Determine the cost to launch the weight of the tiles in space.

Total weight • \$10,000/lb = cost

$$\text{lbs} \cdot \$10,000/\text{lb} = \$$$



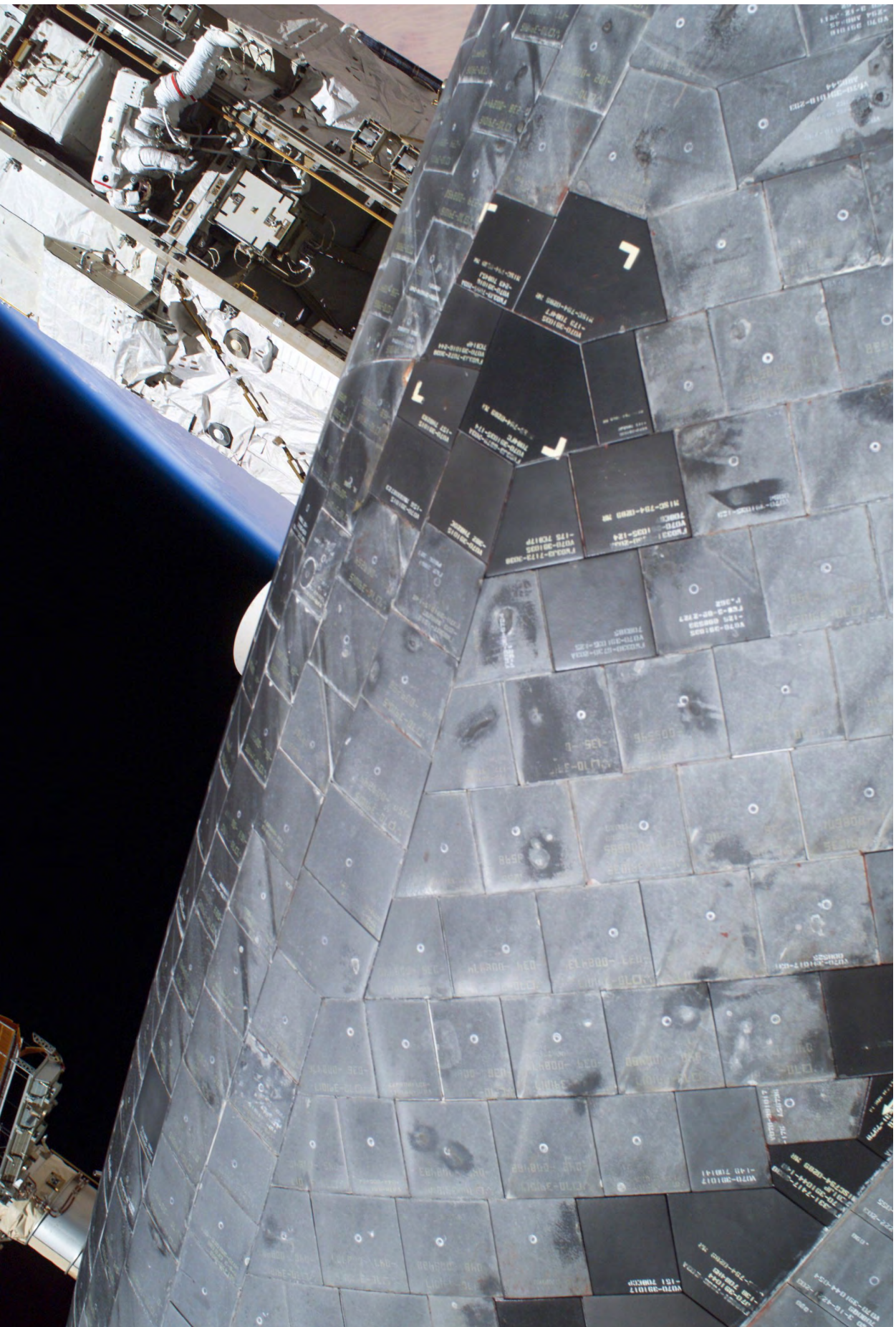
Images

Img. 1 The Space Shuttle Atlantis in orbit.



(Photo courtesy of NASA - www.nasaimages.org)

Img. 2 A close-up of the underside of the orbiter.



(Photo courtesy of NASA - www.nasaimages.org)

Img. 3 Replacing a shuttle tile.



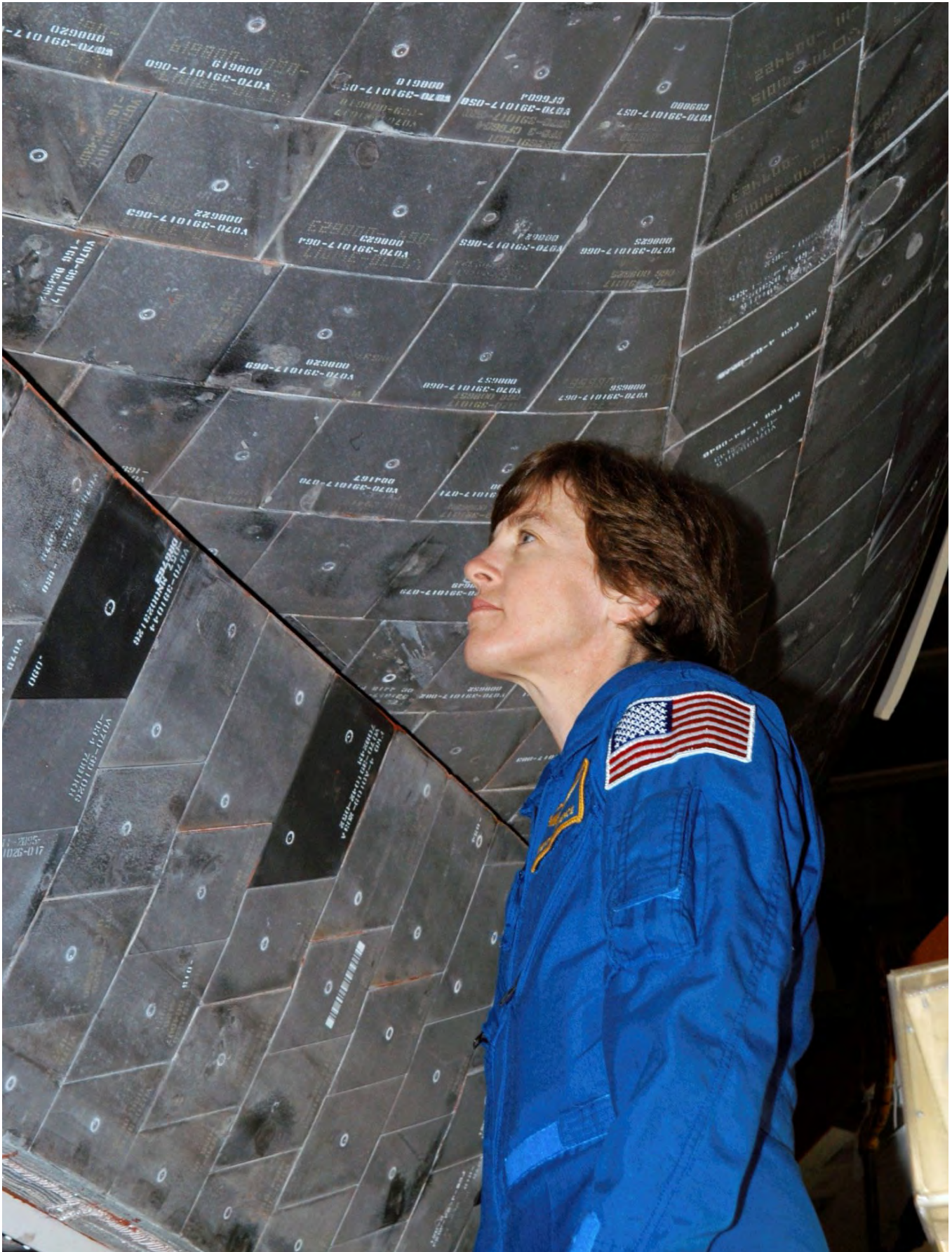
(Photo courtesy of NASA - www.nasaimages.org)

Img. 4 A damaged tile from Space Shuttle Endeavor. The tile was damaged on Mission STS-118 when a piece of foam from the external tank broke off during launch.



(Photo courtesy of NASA - www.nasaimages.org)

Img. 5 A close-up of the tile numbering system.



(Photo courtesy of NASA - www.nasaimages.org)

Img. 6 The underside of the Space Shuttle in orbit.



(Photo courtesy of NASA - www.nasaimages.org)

Img. 7 The underside of the Space Shuttle during re-entry.

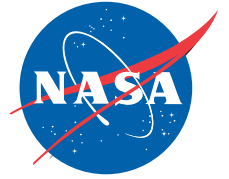


(Photo courtesy of NASA - www.nasaimages.org)

Aeronautics
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structures and materials



GRADES

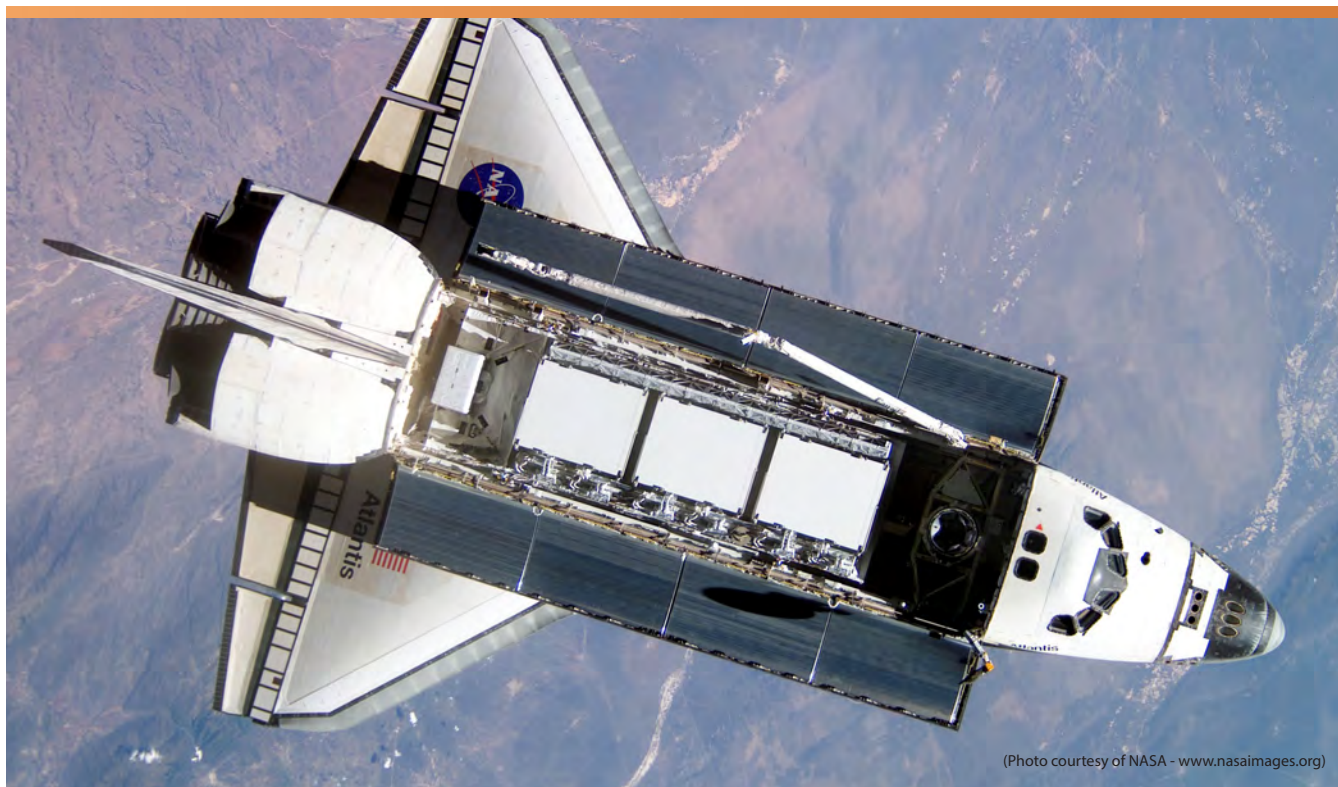
5-8

Space Shuttle Tiles

structures and materials

Aeronautics
Research
Mission
Directorate





(Photo courtesy of NASA - www.nasaimages.org)

Img. 1 The Space Shuttle Atlantis in orbit.

Space Shuttle Tiles

Lesson Overview

This activity is divided into 2 parts—Activity 1 Shuttle Tile Density and Activity 2 Thermal Properties. During the first task the students will determine the density of the shuttle tile included in the MIB. The students will then do Activity 2 to demonstrate the thermal properties of a shuttle tile. Use the background material as a lead into the activity.

SAFETY NOTE FOR SHUTTLE TILE:

The silica material in shuttle tiles is not classified as hazardous either by Federal SARA or CERCLA standards. However, material from the silica fiber layer can cause temporary irritation of the throat and/or itching of the eyes and skin so that touching a bare tile should be avoided. For your convenience, the tile is sealed in a protective plastic wrapping. The plastic wrap should not be removed. Never touch the shuttle tile. More information is available through MSDS (www.MSDS.gov).

Objectives

1. Determine density of a shuttle tile and compare its density with those of other materials
2. Students will determine the thermal properties of 2 different cups of hot water.

Materials:

Included in MIB

Space Shuttle tile
Food scale

Provided by User

Foam cups (1 per group)
Paper cups (1 per group)
Hot water
Thermometers (1 per group)
Two balls of approximately the same size, but different weights, such as a baseball and a tennis ball

GRADES

5-8

Time Requirements: 1 hour

Background

Shuttle Tiles

A key to a successful thermal protection system for the Space Shuttle depends on two things—light weight and the ability to withstand the high temperatures of reentry.

When the space shuttle de-orbits and begins to return to Earth, it faces a serious problem due to frictional heating. Protecting the shuttle and the crew from such heat is very important. When the shuttle reenters Earth's atmosphere at about 400,000 feet or about 122 km, it is traveling at about 25 times the speed of sound (Mach 25). It uses the friction of reentry to slow the shuttle down, but in doing so it pays a price in the form of frictional heating. Temperatures on the shuttle reach several thousand degrees. If the shuttle had a metal exterior like an airplane, it would be burn up due to the heat produced by the friction.

The tiles on the shuttle provide a means for thermal protection.

There are some 24,300 tiles that measure about six inches long on each side (15.25cm) and vary in thickness from 1 to 5 inches (2.54 to 12.7 cm) depending on where they are attached. They are made up of what is called a porous silicon material that is very light and extremely heat resistant. There are two main types of tiles, one a black-coated tile called HRSI for High-Temperature Reusable Surface Insulation tile. These tiles can withstand up to 2,300 degrees F (1,260 degrees C). They cover the bottom of the shuttle, areas around the forward windows, and several other key areas. The densities of these tiles range from 9-22 pounds per cubic foot.



Img. 2 A close-up of the underside of the orbiter.



(Photo courtesy of NASA - www.nasaimages.org)

The second type are white-coated tiles and are Low Temperature Reusable Surface Insulation (LRSI). They are made to insulate the shuttle up to 1,200 degrees F (650 degrees C). These tiles are usually larger and thinner, 8 inches long on each side (20.3cm) and from less than a half inch (1 cm) thick up to 1 inch (2.54 cm) in thickness. The densities range from 9 to 12 pounds per cubic foot.

The making of tiles begins with pure silica that comes from refined sand. This material is formed in fibers and mixed with pure water and other chemicals and then poured into a mold where the excess water is squeezed



(Photo courtesy of NASA - www.nasaimages.org)

A close-up of the tile numbering system.

out. This is then taken to the largest microwave oven in America located at the Lockheed Space Operations plant in Sunnyvale, California. After this they are treated in an oven at a temperature of 2,350 F (1,288 C). This process fuses the fibers without a tually melting them.

The two types of tiles are essentially the same except for the coatings and cut. No two tiles are exactly alike. They fit y being trimmed to an exact size depending on its location on the shuttle. The tiles form the ultimate "jigsaw puzzle", only in this case, each piece is numbered so its location is easy to fin .

Activity 1

Shuttle Tile Density

GRADES

5-8

Time Requirement: 30 minutes

Materials:In the Box

Space Shuttle tile
Food scale

Supplied by user

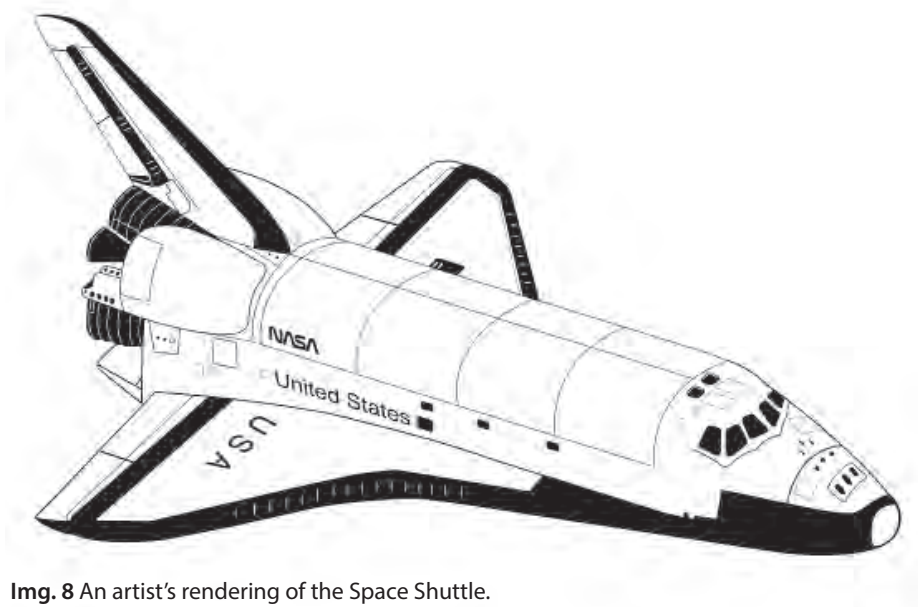
A Baseball
A Tennis ball

Worksheets

Shuttle Tile Volume
(Worksheet 1)

Reference Materials

None



Img. 8 An artist's rendering of the Space Shuttle.

Objective:

Discover how material densities affect a Space Shuttle launch.

Activity:

1. Toss the baseball and tennis ball in your hands. Ask the students to describe what is different about the balls. Infer how the difference in weight (and thus the densities of the balls) would affect how the balls are thrown. Students may say that you need more force to throw the baseball than to throw the tennis ball the same distance. Lead the students to discuss how the force exerted on the balls is proportional to the work done in throwing the balls and thus, the amount of energy. They should arrive at the conclusion that it takes more energy to move a heavier ball than one of less weight.
2. Discuss how you would find the densities of the balls (mass/ volume). They both have the same approximate volume, but because the baseball has more mass (and thus more weight), it is more dense.
3. Explain that engineers must consider many factors when designing and choosing materials for various purposes. Show the students the picture of the space shuttle orbiter. Point out the tiles and ask the students to infer the function of the tiles. (To protect the shuttle (and thus the shuttle occupants)

from heat that is produced (from friction) as the shuttle moves through the atmosphere.) Show the students the space shuttle tile. What would be some characteristics of materials that engineers would find desirable for a shuttle tile? As students name characteristics, write these on the board or on chart paper. (Low cost, safe, durable, high thermal insulating ability, low density.) Now, go back to the analogy with the tennis ball and baseball – why would good material for a space shuttle tile be low density? (Less weight takes less energy (and less cost) to launch into space.) Pass the shuttle tile around. The tile is very fragile and students should be instructed on how to handle the tile carefully. **** CAUTION – The tile must stay in the plastic bag! **** Now we will determine the density of the space shuttle tile and compare it to the density of other objects.

4. Perform the following density calculations.

**Note: Numbers in the following calculations are for example only. Class calculation will vary by individual tile.*

- a. Determine the volume of the shuttle tile. Measure its length, width and height then multiply these numbers to determine the volume in cubic inches.

$$\text{length} \cdot \text{width} \cdot \text{height} = \text{volume}$$

$$6 \text{ in} \cdot 6 \text{ in} \cdot 3 \text{ in} = 108 \text{ in}^3$$

- b. Weigh the shuttle tile.

Tile weight: 0.8 lb

- c. Determine the density of the shuttle tile

$$\frac{\text{Weight}}{\text{Volume}} = \text{Density (lbs/in}^3\text{)} \quad \frac{.08 \text{ lb}}{108 \text{ in}^3} = 0.0074 \text{ lbs/in}^3$$

- d. Compare the density of a shuttle tile with the density of other materials. The density of several common materials are listed below. Convert the density measurement for each of these materials to pounds/cubic inch. To do this, divide the measurement by the number of cubic inches in a cubic foot, which is 1,728 in³.

Aluminum

$$\frac{165 \text{ lb/ft}^3}{1,728 \text{ in}^3/\text{ft}^3} = 0.0955 \text{ lbs/in}^3$$

Iron

$$\frac{495 \text{ lb/ft}^3}{1,728 \text{ in}^3/\text{ft}^3} = 0.2865 \text{ lbs/in}^3$$

Material	Density lbs/ft ³	Density lbs/in ³
Metal		
Aluminum	165 lbs/ft ³	0.0955 lb/in ³
Iron	495 lbs/ft ³	0.2865 lb/in ³
Gold	1204 lbs/ft ³	0.6968 lb/in ³
Woods		
Pine	26 lbs/ft ³	0.0150 lb/in ³
Oak	59 lbs/ft ³	0.0341 lb/in ³
Shuttle Tile	--	0.0074 lb/in ³

- f. Arrange the items above including the shuttle tile from least density per cubic inch to highest density.

Answer: 1. Tile 2. Pine 3. Oak 4. Aluminum 5. Iron 6. Gold

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES

- Science and technology in society

NATIONAL MATH STANDARDS K-12

NUMBER AND OPERATIONS

- Understand numbers, ways of representing numbers, relationships among numbers, and number systems
- Understand meanings of operations and how they relate to one another
- Compute fluently and make reasonable estimates

ALGEBRA

- Represent and analyze mathematical situations and structures using algebraic symbols
- Use mathematical models to represent and understand quantitative relationships

MEASUREMENT

- Understand measurable attributes of objects and the units, systems, and processes of measurement
- Apply appropriate techniques, tools, and formulas to determine measurements.

DATA ANALYSIS AND PROBABILITY

- Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them

PROCESS

- Problem Solving
- Communication
- Connections
- Representation

Activity 2

Thermal Properties

GRADES**5-8****Time Requirement:** 30 minutes**Materials:**In the Box

Space Shuttle tile

Supplied by userFoam cups
(1 per group)Paper cups
(1 per group)Hot water
Thermometers
(1 per group)WorksheetsThermal Properties
of a Paper and
Styrofoam Cup
(Worksheet 2)Reference Materials

Figure 1

Activity:

1. Explain to the students that heat is a form of energy that we refer to as thermal energy, while conduction is the flow of energy from one object to another. Emphasize that heat energy always moves from a warmer object or area to a cooler object or area. An example is an ice cube that you hold in your hand. The heat energy moves from your hand to the ice cube causing it to melt. Many students think that the cold is leaving the ice cube and entering their hand. (That is certainly what it feels like!) However, what is really happening is that thermal energy is leaving your warm hand and going to ice cube.

Some objects have high thermal conductivity, meaning thermal energy transfers more quickly between the objects. Other objects have a lower thermal conductivity and do not transfer thermal energy as well. Many students believe that objects such as blankets and sweaters actually generate heat. They do not. Sweaters and blankets are good insulators. They do not allow heat to easily leave your body. They keep you warm by restricting heat flow between your body and the environment, not by generating heat.

2. Refer to the list of desirable shuttle tile characteristics that was generated earlier. We have already discussed that the tiles need to have a low density. Another characteristic of the tile is that it must be a good thermal insulator. Thermal insulators do not allow heat to flow easily from one material to another. The friction between the shuttle and the atmosphere generates an enormous amount of heat. The tiles are good insulators and they protect the shuttle from the heat. Compare and contrast the terms “insulator” and “conductor.” Draw a chart on the board or on chart paper and list materials known to students as good insulators of heat and good conductors of heat. Record all answers – even those that are incorrect.
3. Explain to the students that they will be working in groups to determine the thermal properties of paper and Styrofoam cups. First ask the students to discuss with their partners what they already know about paper and Styrofoam cups.

4. Ask the students to use their background knowledge of the cups to create a hypothesis regarding which cup will keep water warm the longest – paper or Styrofoam? Students should record their hypothesis on their Thermal Properties of a Paper and Styrofoam Cup worksheet.
5. Ask the students to design an experiment to test their hypothesis. Explain that they will be given a paper cup and a Styrofoam cup and a thermometer. What will the variables be? What will the procedure be? Students should discuss their experimental design with their partners and record the variables and procedure on their worksheet. Go over their procedures. The recommended procedure is as follows:
 - a. Pour an equal amount of hot (not boiling) water into each cup.
 - b. Measure and record the temperature of the water in each cup.
 - c. After 1 minute, measure and record the temperature of the water in the cups. Each team member should also feel the outside of the cup.
 - d. Repeat Step 3 every minute for ten minutes.
 - e. If possible, have the students determine how long it will take for the temperature of the water in both cups to reach the same temperature.
6. Students should begin the experiment. ****CAUTION: Students should be instructed to use care when working with hot water.**** Students should record their data in the data chart provided in the handout, or they can create their own data chart. Students should also answer the analysis questions and write a conclusion summarizing their finding .
7. Refer back to the chart the class created comparing insulators and conductors. Are there any corrections to be made? Be sure that Styrofoam and Shuttle Tiles are listed as insulators.

Discussion Points:

1. Explain why you would choose a Styrofoam cup to keep your cold drink cold during the summer?
2. Explain how the space shuttle tile is able to protect the shuttle from the heat when re-entering the earth's atmosphere. Have them use the terms: thermal energy, conductivity, and heat transfer. *A possible answer might be that thermal energy is transferred to the shuttle tile due to air friction in reentry. The shuttle tile has a very low conductivity and therefore does not allow the thermal energy to be transferred through it to the shuttle. Refer to the conductivity rate in the Some Specifics of Shuttle Tile chart Fig. 1.*
3. What is meant by the term density?
4. What are characteristics of low density materials?
5. Have students identify and classify materials in their homes as either conductors or insulators. Are there any common characteristics among the materials in either group? What makes a material a good conductor or insulator?

NATIONAL SCIENCE STANDARDS 5-8

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NATIONAL MATH STANDARDS K-12

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Joule:

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is the energy of motion

Mass:

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Newton:

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Work:

refers to an activity involving a force and movement in the direction of the force. A force of 20 Newtons pushing an object 5 meters in the direction of the force does 100 Joules of work.



Reference Materials

MUSEUM IN A BOX - REFERENCE MAT

Fig. 1 Some Specifics of Shuttle Tile

Some of the specifics of the shuttle tile:	
Density	9 lb/ft ³
Specific heat	.15 BTU/lb-°F
Thermal conductivity	.028 BTU/ft-hr-°F at 70°F and 1 atm .073 BTU/ft-hr-°F at 2000°F and 10 ⁻⁴ atm
Maximum reuse temperature	>2300°F
Maximum single use temperature	2800°F
Reusability at 2300°F	>100 missions

MUSEUM IN A BOX

Student Worksheets



Worksheet 1 Shuttle Tile Volume

- Determine the volume of the shuttle tile. Measure its length, width and height then multiply these numbers to determine the volume in cubic inches.

$$\text{length} \cdot \text{width} \cdot \text{height} = \text{volume}$$

$$\square \text{ in} \cdot \square \text{ in} \cdot \square \text{ in} = \square \text{ in}^3$$

- Weigh the shuttle tile.

$$\text{Tile weight: } \square \text{ lb}$$

- Determine the density of the shuttle tile

$$\frac{\text{Weight}}{\text{Volume}} = \text{Density (lbs/in}^3\text{)} \quad \frac{\square \text{ lb}}{\square \text{ in}^3} = \square \text{ lbs/in}^3$$

- Compare the density of a shuttle tile with the density of other materials. The density of several common materials are listed below. Convert the density measurement for each of these materials to pounds/cubic inch. To do this, divide the measurement by the number of cubic inches in a cubic foot, which is 1,728 in³.

Aluminum

$$\frac{165 \text{ lb/ft}^3}{1,728 \text{ in}^3/\text{ft}^3} = \square \text{ lbs/in}^3$$

Material	Density lbs/ft ³	Density lbs/in ³
Metal		
Aluminum	165 lbs/ft ³	lb/in ³
Iron	495 lbs/ft ³	lb/in ³
Gold	1204 lbs/ft ³	lb/in ³
Woods		
Pine	26 lbs/ft ³	lb/in ³
Oak	59 lbs/ft ³	lb/in ³
Shuttle Tile	--	lb/in ³

- Arrange the items above including the shuttle tile from least density per cubic inch to highest density.

-
-
-
-
-
-

Worksheet 2 Thermal Properties of a Paper and Styrofoam Cup

Hypothesis: If hot water is placed into paper and Styrofoam cups, then...

Independent Variable: _____

Dependent Variable: _____

Procedure: _____

Thermal Properties of a Paper and Styrofoam Cup

Paper Cup		Styrofoam Cup	
Time in Minutes	Temperature	Time in Minutes	Temperature
Starting Temperature			
1 minute		1 minute	
2 minutes		2 minutes	
3 minutes		3 minutes	
4 minutes		4 minutes	
5 minutes		5 minutes	
6 minutes		6 minutes	
7 minutes		7 minutes	
8 minutes		8 minutes	
9 minutes		9 minutes	
10 minutes		10 minutes	
Average		Average	

Worksheet 2 Continued

Analysis:

1. Which cup loses heat more quickly?

2. What might account for the differences between the cups?

3. What was the percent of the original temperature in each cup? As an example, if the original temperature was 100° and at the end of 10 minutes it was still 100° it would be 100 percent; however if it was only 90° , it would only be 90 percent of the original temperature. What is the percent of the original temperature in the paper cup _____ and Styrofoam cup _____?

4. What might be some ways to reduce the thermal conductivity even more?

5. If you put cold water in the cups instead of hot water would the temperature change be the same?

Conclusion:



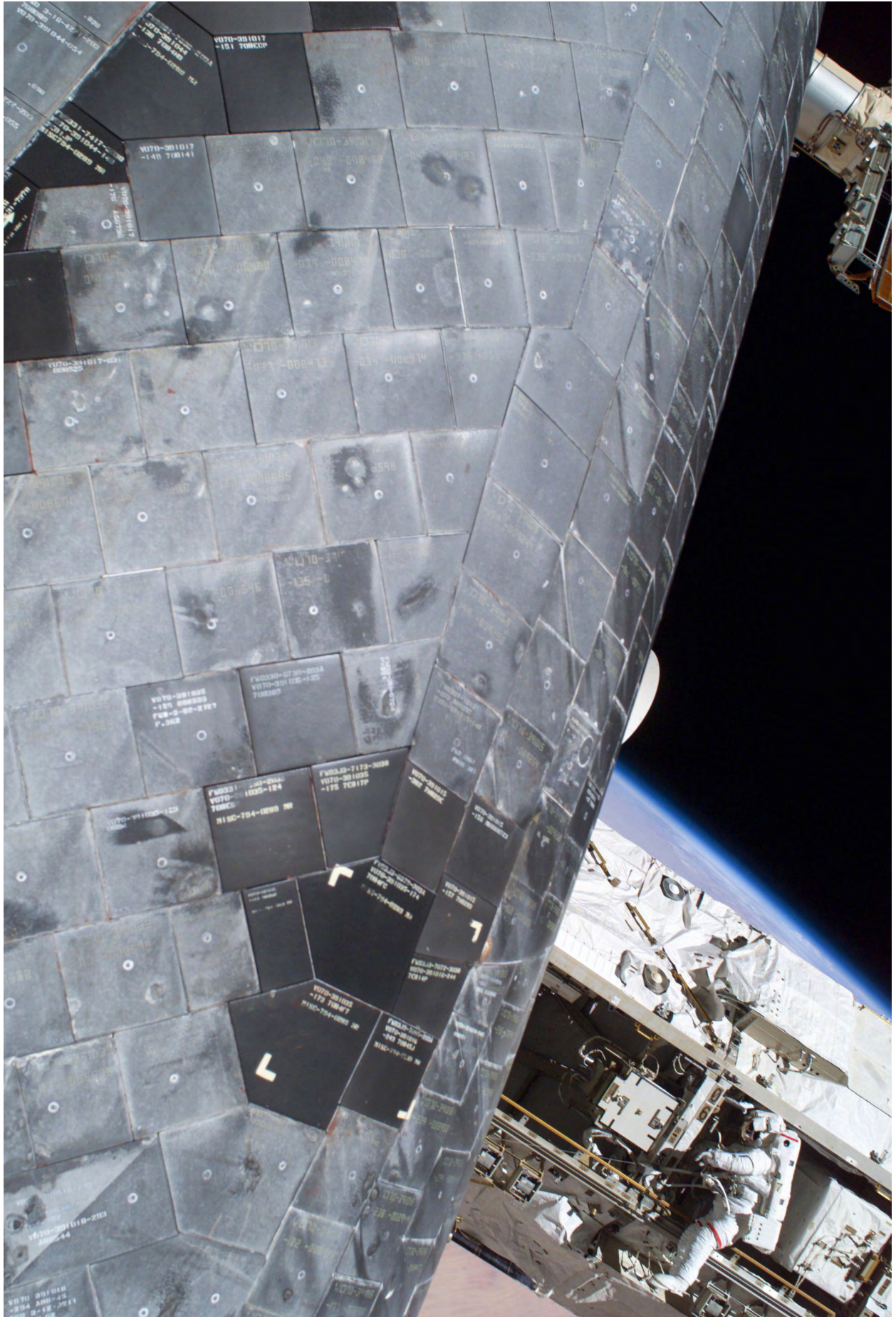
Images

Img. 1 The Space Shuttle Atlantis in orbit.



(Photo courtesy of NASA - www.nasaimages.org)

Img. 2 A close-up of the underside of the orbiter.



(Photo courtesy of NASA - www.nasaimages.org)

Img. 3 Replacing a shuttle tile.



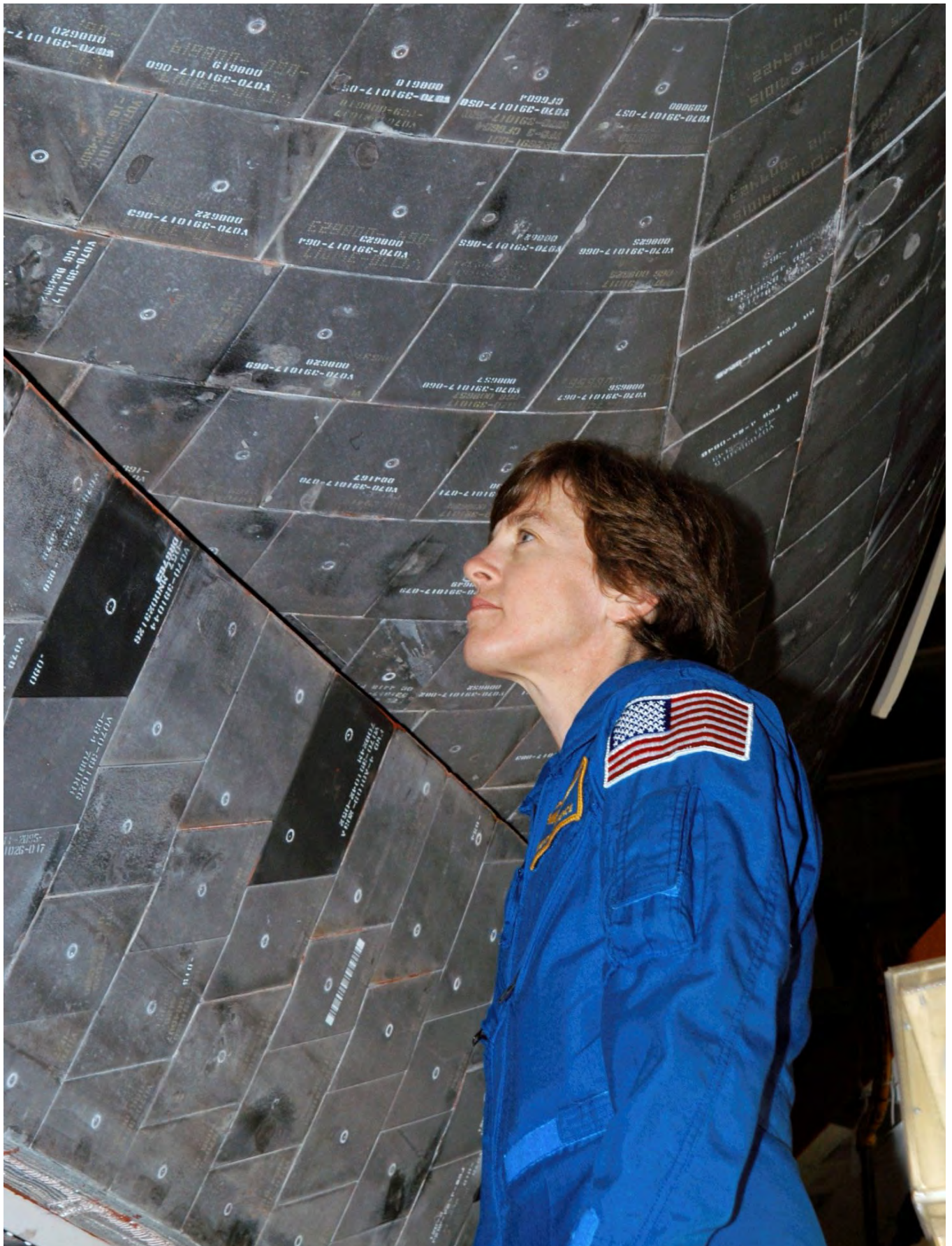
(Photo courtesy of NASA - www.nasaimages.org)

Img. 4 Shuttle tile showing signs of damage.



(Photo courtesy of NASA - www.nasaimages.org)

Img. 5 A close-up of the tile numbering system.



MUSEUM IN A BOX - IMAGES

(Photo courtesy of NASA - www.nasaimages.org)

Img. 6 The underside of the Space Shuttle in orbit.



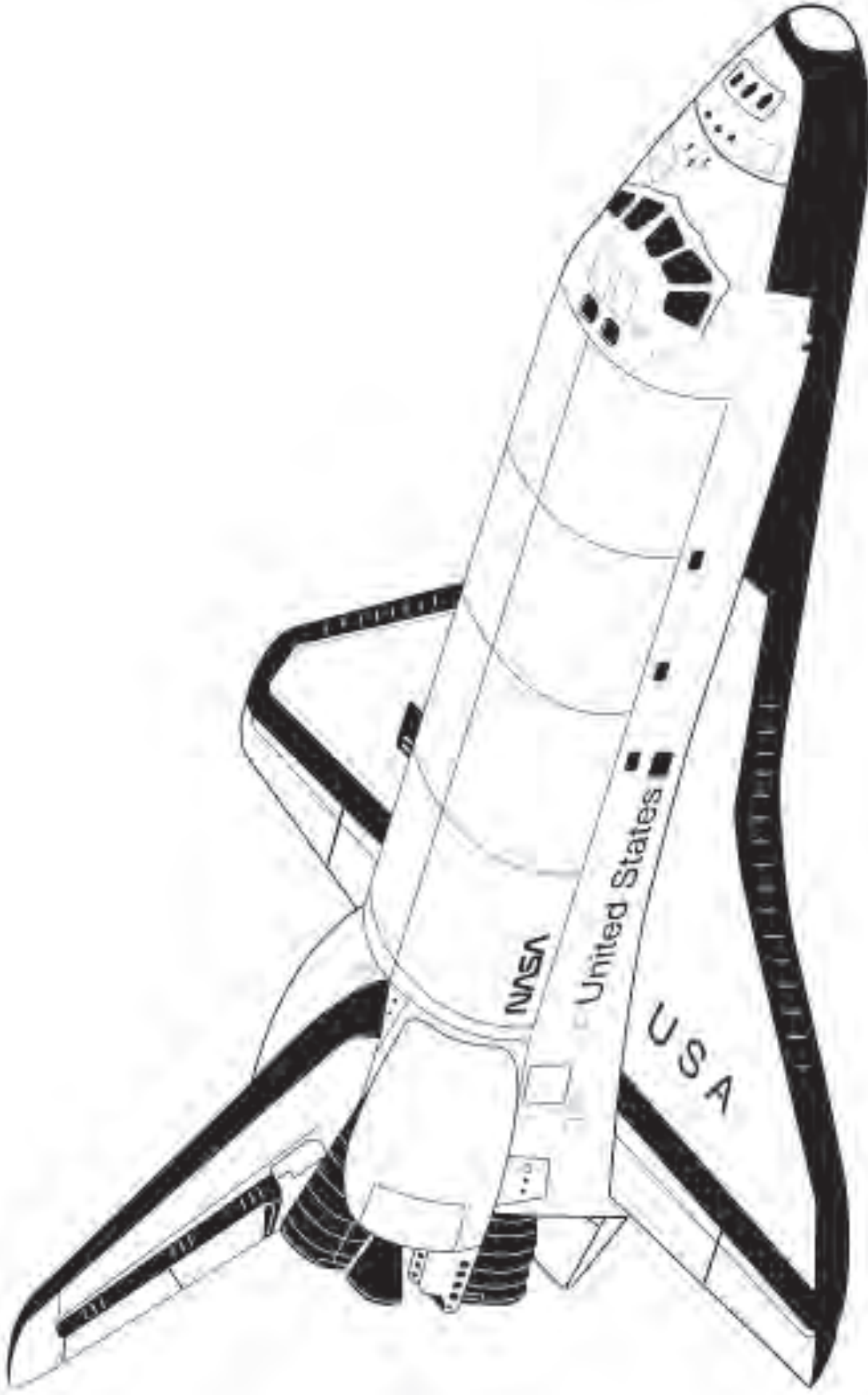
(Photo courtesy of NASA - www.nasaimages.org)

Img. 7 The underside of the Space Shuttle during re-entry.



(Photo courtesy of NASA - www.nasaimages.org)

Img. 8 An artist's rendering of the Space Shuttle.

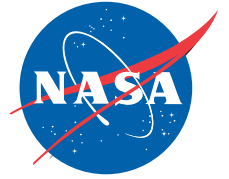


(Photo courtesy of NASA - www.nasaimages.org)

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structures and materials



GRADES

9-12

Space Shuttle Tiles

structures and materials

Aeronautics
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Img. 1 The Space Shuttle Atlantis in orbit.

Space Shuttle Tiles

Lesson Overview

In this lesson, students observe the properties of a space shuttle tile and consider how these properties relate to the threats imposed on the shuttle by space debris. The students will use a tissue paper covered box to represent the tile as they experiment to determine the amount of energy required to penetrate the tissue paper.

SAFETY NOTE FOR SHUTTLE TILE:

The silica material in shuttle tiles is not classified as hazardous either by Federal SARA or CERCLA standards. However, material from the silica fiber layer can cause temporary irritation of the throat and/or itching of the eyes and skin so that touching a bare tile should be avoided. For your convenience, the tile is sealed in a protective plastic wrapping. The plastic wrap should not be removed. Never touch the shuttle tile. More information is available through MSDS (www.MSDS.gov).

Objectives

1. Compare the effect on tissue paper penetration between objects of different masses traveling the same speed.

Materials:

Included in MIB

Space Shuttle tile
Scale or balance

Provided by User

Small objects, i.e. popcorn kernels, marbles, ball bearings (up to 10 per group)
Boxes, i.e. shoebox, cardboard or plastic (1 per group)
Tissue paper (the kind for wrapping gifts; enough to cover the opening of each box)
Tape
Eye protection (1 pair per student)
Meter stick (1 per group)

GRADES

9-12

Time Requirements: 30 minutes

Background

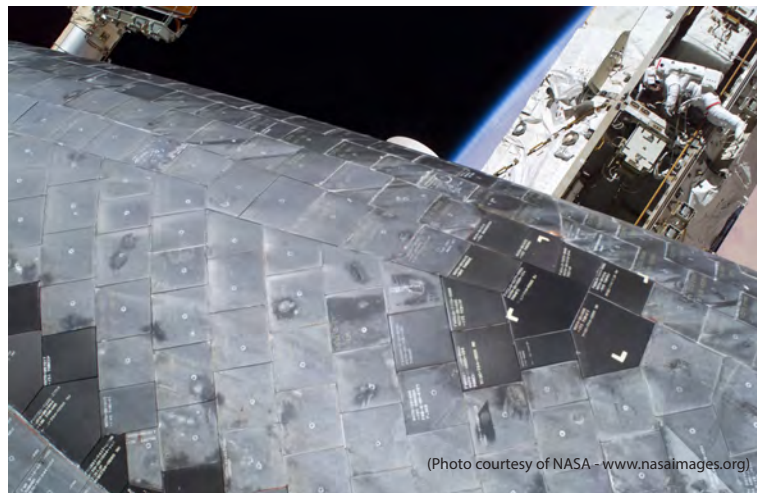
Shuttle Tiles

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When the space shuttle de-orbits and begins to return to Earth, it faces a serious problem due to frictional heating. Protecting the shuttle and the crew from such heat is very important. When the shuttle reenters Earth's atmosphere at about 400,000 feet or about 122 km, it is traveling at about 25 times the speed of sound (Mach 25). It uses the friction of reentry to slow the shuttle down, but in doing so it pays a price in the form of frictional heating. Temperatures on the shuttle reach several thousand degrees. If the shuttle had a metal exterior like an airplane, it would be burn up due to the heat produced by the friction.

The tiles on the shuttle provide a means for thermal protection.

There are some 24,300 tiles that measure about six inches long on each side (15.25cm) and vary in thickness from 1 to 5 inches (2.54 to 12.7 cm) depending on where they are attached. They are made up of what is called a porous silicon material that is very light and extremely heat resistant. There are two main types of tiles, one a black-coated tile called HRSI for High-Temperature Reusable Surface Insulation tile. These tiles can withstand up to 2,300 degrees F (1,260 degrees C). They cover the bottom of the shuttle, areas around the forward windows, and several other key areas. The densities of these tiles range from 9-22 pounds per cubic foot.



Img. 2 A close-up of the underside of the orbiter.

The second type are white-coated tiles and are Low Temperature Reusable Surface Insulation (LRSI). They are made to insulate the shuttle up to 1,200 degrees F (650 degrees C). These tiles are usually larger and thinner, 8 inches long on each side (20.3cm) and from less than a half inch (1 cm) thick up to 1 inch (2.54 cm) in thickness. The densities range from 9 to 12 pounds per cubic foot.

The shuttle tile is made of a material which is a silica, alumina fiber and borosilicate glass composite. The making of tiles begins with pure silica that comes from refined sand. This material is formed in fibers and mixed with



Img. 4 A damaged tile from Space Shuttle Endeavor. The tile was damaged on Mission STS-118 when a piece of foam from the external tank broke off during launch.

pure water and other chemicals, then poured into a mold where the excess water is squeezed out. This is then taken to the largest microwave oven in America located at the Lockheed Space Operations plant in Sunnyvale, California. After this, they are treated in an oven at a temperature of 2,350 F (1,288 C). This process fuses the fibers without actually melting them.

The two types of tiles are essentially the same except for the coatings and cut. No two tiles are exactly alike. They fit by being trimmed to an exact size depending on its location on the shuttle. It is the ultimate jigsaw puzzle, only in this case each piece is numbered so its location is easy to find.

One of the problems with the insulation material used to protect the shuttle is its inherent fragile nature. The tiles feel a bit like Styrofoam and their surfaces easily compress or rub off onto other surfaces, such as hands. Great care must be taken when installing them to the surface of the shuttle so as to not damage them before launch. However, once installed, there are still several possible hazards, the first of which is ice.

This may sound strange, as the launch facility is located in Florida, a state that seldom sees ice. The ice comes from the main fuel tank for the shuttle. This large, orange, silo shaped object to which the shuttle and solid rocket engines are attached is filled with two liquids: Hydrogen and Oxygen. These liquids are extremely cold (Liquid Oxygen is -183°C and liquid Hydrogen is -253°C). The tank that holds them is insulated with a thick foam-like material. This, however, is not enough, for the humid warm air of the area condenses and freezes to its surface. Upon launch, pieces of the built up ice fall off and, in some cases, impact certain areas of the shuttle. These impacts can cause considerable damage to the delicate material that makes up each tile.

The second danger is a constant threat to space travel: impacts caused by space debris. Space debris consists of everything from entire spent rocket stages and non-operational satellites, to explosion fragments, paint flakes, slag from solid rocket motors as well as many other objects. A collision with a 2.2 pound object at orbital velocities will typically destroy a spacecraft. Thank goodness the vast majority of the estimated tens of millions of pieces of space debris are small particles, like paint flakes and solid rocket fuel slag. Contact with these particles causes erosive damage, similar to sandblasting. Notice the damaged tile in **image 4**. The pit was caused by a piece of foam from the external tank striking one of the shuttle's tiles during launch.

Activity 1

Shuttle Tile Density

GRADES 9-12

Time Requirement: 10 minutes

Materials:

In the Box

Space Shuttle tile

Supplied by user

None

Worksheets

Tile Material
Hypothesis
(Worksheet 1)

Activity:

1. Display the shuttle tile.

Ask the students to guess what it is.

2. Pass around the shuttle tile.

****CAUTION! The tile is very fragile and students must be instructed on how to handle it properly. Do not remove the shuttle tile from the plastic bag!****

Do the students have any new guesses now that they have held the tile?

3. Tell the students that they are looking at a shuttle tile. Show the students **image 2** of the shuttle and point out the tiles. Ask the students to infer the purpose of the tiles. (The tiles protect the shuttle (and thus the shuttle occupants) from intense heat that is generated from the friction between the shuttle and the Earth's atmosphere during launch and entry.)
4. Explain that engineers must consider many factors when designing and choosing materials for various purposes. What would be some characteristics of materials that engineers would find desirable for a shuttle tile? As students name characteristics, write these on the board or on chart paper. (Low cost, safe, durable, high thermal insulating ability, low density.) Does the tile match all of the characteristics?
5. Distribute the student worksheets. Explain to the students that the tiles are made from silica (which comes from sand), alumina fiber, and glass composite. What are the costs/benefits of using this material? Ask your students to hypothesize about the impacts of using this material, considering the associated costs and benefits. Have your students record their thinking on their worksheets. (The students will notice that the tile has a low density, which is desirable, since it costs more than \$10,000 per pound to launch items into space! However, they may notice that



Img. 2 A close-up of the underside of the orbiter.

pieces of the tile are crumbling off. The tiles are delicate. The collisions between the tiles and ice (from the external tank) or space debris can cause considerable damage.)

6. After discussing costs and benefit , and in particular, the potential threats to the tile due to debris, show the students the picture of the damaged tile in **image 4**.



Img. 4 A damaged tile from Space Shuttle Endeavor. The tile was damaged on Mission STS-118 when a piece of foam from the external tank broke off during launch.

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES

- Science and technology in local, national, and global challenges

HISTORY AND NATURE OF SCIENCE

- Science as human endeavor
- Nature of scientific knowledge
- Historical perspectives

NATIONAL MATH STANDARDS K-12

NUMBER AND OPERATIONS

- Understand numbers, ways of representing numbers, relationships among numbers, and number systems
- Understand meanings of operations and how they relate to one another
- Compute fluently and make reasonable estimates

ALGEBRA

- Represent and analyze mathematical situations and structures using algebraic symbols
- Use mathematical models to represent and understand quantitative relationships

MEASUREMENT

- Understand measurable attributes of objects and the units, systems, and processes of measurement
- Apply appropriate techniques, tools, and formulas to determine measurements.

DATA ANALYSIS AND PROBABILITY

- Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them

PROCESS

- Problem Solving
- Communication
- Connections
- Representation

Activity 2

Tiles as Shuttle Protection

GRADES 9-12**Time Requirement:** 20 minutes**Materials:**In the Box

Space Shuttle tile
Scale or balance
1

Supplied by user

Small objects,
i.e. popcorn kernels,
marbles, ball bearings,
etc. (up to 10 per group)

Boxes i.e. shoebox,
cardboard or plastic
(1 per group)

Tissue paper i.e. the
kind for wrapping gifts;
enough to cover the
opening of each box

Tape

Eye protection
(1 pair per student)

Meter stick
(1 per group)

Worksheets

Effect of Mass on
the Penetration of
Tissue Paper
(Worksheet 2)

Key Terms:

Kinetic Energy

Activity Overview:

Today we will investigate the effects of debris on the shuttle tiles. We will be representing the debris with small objects (popcorn kernels, dried peas, ball bearings, marbles, etc.) and the tile with a shoebox covered in tissue paper. Ask the students to design an experiment to determine the amount of energy (in Joules) required to penetrate the tissue paper. They should record their procedure on Worksheet 2, Effect of Mass on the Penetration of Tissue Paper. A recommended procedure follows.

Activity:

1. Cover the opening of a box with tissue paper. Stretch the paper tight.
2. Determine the mass of the pea or other light projectile in grams. Then drop the pea or other projectile from a distance of 1 meter onto the tissue paper. Did the pea or object penetrate the tissue paper? Record the mass on the data sheet.
3. Select another object which is slightly heavier than the first object and determine its mass. Then drop this object from a distance of 1 meter onto the tissue paper. Did this object penetrate? Record the mass on the data sheet.
4. Keep dropping heavier objects from 1 meter until the object penetrates the tissue paper. Record the mass of each on the data sheet.
5. Investigate what happens when more than one layer of tissue paper is used to cover the box opening.
6. Solve for the velocity and kinetic energy of each object at impact and record their answers on their data charts.
 - a. Determine the time it takes for an object to fall 1 meter using the following equation:

$$S = \frac{1}{2} at^2$$

S = distance of fall. In this case, distance equals 1 meter.

A = acceleration of a falling body

(assuming no air resistance), equals 9.8 m/s²

T = time

$$1 \text{ meter} = \frac{1}{2} (9.8 \frac{\text{meters}}{\text{sec}^2}) t^2$$

$$t^2 = \frac{2 \text{ meters}}{9.8 \frac{\text{meters}}{\text{sec}^2}}$$

$$t^2 = 0.2 \text{ sec}^2$$

$$t = .45 \text{ sec}$$

The time required for the object to fall one meter is 0.45 seconds.

b. Now solve for velocity:

$$V_f^2 = V_i^2 + 2as$$

$$V_f^2 = 0\text{m}^2 + 2 (9.8 \frac{\text{meters}}{\text{sec}^2}) (1\text{m})^2$$

$$V_f^2 = \frac{19.6\text{m}^2}{1\text{sec}^2}$$

$$V = 4.43 \text{ m/s}$$

Calculate the velocity of each object at the time of its impact with the tissue paper and record your result on your worksheet.

7. Kinetic Energy

When something is in motion, it has kinetic energy (KE). For an object that is moving the kinetic energy equals one half times the mass of the object times the square of the speed of the object. In symbols:

$$KE = \frac{1}{2} mv^2 \quad m \text{ is in kg and } v \text{ in m/sec}$$

Example: Object mass is 3kg and velocity is 5 m/sec

$$KE = \frac{1}{2} (3\text{kg})(5\text{m/sec})^2 = 37.5 \text{ Joules}$$

One Joule is equal to:

- the amount of KE of an adult human moving at a speed of about a handspan every second.
- the amount of KE of a tennis ball moving at 14 miles per hour.

Calculate the kinetic energy of each object at the time of its impact with the tissue paper and record your result on your worksheet.

8. Space Debris Problems

a. A bolt has escaped from a spacecraft and is in orbit around Earth. It is traveling at 20 km/sec and has a mass of 8 grams. Solve for its KE.

Formula: $KE = \frac{1}{2} mv^2$

1. Convert 8 grams into kg; divide by 1,000.

$$1 \text{ kg} = 1,000$$

$$\frac{8 \text{ grams}}{1000 \text{ grams/kg}} = .008 \text{ kg}$$

3. Convert km to meters; multiply by 1000.

$$1 \text{ km} = 1,000 \text{ m}$$

$$20 \text{ km/sec} \cdot 1000 \text{ m/km} = 20,000 \text{ meters/sec}$$

- c. Now solve for KE.

$$KE = \frac{1}{2} (.008 \text{ kg}) \cdot (20,000 \text{ meters/sec})^2 = 1,600,000 \text{ Joules}$$

- b. The bolt in problem 8a has the kinetic energy equivalent to how many pounds of TNT?

1. 1 gram of TNT contains 4.184×10^3 Joules of energy

1 kilogram of TNT contains 4.184×10^6 Joules of energy

Determine the bolt's energy equivalent to 1 kg of TNT. To do this, divide the KE of the bolt by the KE of 1 kg of TNT

$$\frac{1,600,000 \text{ J}}{\frac{4,184,000 \text{ J}}{\text{kg of TNT}}} = 0.382 \text{ kg of TNT}$$

2. There are 2.2 pounds in 1 kilogram. Convert the mass of TNT in kilograms to pounds:

$$\frac{2.2 \text{ lbs}}{1 \text{ kg}} = 0.382 \text{ kg} = 0.84 \text{ lbs}$$

Isn't it amazing that an 8 gram object traveling at 20 km/sec in space hitting an object will release the same amount of energy as exploding 0.84 pounds of TNT?

- c. Now solve for the KE in terms of TNT if the speed of impact were 35 km/sec in the problem above.

1. Calculate the KE

Formula: $V = 35 \text{ km/sec}$
 $KE = \frac{1}{2} mv^2$ $M = 0.008 \text{ kg}$
 $1 \text{ km} = 1,000 \text{ m}$

$$KE = \frac{1}{2} (.008 \text{ kg}) \cdot (35,000 \text{ meters/sec})^2$$

$$KE = 4,900,000 \text{ J}$$

2. Convert to TNT equivalent

$$\frac{4,900,000 \text{ J}}{4,184,000 \text{ J}} = 1.17 \text{ kg of TNT}$$

d. What generalizations can you make from your calculations?

KE is dependent on the square of the velocity. Doubling the velocity will quadruple the KE.

Discussion Points:

1. Have the students define KE and explain why KE can be a problem in space.
2. Have the students come up with solutions to protect a spacecraft from space debris impacts. Research the Skylab II mission for ideas.
3. Have students explain why driving a car at high rates of speed is so dangerous as it relates to KE.
4. Determine the KE of a 3,000 pound car traveling at 60 miles per hour hitting a tree.
Hint: 1 kg = 2.2 lbs.
1 mile = 1.61 km
5. Use the following equation to calculate the deceleration forces generated when an object slows from one speed to another in some given distance. The deceleration is measured in Gs.

$$\text{Deceleration in Gs} = \frac{\text{speed change}^2}{(30) \cdot (\text{deceleration distance})}$$

Assume you are riding in an automobile going 60 miles per hour. An emergency occurs and you are able to stop your auto in 6 feet. How many Gs does your body experience?

$$\text{Deceleration in Gs} = \frac{60^2}{(30) \cdot (6 \text{ feet})} = \frac{3,600}{180} = 20\text{Gs}$$

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES

- Science and technology in local, national, and global challenges

HISTORY AND NATURE OF SCIENCE

- Science as human endeavor
- Nature of scientific knowledge
- Historical perspectives

NATIONAL MATH STANDARDS K-12

NUMBER AND OPERATIONS

- Understand numbers, ways of representing numbers, relationships among numbers, and number systems
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ALGEBRA

- Represent and analyze mathematical situations and structures using algebraic symbols
- Use mathematical models to represent and understand quantitative relationships

MEASUREMENT

- Understand measurable attributes of objects and the units, systems, and processes of measurement
- Apply appropriate techniques, tools, and formulas to determine measurements.

DATA ANALYSIS AND PROBABILITY

- Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them

PROCESS

- Problem Solving
- Communication
- Connections
- Representation

Glossary

Acceleration:

is the rate of change of velocity. An object is accelerating if it is changing its velocity.

Energy:

is the capacity for doing work. You must have energy to accomplish work - it is like the "currency" for performing work. To do 1000 Joules of work, you must expend 1000 Joules of energy.

Friction:

is the surface resistance to relative motion, as of a body sliding or rolling.

Joule:

is the unit of energy equal to the energy exerted by a force of one Newton acting to move an object through a distance of one meter.

Kinetic Energy:

is the energy of motion

Mass:

is a measurement of how much matter there is in a body.

Newton:

is the unit of force equal to the force required to cause a mass of one kilogram to accelerate at a rate of one meter per second squared.

Power:

is the rate of doing work or the rate of using energy, which are numerically the same. If you do 100 Joules of work in one second (using 100 Joules of energy), the power is 100 Watts.

Work:

refers to an activity involving a force and movement in the direction of the force. A force of 20 Newtons pushing an object 5 meters in the direction of the force does 100 Joules of work.

MUSEUM IN A BOX

Student Worksheets

Worksheet 1 Tile Material Hypothesis

Shuttle tile material is made from silica (which comes from sand), alumina fiber, and glass composite.

1. What are the costs/benefits of using this material?

2. Hypothesize the impacts of using this material, considering the associated costs and benefit.

Worksheet 2 Effect of Mass on the Penetration of Tissue Paper

Today we will investigate the effects of debris on the shuttle tiles. We will be representing the debris with small objects of various masses and the tile with a shoebox covered in tissue paper. Design an experiment to determine the amount of energy (in Joules) required to penetrate the tissue paper.

Data: The Effect of Mass on Penetration of Tissue Paper

Object	Mass (g)	Penetrate tissue paper? (Y/N)	Velocity at impact (m/s)	Kinetic Energy at impact (J)
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				

Number of Joules required for an object to penetrate the tissue paper:

Worksheet 2 Continued

Analysis:

1. Calculate the velocity and kinetic energy of each object at impact and record it in the above data table.

$$V_f^2 = V_i^2 + 2as$$

$$KE = \frac{1}{2} mv^2 \quad m \text{ is in kg and } v \text{ in m/sec}$$

2. How many Joules of energy are required to penetrate the tissue paper?

3. Does the velocity at impact depend on the mass of the object?

4. Does the kinetic energy at impact depend on the mass of the object?

5. Does the mass of an object change when it travels to space?

Conclusion:

Worksheet 2 Continued

Space Debris Problems:

1. A bolt has escaped from a spacecraft and is in orbit around the Earth. It is traveling at 20 km/sec and has a mass of 8 grams. Solve for its KE.

$$KE = \frac{1}{2} mv^2$$

1 kg = 1,000 g
1 km = 1,000 m

2. An exploding gram of TNT releases 4.184×10^3 J of energy. Using your answer from the above problem, how many kg of TNT is equivalent to the KE of an 8 g object traveling at 20 km/sec? Divide the KE of the bolt by the KE of 1 kg of TNT. Convert kg of TNT to pounds (1 kg = 2.2 pounds). Does your answer surprise you?

1 gram of TNT contains 4.184×10^3 Joules of energy

1 kilogram of TNT contains 4.184×10^6 Joules of energy

Worksheet 2 Continued

3. Now solve for the KE in terms of TNT if the speed of impact was 35 km/sec in the problem above.

$$KE = \frac{1}{2} mv^2$$

4. What generalizations can you make from your calculation?



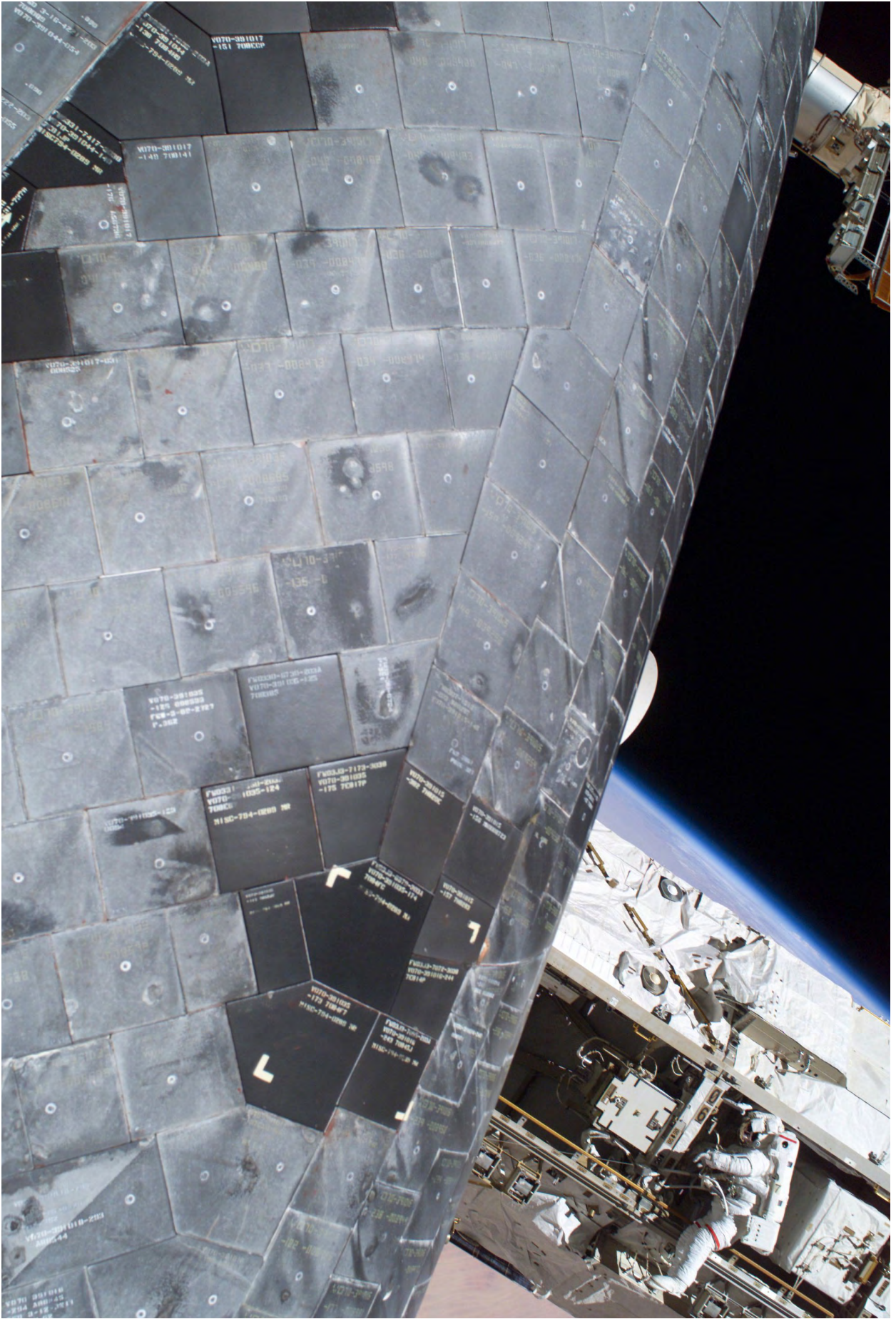
Images

Img. 1 The Space Shuttle Atlantis in orbit.



(Photo courtesy of NASA - www.nasaimages.org)

Img. 2 A close-up of the underside of the orbiter.



Img. 3 Replacing a shuttle tile.

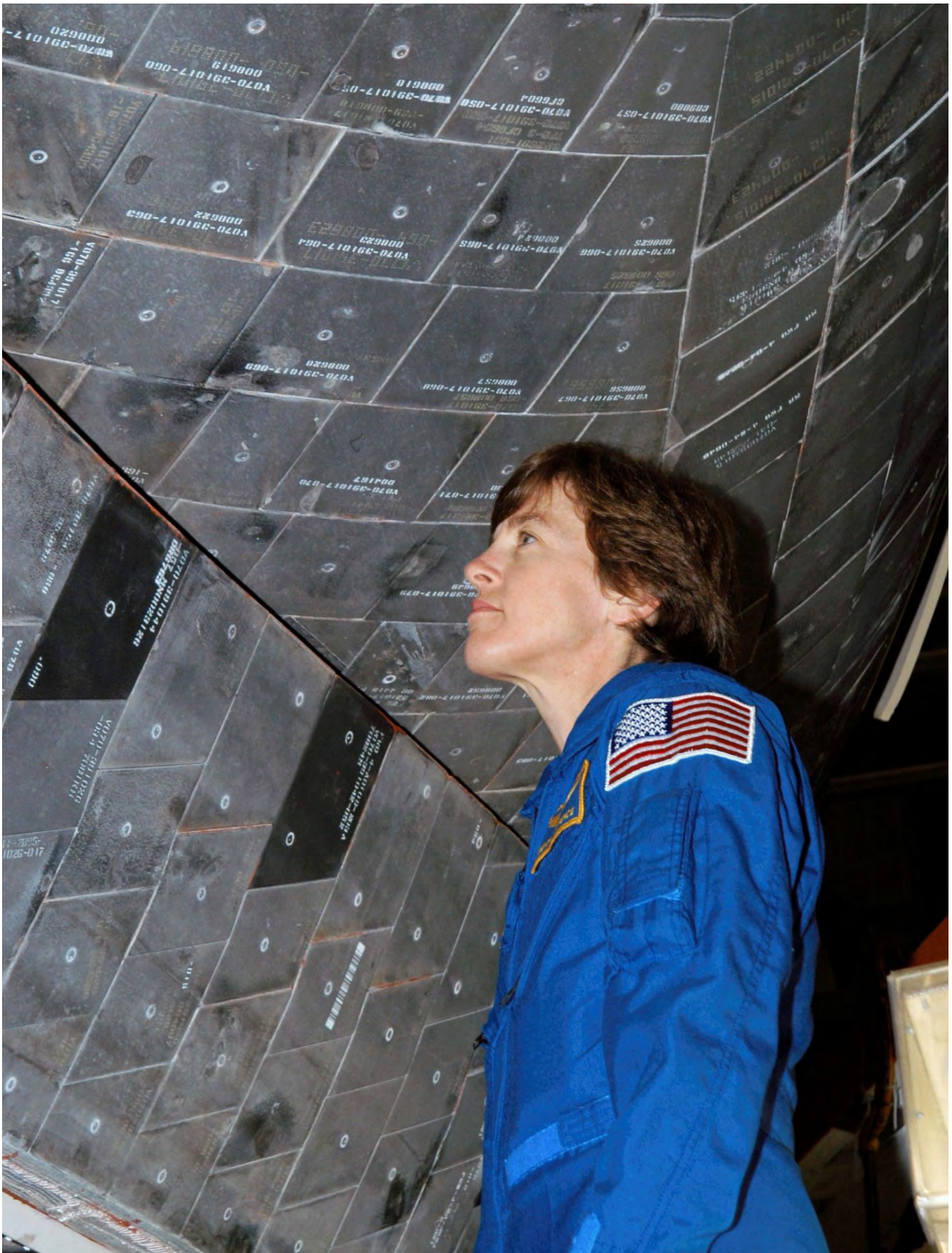


(Photo courtesy of NASA - www.nasaimages.org)

Img. 4 A damaged tile from Space Shuttle Endeavor. The tile was damaged on Mission STS-118 when a piece of foam from the external tank broke off during launch.



Img. 5 A close-up of the tiles numbering system.



(Photo courtesy of NASA - www.nasaimages.org)

Img. 6 The underside of the Space Shuttle in orbit.

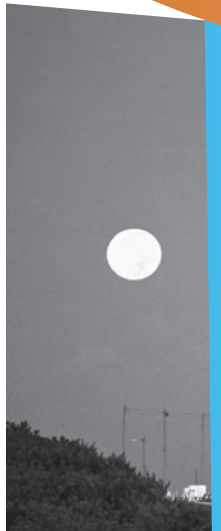


(Photo courtesy of NASA - www.nasaimages.org)

Img. 7 The underside of the Space Shuttle during re-entry.



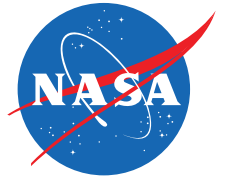
(Photo courtesy of NASA - www.nasaimages.org)



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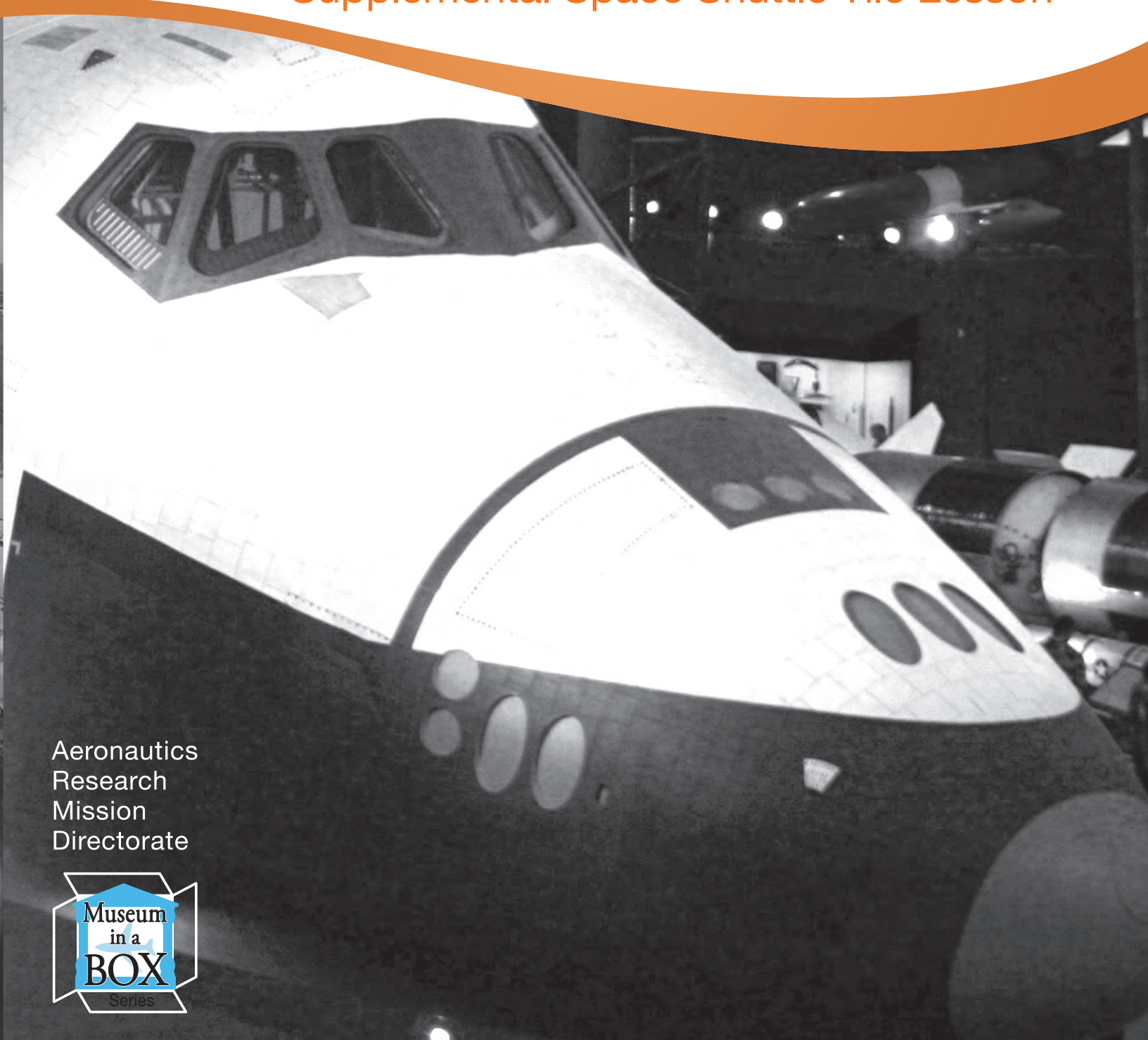


structures and materials



GRADES 9-12

Supplemental Space Shuttle Tile Lesson



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Supplemental Activity 1

A Piece of History: Space Shuttle Thermal Tiles

GRADES
9–12


Activity Overview:

Approximately 24,300 tiles were installed on each Space Shuttle, and each tile was designed to survive 100 trips to space and back. Varying in thickness from 1 inch (2.54 centimeters [cm]) to 5 inches (12.7 cm) depending on the heating they would be subjected to, the tiles collectively protected the orbiter from temperatures as high as 2,300 degrees Fahrenheit during its reentry into Earth's atmosphere.

The silica tile material is referred to as LI-900. It insulates heat so well that tiles can be held bare-handed on one side even while the opposite side is still red hot. Educators can demonstrate that ability in the classroom, substituting a blowtorch for the reentry-generated heating.

LI-900 has a density of 9 pounds per cubic foot (144.2 kilograms per cubic meter [kg/m^3]). It is made from pure silica glass fiber, but 94 percent of the volume of each tile is pure air, making each tile incredibly light and strong!



Problem 1—If the dimensions of an average tile are 15 cm \times 15 cm \times 6 cm, what is the total volume of the Space Shuttle heat shield provided by the 24,300 tiles in cubic meters?

Problem 2—About what is the mass, in grams, of one average tile?

Problem 3—What is the total mass of the Space Shuttle heat shield in

A) kilograms?

B) pounds? (if 1 pound = 0.453 kg)

Space Math, <http://spacemath.gsfc.nasa.gov>

Supplemental Activity 1

A Piece of History: Space Shuttle Thermal Tiles

GRADES
9–12
Answer Key


Activity Overview:

Approximately 24,300 tiles were installed on each Space Shuttle, and each tile was designed to survive 100 trips to space and back. Varying in thickness from 1 inch (2.54 centimeters [cm]) to 5 inches (12.7 cm) depending on the heating they would be subjected to, the tiles collectively protected the orbiter from temperatures as high as 2,300 degrees Fahrenheit during its reentry into Earth's atmosphere.



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Problem 1—If the dimensions of an average tile are 15 cm × 15 cm × 6 cm, what is the total volume of the Space Shuttle heat shield provided by the 24,300 tiles in cubic meters?

Answer:

A single average tile has a volume of

$$V = 0.15 \text{ m} \times 0.15 \text{ m} \times 0.06 \text{ m}$$

$$V = 0.00135 \text{ meters}^3$$

So the total volume occupied by 24,300 tiles is about

$$V = 24,300 \times 0.00135 = 32.8 \text{ cubic meters}$$

Problem 2—About what is the mass, in grams, of one average tile?

Answer:

$$\text{Mass} = \text{Volume} \times \text{Density}$$

$$\text{Mass} = 0.00135 \text{ m}^3 \times 144.2 \text{ kg/m}^3$$

$$\text{Mass} = 0.195 \text{ kilograms}$$

Since 1 kilogram = 1,000 grams, we have a mass per tile of about 195 grams

Problem 3—What is the total mass of the Space Shuttle heat shield in

Answer:

A) kilograms? $\text{Mass} = \text{volume} \times \text{density}$

$$\text{Mass} = 32.8 \text{ m}^3 \times 144.2 \text{ kg/m}^3 = 4,730 \text{ kg}$$

B) pounds? (if 1 pound = 0.453 kg) $4,730 \text{ kg} \times (1 \text{ pound}/0.453 \text{ kg}) = 10,441 \text{ pounds (or about 5 tons!)}$

Space Math, <http://spacemath.gsfc.nasa.gov>

structures and materials

SPACE SHUTTLE TIRES LESSONS: NATIONAL SCIENCE STANDARDS

9–12

UNIFYING CONCEPTS AND PROCESSES

All students should develop an understanding of

- Systems, order, and organization

SCIENCE AND TECHNOLOGY

All students should develop

- Understandings about science and technology

PERSONAL AND SOCIAL PERSPECTIVES

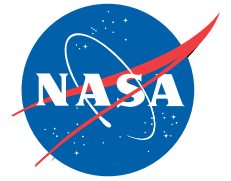
All students should develop an understanding of

- Science and technology in local, national, and global challenges
- Science as a human endeavor

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structures and materials



GRADES

K-12

Rockets Away

propulsion

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(Photo courtesy of NASA - www.nasaimages.org)

Rockets Away

Lesson Overview

In this lesson students will discover Isaac Newton's Third Law, which states "To every action, there is always an equal and opposite reaction". Through experimentation with different propellants, students will learn how pressures and chemical reactions can be used to generate the thrust needed to launch their own rocket.

Objectives

Students will:

1. Learn how thrust is produced by creating a Hero engine.
2. Discover how thrust is generated through the use of compressed air. (Ages K-6)
3. Discover that thrust can be generated through the use of compressed air. (Ages 7-12)
4. Demonstrate how thrust is generated through chemical reaction.

Materials:

In the Box

- Large tank
- Stomp Rocket Kit
- Air Rocket Kit
- Bicycle pump
- Stop watch

Provided by User:

- Empty soda can with opener still attached (one per two students)
- 18 - 24" length of string or fishing line (one per two students)
- Medium sized nail (one per two students)
- Water
- 35mm Film Canisters - the clear Fuji Film™ ones work best (1 per group)
- Alka-Seltzer™ or other type of effervescent tablets (at least 6 per group)
- Fine permanent marker (1 per group)
- Yard stick / long ruler (1 per group)
- Butter knife / pill cutter (1 per group)

GRADES

K-12

Time Requirements: 3 hours 30 minutes

Background

The History of the Rocket

For centuries, rockets have played an important role in human civilization. Dating back to 1300 BC, the Chinese used rocket power to make arrows fly farther than was possible with a regular bow. Countries have been destroyed and created all due to the humble rocket. Even the U.S. National Anthem refers to “the rocket’s red glare”!

It wasn’t until 1686 that, thanks to the Englishman Sir Isaac Newton (Img. 1), we truly understood how and why they worked. His theory, that “To every action, there is always an equal and opposite reaction”, demonstrated quite simply that if Object A exerts a force on Object B, then Object B exerts an equal force on Object A, but in the opposite direction (Fig.1).

In “Action & Reaction” (Fig. 1) you can see that the jet engine (A) is creating exhaust gasses (B). As the engine pushes the gasses outward, those same gasses exert a force on the engine, pushing it forward. This is how the thrust is produced, generating the energy our rocket needs for flight.

After World War II, the United States and the Soviet Union engaged in what became known as “The Space Race”. Initially, both sides planned to use modified missiles capable of carrying passengers instead of their usual, more lethal payloads. By using the world’s first intercontinental Ballistic Missile, the R-7 Semyorka rocket, the USSR ultimately won the first round in 1957 with the launch of the Spunik I. In 1962, the Soviets were also the first country to put a human into space. Yuri Gagarin’s flight lasted just an hour and forty-eight minutes but provided America with much needed inspiration as just three days later, President John F. Kennedy pledged to place a man on the Moon by decade’s end.

Project Mercury was the United States’ first manned space program, with John H. Glenn being of the first American in true orbit. (Alan Shepard was the first of flight, but his mission was not intended to reach orbit.) Mercury led the way for the Gemini program, which was based around a Titan intercontinental ballistic missile. With missions lasting up to 14 days, the Gemini astronauts demonstrated successful space walks and docking procedures, both of which would be vital to any lunar mission.

The quest to land a man on the Moon was accomplished at 10:56 p.m. EDT on July 20th, 1969 when Neil Armstrong and Buzz Aldrin set foot on the Moon, while Michael Collins circled the Moon in the Command Module. The liftoff for the Apollo 11 crew was on a Saturn V rocket developed especially to launch the different Apollo astronaut crews to the Moon.

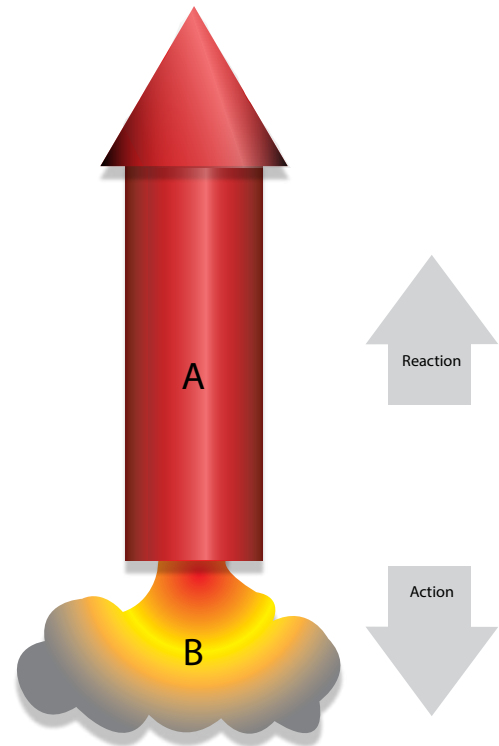


Fig. 1 Action & Reaction



Img. 1 Sir Isaac Newton (age 46)

The timeline below highlights some of human space flight's milestones. Starting with the Sputnik capsule back in 1957 all the way through to the end of the Space Shuttle program in 2011.



Img. 2 A history of manned space flight

Activity 1

The Aeolipile or Hero Engine

GRADES K-12**Time Requirement:** 30 minutes**Materials:**In the Box:

Large tank

Provided by User:Empty soda can with opener still attached
(one per two students)18 – 24" length of string or fishing line
(one per two students)Medium sized nail
(one per two students)

Water

Worksheets:Hero Engine
(Worksheet 1)Reference Materials:

None

Key Terms:

The Aeolipile

Thrust

Newton's Third

Law of Motion

Force

Objective:

Students will learn how thrust is produced by creating a Hero engine.

Activity Overview:

The Aeolipile (Img. 2) or Hero engine was invented by Hero of Alexandria in 1 BC . He used a water-filled copper sphere that when heated, generated steam which could be used to create motion. For safety, we will use the thrust provided by the release of water instead of steam.

Activity:

1. **Fill the tank with water and place in a safe area.** This area WILL get wet during the activity.
2. **Divide the class into pairs and provide each pair with string, a nail and a soda can.**
3. **Have the students tie the string onto the opener of the soda can so that when in use, the can is able to rotate freely on the string.**



Img. 2 A reproduction of Hero's Engine



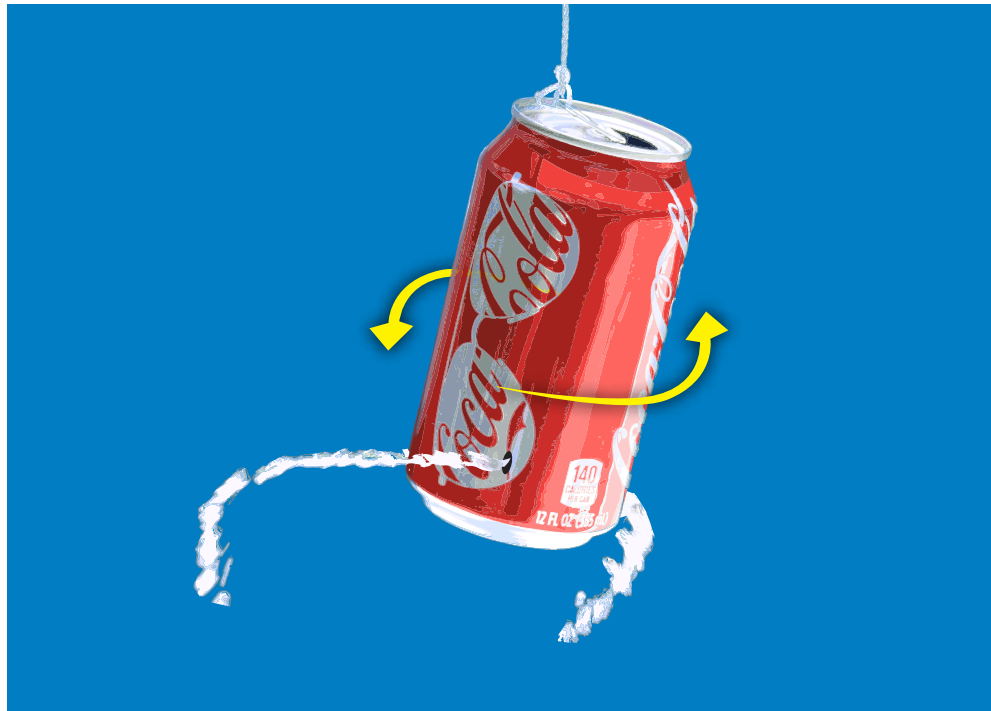
CAUTION: Exercise caution when handling the nails. Supervision may be necessary if working with younger students.

- Using the nail, have students make two equally spaced holes in the side of the can, near the base. Before removing, push the nail to the left in order to slant the hole in that direction.
- Have the students submerge the can in the tank of water. Once full, lift the can out of the water using the string and count the rotations the can makes. Record the number of rotations in the "2 holes" column of Worksheet 1.
- Have the students add additional holes to the can and repeat the experiment several times, recording the number of holes and number of rotations made by the can on the worksheet.



Discussion Points:**1. Why did the soda can rotate when it was lifted out of the water?**

As the water escaped from the soda can, it generated a force away from the can. As per Newton's Third Law of Motion, that also created an equal but opposite force which pushed towards the can. Since the can was held in place by the string, it caused the resultant rotational force to turn the can.

**2. What happened when additional holes were added to the can? Did it rotate more or less?**

While each student's answer will be different, it should be discovered that the can initially rotated faster but stopped sooner. This is because the additional flow of water created more force but that meant that the water ran out sooner.

3. How could the Hero engine be used in a real life scenario?

Answers will vary but anything that requires a turning force could be modified to use a Hero engine. In actuality, it is not known if Hero ever used this device.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Properties and changes of properties in matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
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PHYSICAL SCIENCE

- Structure and properties of matter
- Interactions of energy and matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

Activity 2

Stomp Rocket

GRADES K-12

Time Requirement: 30 minutes

Materials:

In the Box:

Stomp Rocket Kit

Provided by User:

None

Worksheets:

None

Key Terms:

Thrust

Objective:

To discover how thrust is generated through the use of compressed air.

Activity Overview:

In this activity, students will demonstrate how compressed air can be used to power a rocket.

WARNING: This activity should be performed outdoors or in a room with a high ceiling.

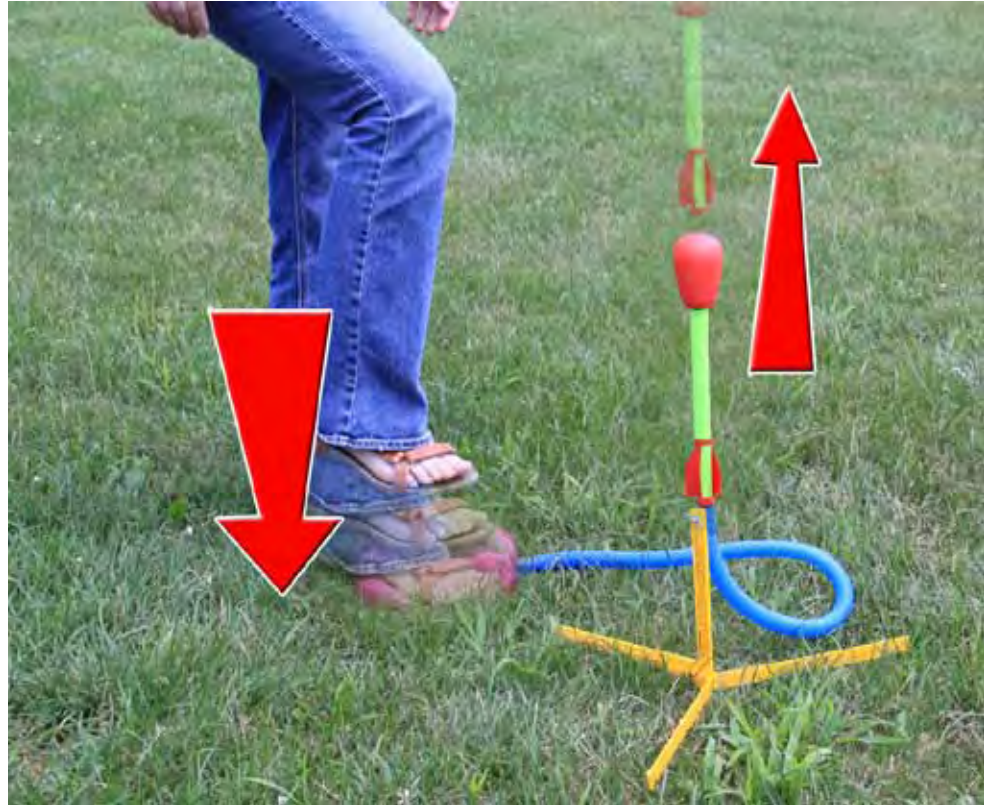
NOTE: This activity is best suited for younger students who are being introduced to compressed air for the first time. For older students, [Activity 3 – Air Rocket](#) may be a better option.

Activity:

1. **Create a “safe zone” that can be used to safely launch the rocket.** Explain to the students that as the rocket will fall back to Earth, it is important they always watch where it will land and move if necessary.
2. **Construct the launch pad using the instructions provided in the kit.**



3. **Demonstrate to the students how the rocket works by placing the rocket onto the launch tube and stepping on the stomp bottle.** If desired, have the students provide a countdown prior to launch.
4. **Repeat with each student, allowing them to apply different amounts of pressure to the stomp bottle such as by jumping on or gently squeezing the bottle.**



Discussion Points:

1. **What caused the rocket to launch?**
As you pressed on the stomp bottle it compressed the air inside. This compressed air created a force that passed down the hose and into the rocket. The force into the rocket created an opposing force that pushed the rocket away from the launch pad.
2. **Why did it sometimes launch higher than others?**
Because the rocket relies on air pressure for thrust, the higher air pressures provided more thrust for the rocket. The larger students or those who jumped or stomped on the bottle generated much higher air pressures than those who gently pressed or squeezed the bottle.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

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PHYSICAL SCIENCE

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NATIONAL SCIENCE STANDARDS 5-8

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NATIONAL SCIENCE STANDARDS 9-12

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SCIENCE AND TECHNOLOGY

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- Understanding about science and technology

Activity 3

Air Rocket

GRADES K-12**Time Requirement:** 60 minutes**Materials:**In the box:

Air Rocket Kit
Bicycle pump
Stop watch

Provided by User:

None

Worksheets:

None

Worksheet:

Air Rocket
(Worksheet 2)

Objective:

To discover that thrust can be generated through the use of compressed air.

Activity Overview:

In this activity, students will experience how compressed air can be used to power a rocket.

WARNING: This activity **MUST** be performed outdoors.

NOTE: This activity is best suited for older students as it involves the use of high pressure compressed air. For younger students, [Activity 2 – Stomp Rocket](#) may be a better option.

Activity:

1. **Create a “safe zone” that can be used to safely launch the rocket.** As this experiment creates high powered projectiles, it is vital that the safe zone be sufficiently large and roped off to ensure the safety of those around you. A sports field will work well for this activity.
2. **Construct the launch pad using the instructions provided in the kit.**
3. **The kit includes red and white disks which are referred to by the manufacturer as “Photons” (white) and “Bozons” (red).** These plastic disks are used to control the height that the rocket can reach by altering the pressure required for launch.

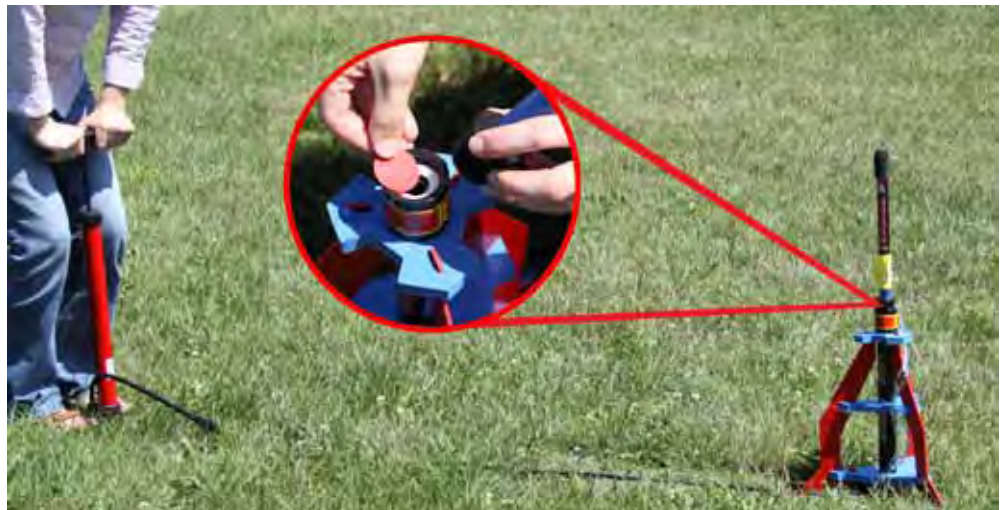


Disk Combination	Approximate number of pumps to launch	Approximate Height	Pressure
1 White	3	250 ft.	40 psi
2 White	5	500 ft.	80 psi
1 Red	7	600 ft.	90 psi

Table 1: Air Rocket disk combination specifications

CAUTION: At no time should you exceed 2 red disks or 150psi.

- Next, have the students take turns launching the rocket using the 3 disk combinations listed in Table 1 while others use the stopwatch to record the time it spends in flight, collecting the results onto their worksheet. Repeat as necessary to ensure all the students have had an opportunity to both time and launch the rocket.
- Using the worksheet, plot the results of the 3 different disk combinations to compare time of flight with the amount of air pressure required to launch the rocket.



Discussion Points:

- What caused the rocket to launch?**
As you pushed on the bicycle pump it compressed the air inside the launch tower. Once the air pressure limit was reached, as determined by the selected disk, it released that air into the rocket. This force created an opposing force which pushed the rocket away from the launch pad.
- Discuss the data the students plotted. Is there a direct correlation between time flown and air pressure?**
This will vary due to environmental factors such as gusty winds but it should be discovered that there is a fairly linear correlation between them. (The line plotted should be somewhat straight.)

3. **How does the propulsion system of this rocket differ from those used by NASA?**
Apart from the main difference of rocket fuel vs. compressed air, the primary difference is that with real rockets, the fuel is stored and burned in the rocket itself, whereas with the air rocket the air is stored externally prior to launch.
4. **What are the benefits and drawbacks of such a design?**
With the fuel stored externally it means the rocket can be much lighter since on launch, it only has to lift its own weight. With stored fuel, the rocket also needs additional thrust in order to lift the weight of the rocket and the fuel skyward. The biggest drawback however is that with an external supply, once the rocket has left the launch tower it no longer has any propulsion and will start to slow down immediately. With an on-board supply the rocket will continue to accelerate until the fuel supply is exhausted.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
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PHYSICAL SCIENCE

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SCIENCE AND TECHNOLOGY

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NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

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NATIONAL MATH STANDARDS K-12

NUMBER AND OPERATIONS

- Understand numbers, ways of representing numbers, relationships among numbers, and number systems
- Understand meanings of operations and how they relate to one another
- Compute fluently and make reasonable estimates

ALGEBRA

- Represent and analyze mathematical situations and structures using algebraic symbols
- Use mathematical models to represent and understand quantitative relationships

MEASUREMENT

- Understand measurable attributes of objects and the units, systems, and processes of measurement
- Apply appropriate techniques, tools, and formulas to determine measurements.

DATA ANALYSIS AND PROBABILITY

- Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them

PROCESS

- Problem Solving
- Communication
- Connections
- Representation

Activity 4

Alka-Seltzer™ Rocket

GRADES K-12**Time Requirement:** 60 minutes**Materials:**In the Box:

None

Provided by User:

35mm film canisters
the clear FujiFilm™
one work best
(1 per group)

Water

Alka-Seltzer™
or other type of
effervescent tablets
(at least 6 per group)

Fine permanent marker
(1 per group)

Yard stick / long ruler
(1 per group)

Butter knife / pill cutter
(1 per group)

Worksheets:

Alka-Seltzer™ Rocket
(Worksheet 3)

Key Terms:

Thrust

Objective:

To demonstrate how thrust is generated through chemical reaction.

Activity Overview:

By using an effervescent tablet to create carbon dioxide, students will demonstrate the explosive force of a gas by measuring how high it can launch a film canister.

Activity:

1. **Divide the students into groups of two. Have each group perform the remaining steps.**

2. **Start by dividing the canister into quarters by marking lines on the side.** This will be used to measure the quantity of water used later.

3. **Create a control launch.**

To do this:

a. Have one student hold the ruler vertically in preparation of the launch.

b. Fill the film canister one quarter full of water.

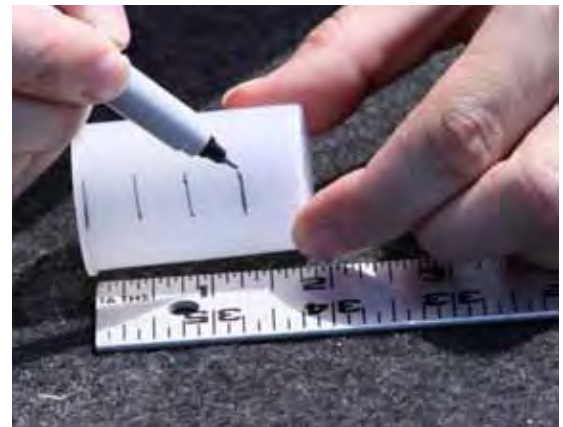
c. Cut a tablet into quarters and place just one quarter into the water. Quickly replace the lid.

d. Shake the canister for a few seconds, then place it lid-side down on a table.

e. Wait for launch!

f. Measure and record the height that the canister reached on the worksheet.

4. **Try various combinations of tablet and water quantities in order to determine which combination lifts the canister the highest.** Record the results on the worksheet.





Discussion Points:

1. **What causes the canister to suddenly jump into the air?**

When the effervescent tablet interacts with water it produces carbon dioxide gas. As this gas builds up inside the canister, it pressurizes, generating energy. Eventually, the friction of the lid cannot hold back this building pressure and releases, allowing the gas to escape. This force creates the opposing force that lifts the canister into the air.

2. **What combination of water and tablet quantities provided the most lift?**

While the students' answers will vary, it should be discovered that some air is needed in the canister to provide the best results. This is because the carbon dioxide needs space to build and compress. With a canister full of water the gas has no option but to escape immediately, preventing pressure from building up.

3. **What else can be done to increase the height of the canister?**

Greater height requires an increase in pressure inside the canister. This can be done for example by securing the lid with tape or glue, or by adding additional tablets.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
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NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

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NATIONAL SCIENCE STANDARDS 9-12

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NATIONAL MATH STANDARDS K-12

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- Understand meanings of operations and how they relate to one another
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- Represent and analyze mathematical situations and structures using algebraic symbols
- Use mathematical models to represent and understand quantitative relationships

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DATA ANALYSIS AND PROBABILITY

- Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them

PROCESS

- Problem Solving
- Communication
- Connections
- Representation



Reference Materials

Glossary

The Aeolipile:

A rocket-style engine that rotates when the water inside is heated, producing steam; often considered the first steam engine or reaction steam turbine

Compressed Air:

Air that is currently at a pressure higher than the atmospheric pressure; often used as a source of power for machines

Force:

An influence on a body which produces (or attempts to produce) a change in movement, direction or shape

Geosynchronous Orbit:

An orbit that completes one revolution in the same amount of time it takes for the Earth to rotate once on its axis. This means that an orbiting object, such as a satellite, would be in the same position of the sky at the same time each day. This should not be confused with a Geostationary Orbit, where the object stays in the same position regardless of the time of day

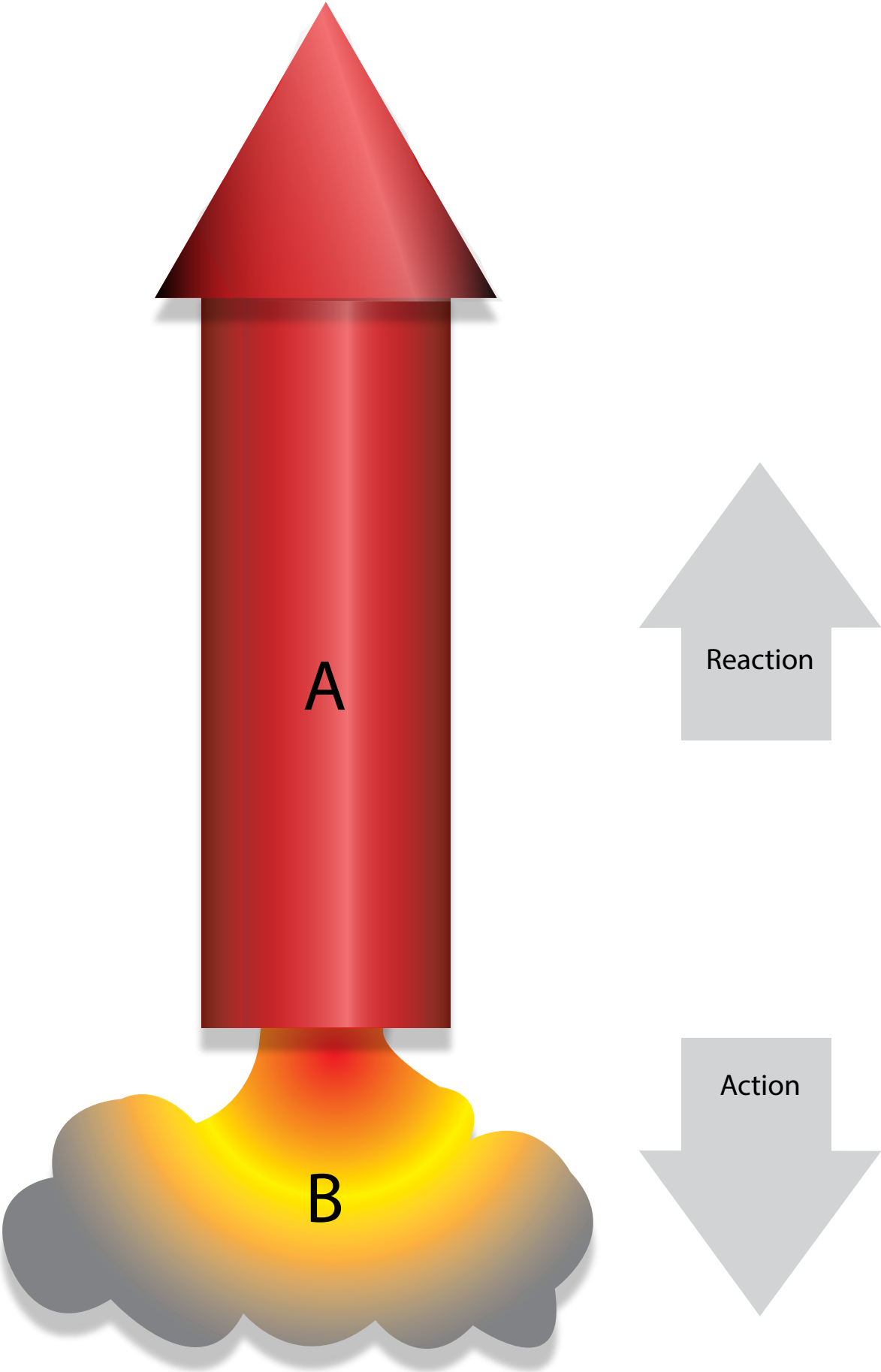
Newton's Third Law of Motion:

To every action, there is always an equal and opposite reaction.

Thrust:

A reactive, linear force exerted in order to propel an object in the opposite direction

Fig. 1 Action & Reaction



Img. 2 A history of manned space flight



October 4th 1957

Country: USSR
Rocket: Vostok (R-7 Derivitive)
Cosmonaut: Yuri Gagarin
Fact: The first man to enter Earth's orbit



May 5th 1961

Country: USA
Rocket: Atlas
Astronauts: John Glenn
Fact: The first American in Earth's orbit




February 20th 1962

Country: USSR
Rocket: Soyuz
Cosmonaut: Colonel Vladimir Komarov
Fact: First confirmed fatality when the capsule crashed upon landing




March 23rd 1965

Country: USA
Rocket: Space Shuttle Columbia (OV-102)
Astronauts: John Young, Robert Crippen
Fact: The first flight of the US Space Shuttle program



April 12th 1961

Country: USSR
Rocket: R-7
Cosmonaut: Unmanned
Fact: The first man-made object to orbit the Earth



April 24th 1968

Country: USA
Rocket: Titan II
Astronauts: Virgil "Gus" Grissom
John Young
Fact: First manned flight of the Gemini program



July 20th 1969

Country: USA
Rocket: Saturn V
Astronauts: Neil Armstrong, Edwin "Buzz" Aldrin, Michael Collins
Fact: Took the first men to land on the Moon



April 12th 1981

Country: USA
Rocket: Space Shuttle Atlantis (OV-104)
Astronauts: Chris Ferguson, Doug Hurley, Rex Walheim, Sandy Magnus
Fact: The final flight of the US Space Shuttle program



July 8th 2011



Student Worksheets

Worksheet 1

Hero Engine

Record the number of revolutions your can makes in the table below.

	2 Holes	_____ Holes	_____ Holes	_____ Holes	_____ Holes
Number of Rotations					

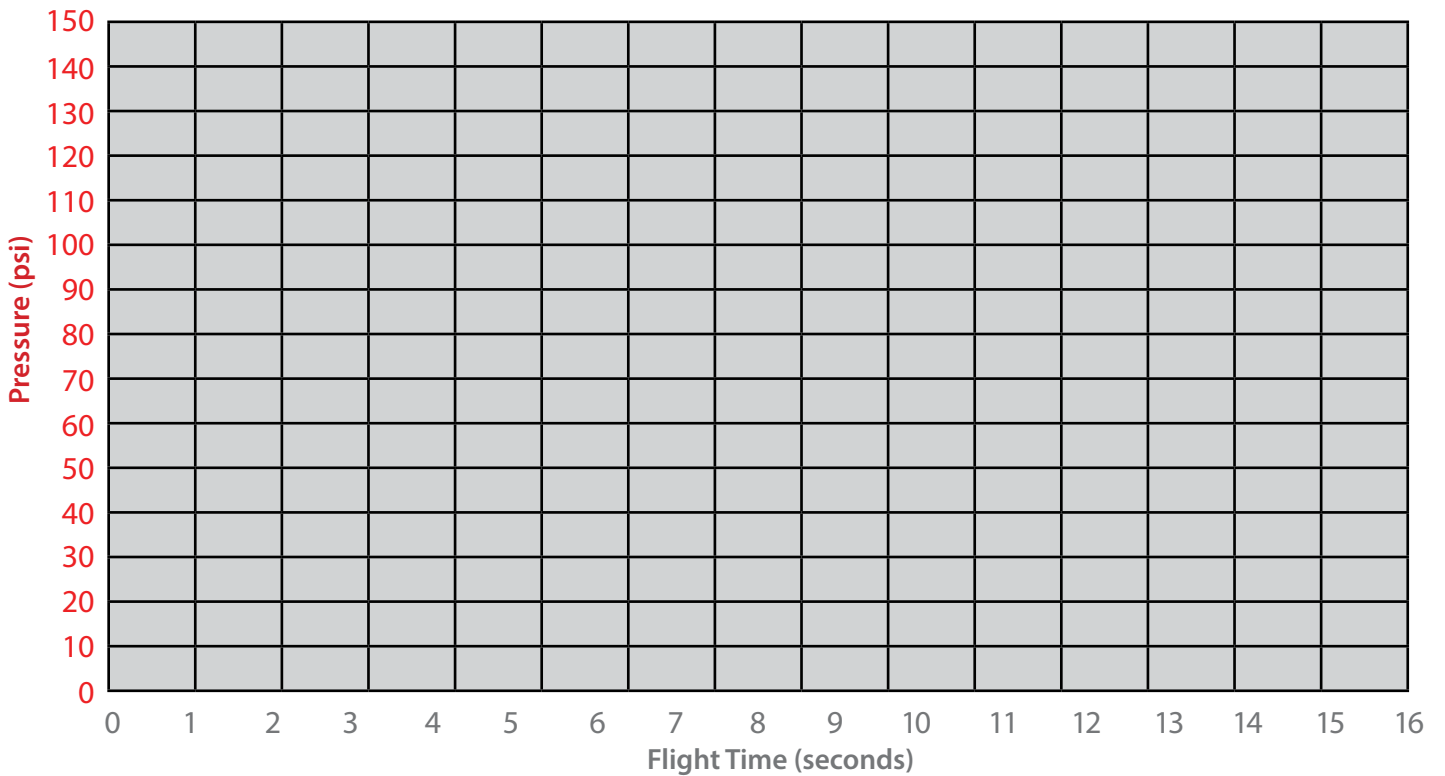
Worksheet 2

Air Rocket

Record the rocket's total time airborne for each combination of disks in the tables below.

Disks	1 White Disk	2 White Disks	1 Red Disks
Flight Time			

Graph your results from the table above.



Worksheet 3

Alka-Seltzer™ Rocket

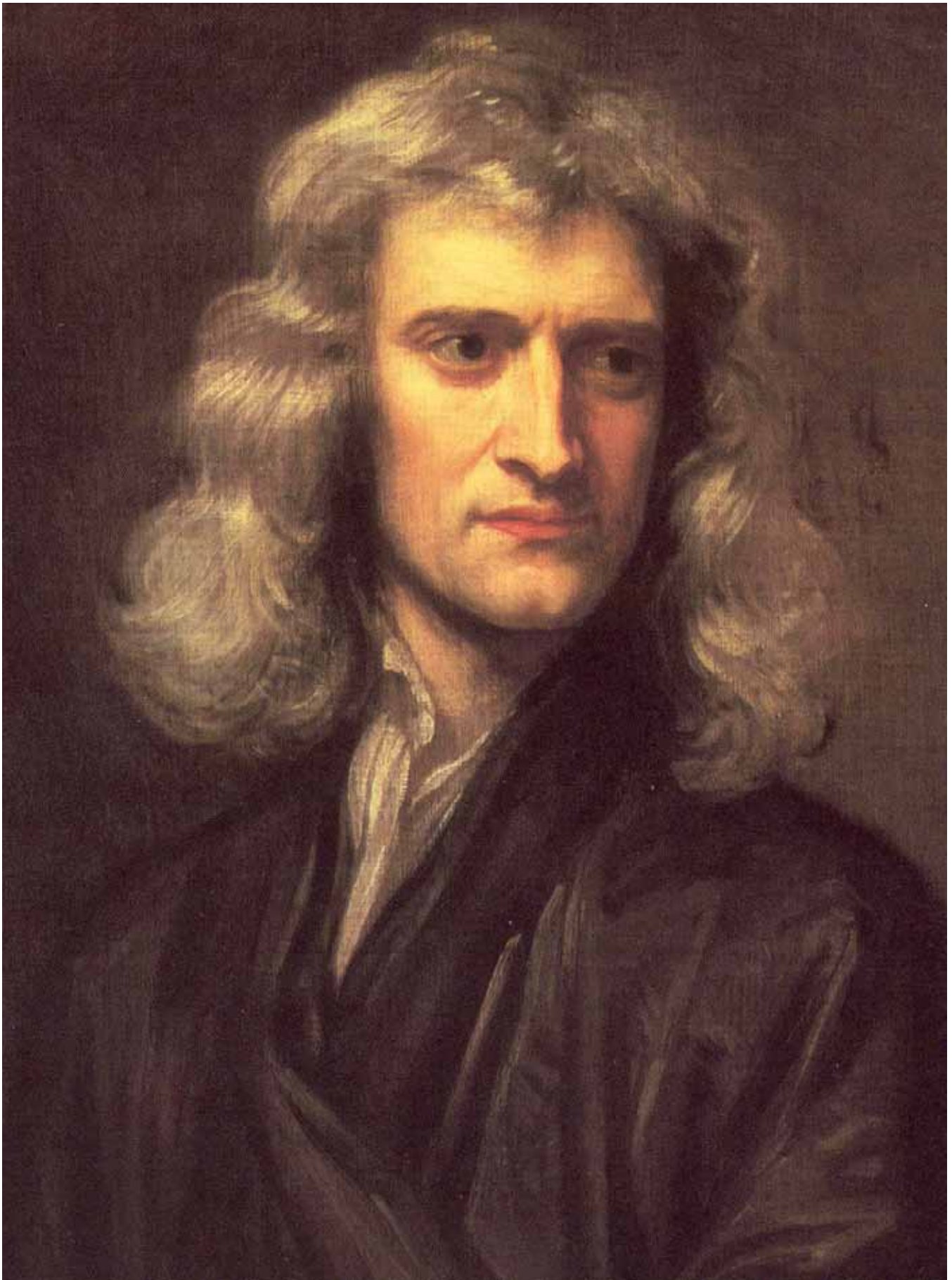
Record the height achieved by the canister for each combination of water amount and tablet pieces in the table below.

Water	1/4 Full	_____ Full	_____ Full	_____ Full
Tablets				
1/4 Tablet				
_____ Tablet				
_____ Tablet				
_____ Tablet				
_____ Tablet				
_____ Tablet				
_____ Tablet				
_____ Tablet				



Images

Img. 1 Sir Isaac Newton (age 46)



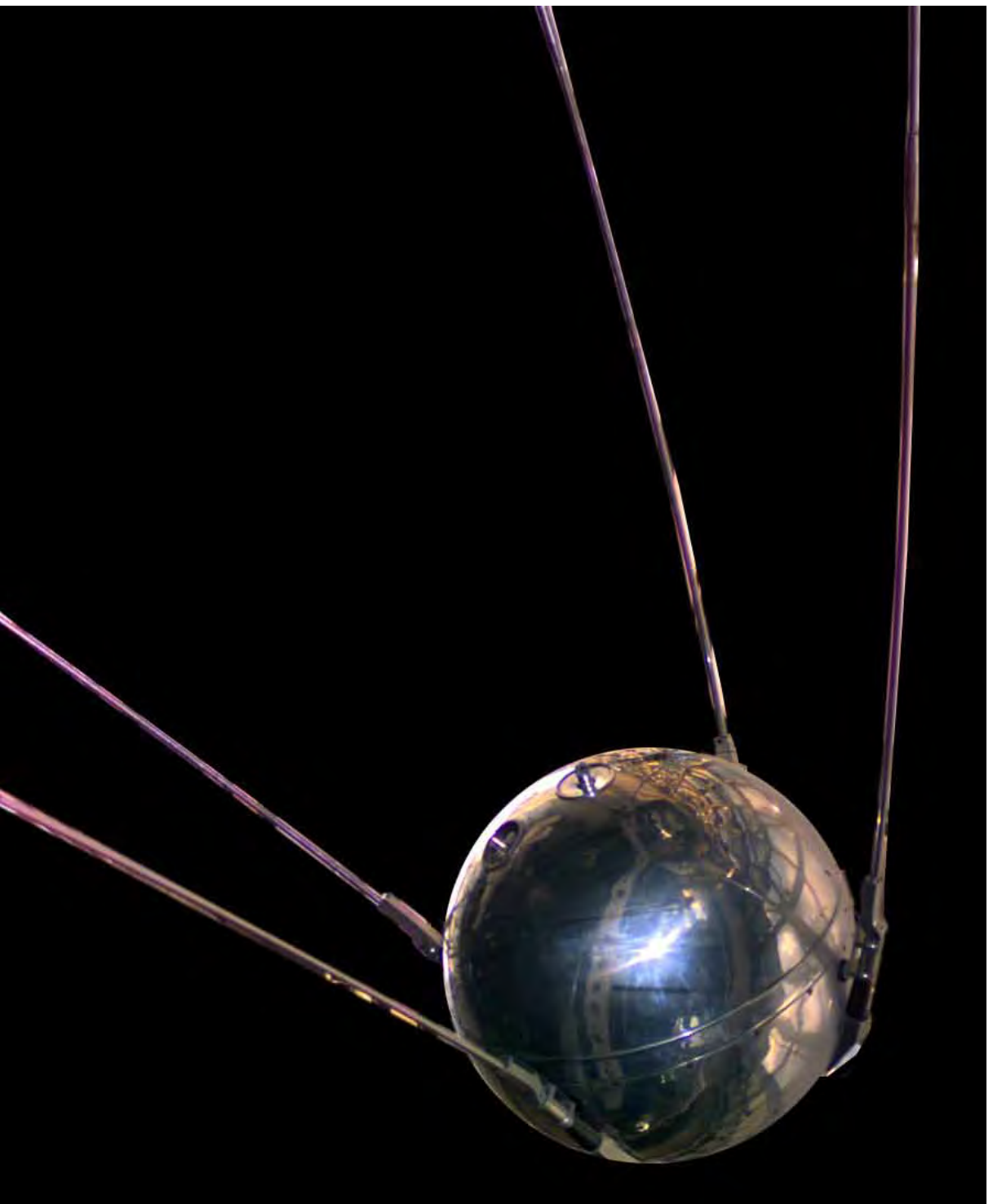
(Painting by Sir Godfrey Kneller - 1689)

Img. 2 A reproduction of Hero's Engine



(Photo courtesy of Tamorlan - Attribution 3.0 hhv)

Img. 3 The Sputnik Capsule



(Photo courtesy of NASA - www.nasaimages.org)

Img. 4 The Vostok Rocket



(Image courtesy of Sergei Korolyov - GNU Free Documentation License)

Img. 5 The launch of Mercury 3 on a Redstone rocket



(Photo courtesy of NASA - www.nasaimages.org)

Img. 6 The Launch of Mercury 7 on an Atlas rocket



(Photo courtesy of NASA - www.nasaimages.org)

Img. 7 The Launch of Gemini III on a Titan rocket



(Photo courtesy of NASA - www.nasaimages.org)

Img. 8 A Soyuz rocket being delivered to the launch pad



(Photo courtesy of NASA - www.nasaimages.org)

Img. 9 The Saturn 5 Rocket carrying Apollo 11



(Photo courtesy of NASA - www.nasaimages.org)

Img. 10 The launch of the Space Shuttle Columbia



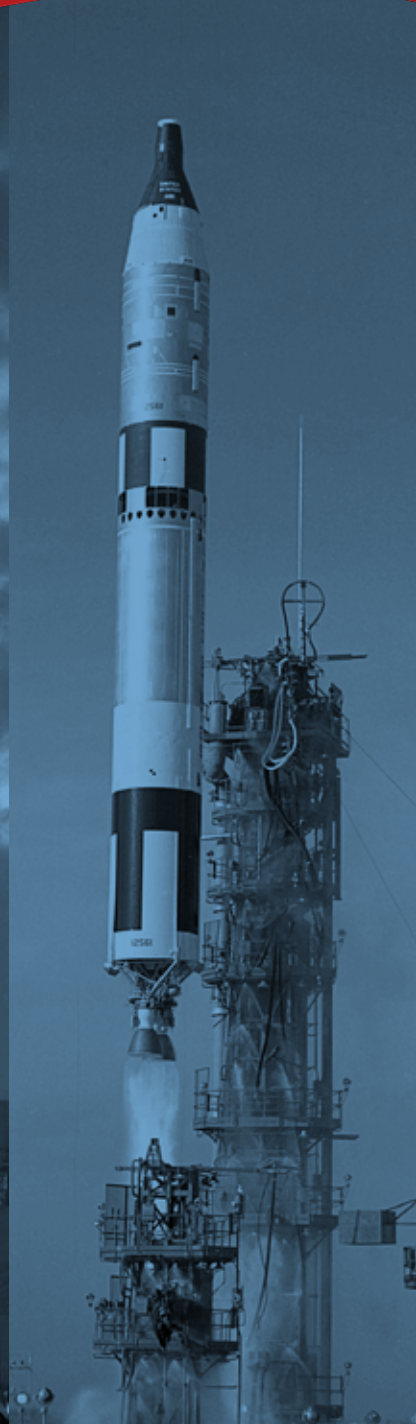
(Photo courtesy of NASA - www.nasaimages.org)

Img. 11 Landing of Space Shuttle Atlantis

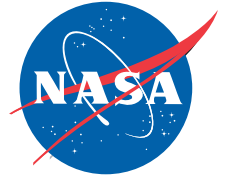


(Photo courtesy of NASA - www.nasainages.org)

Aeronautics
Research
Mission
Directorate



propulsion



GRADES

5-12

Ball Launcher

propulsion

Aeronautics
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Ball Launcher

Lesson Overview

The Ball Launcher lesson is a hands-on activity designed to introduce students to the concept of a parabolic arc by throwing a ball and how NASA flies parabolic arcs to create periods of reduced gravity with the C-9B aircraft in the Reduced Gravity Research Program. In addition, students will measure their reaction time by using a meter stick.

Objectives

Students will:

1. Learn what a parabolic arc is and how it is used by NASA to create a microgravity environment.
2. Use a stopwatch and tape measure to gather data for each ball throw.
3. Use the equation for a falling body to calculate the highest point of the parabolic trajectory.
4. Use other equations to solve for different aspects of the ball's flight such as the angle at which the ball was released.

Materials:

In the Box

Stop watch
 Chuckit ball launcher
 Tape measure or trundle wheel
 Tape
 Meter or yard sticks

Provided by User:

Strips of paper 1cm by 75cm)
 Graph paper

GRADES **5-12** **Time Requirements:** 3 hours

Background

Parabola

In this lesson, students use a Chuckit Ball Launcher to throw a tennis ball and record data related to its flight. If the students were to photograph the path of the tennis ball flight, they would see that the ball goes up and comes down in an arc known as a parabola.

Students often see parabolas and may not recognize them. If the students were to draw a graph that represents the path of a projectile fired by a cannon, it would also represent a parabola. The golden arches on a favorite eating establishment are also parabolas.

Notice the drawing of the parabola in Figure 1. It looks like an upside down 'U'. Students taking a pre-calculus class learn terms associated with a parabola such as Axis of Symmetry, Vertex, Focus, Directrix, Quadratic Equation, Points, and Locus. For this lesson though, the following terms are important to understand: vertex, axis of symmetry, and range.

As shown in Figure 1, the vertex of a parabola represents the high point of the tennis ball flight. It is also the point where it crosses its axis, referred to as the axis of symmetry. The axis of symmetry is most often a vertical line that passes through the parabola's vertex. It divides the parabola into two perfect halves. Range is the horizontal distance from where the ball was tossed to where it hits the ground.

An excellent example of a parabola in action is Alan Shepard's sub-orbital Mercury Program flight aboard Freedom 7 on May 5, 1961. Shepard's flight lasted 15 minutes and 22 seconds during which time his spacecraft reached an altitude of 187.5 kilometers (116.5 miles). Freedom 7 splashed down into the Atlantic Ocean 486 kilometers (302 miles) from the launch site. If Fig. 1 represented the Shepard's flight, the distance from the vertex to the bottom of the parabola is 187.5 kilometers (116.5 miles). The range from liftoff to splashdown is 486 kilometers (302 miles). The left side of the parabola represents the ascent period, while the right side represents reentry.

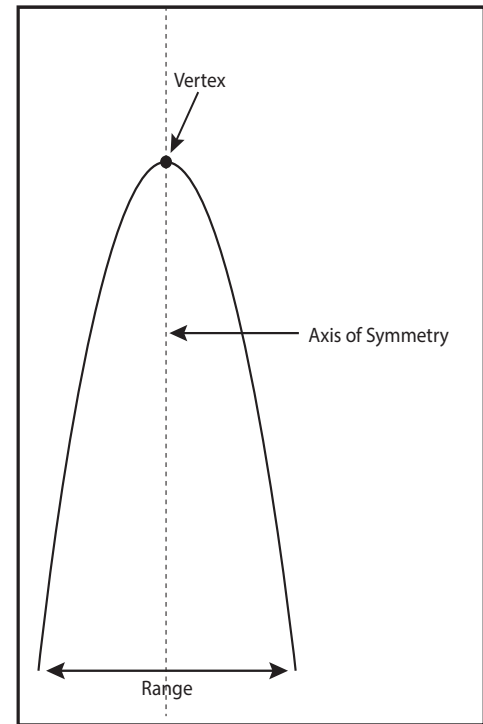


Fig. 1 Parabola



Img. 1 Mercury 3 at launch

Galileo's Falling Bodies Equation

Galileo has been described as one of the greatest scientists that has ever lived. He was a world-renown mathematician, astronomer, physicist, and inventor. Though he really didn't invent the telescope he improved upon it by building his own with a magnification of 30X.

He was the first to use the telescope to observe the heavens and record what he saw such as craters on the moon; that Venus had phases, and that Jupiter had moons. He also built an early thermometer in the 1590s.

Among his many most significant contributions, Galileo demonstrated to us how he deduced laws to explain the results of his observations and experiments. Up until his time, most explanations were just in words. Galileo did something different. He showed the importance of mathematics in understanding natural phenomena and experimentation. It is remarkable to think that Galileo did all of his work without a reliable clock and less scientific equipment than found in today's classrooms. His observation of swaying chandeliers enabled him to better understand the nature of a pendulum which ultimately led to the development of more accurate pendulum clocks.

Galileo's study of projectile motion is one example of his work. Galileo knew that the trajectory of a projectile was a parabola. He realized for the first time that a projectile's motion is influenced by two independent motions. One of the motions is influenced by gravity. He discovered that gravity pulls down a projectile according to the equation for a falling body. The second influence demonstrated that horizontal motion is uniform and constant, according to the principle of inertia. Inertia can be considered the tendency of an object to resist any change in its motion.

Galileo realized, even during his earliest experiments, that the speed of a falling body is independent of its weight. Galileo discovered that the nature of this motion is the same for an object that falls straight down as it is for one that moves forward and down at the same time. Therefore, an arrow shot horizontally from a bow falls at the same rate as one that is simply dropped from the same height that it was shot.

Galileo was able to derive an equation for a falling body:

$$S = \frac{1}{2} at^2. \quad (S = \text{distance, } a = \text{acceleration due to gravity (9.8m[32ft]/\text{sec}^2), \text{ and } t = \text{time})$$

From the above equation, you can also solve for the following:

Instantaneous velocity of a falling object after a certain elapsed time:

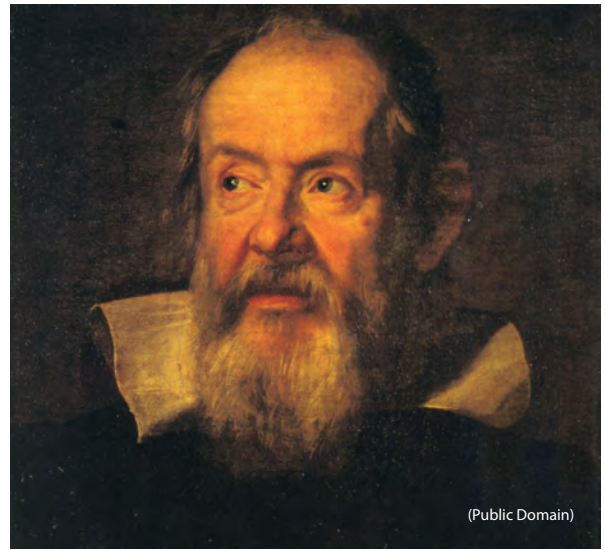
$$V_i = at$$

Average velocity of an object that has been falling for time (averaged over time):

$$V_{avg} = \frac{1}{2} at$$

Launch Angle: The angle that the ball was released when thrown.

Launch Velocity: The initial speed at which the ball was released.



Img. 2 Galileo Galilei by Justus Sustermans (1564-1642)

(Public Domain)

Sample Problem Set:

The following is a set of problems related to throwing a tennis ball with the Chuckit Ball Launcher. Use the formulas you deem most appropriate with your students. The sample problem assumes no air resistance or the height at which the ball was released. These factors can be added later after the students gain a better understanding of a falling body. A tennis ball is thrown and its flight time is 4 seconds. It lands 25 meters from where it was thrown. Remember, in a parabola, it takes half of its flight time to reach the vertex and the other half to reach impact. So, in this case, the time to reach the vertex is 2 seconds.

Now determine the height from the vertex to the ground:

Acceleration due to gravity = 9.8m/sec^2 , t = time

Use the equation: $S = \frac{1}{2} at^2$ to solve for distance.

$$S = \text{Distance, } a = S = \frac{1}{2} 9.8\text{m/sec}^2 (2.0 \text{ sec})^2 = 4.9\text{m/sec}^2 \times (4 \text{ sec}^2) = 19.6 \text{ meters}$$

To convert meters to feet, multiply the number of meters by 3.28 feet/meter:

$$19.6\text{m} (3.28\text{ft/m}) = (64.3 \text{ feet})$$

The vertex is 19.6 meters from the ground.

What was the velocity of the tennis ball after 1.5 seconds?

$$V_i = at = 9.8\text{m/sec}^2 \times 1.5 \text{ sec} = 14.7 \text{ m/sec (48.23 feet/sec)}$$

What was the average velocity of the tennis ball?

$$Va = \frac{1}{2} at = \frac{1}{2} (9.8\text{m/sec}^2) (2.0 \text{ sec}) = (4.9\text{m/sec}^2) (2.0 \text{ sec}) = 9.8\text{m/sec (32.1ft/sec)}$$

To determine launch angle:

$$\text{Launch Angle} = \frac{S}{R} = \frac{\tan\theta}{4}$$

R = Range

S = Height of vertex in meters

$$\text{Launch Angle} = \frac{19.6\text{m}}{25\text{m}} = \frac{\tan\theta}{4}$$

$$\text{Launch Angle} = \frac{78.4\text{m}}{25\text{m}} = \frac{\tan\theta}{4}$$

$$\tan\theta \frac{78.4\text{m}}{25\text{m}} = 3.14 = 72.3^\circ$$

Launch angle was 72.3°

To determine launch velocity:

R = Range

a = Acceleration due to gravity (9.8m/sec^2)

$$\text{Launch velocity} = V_o = \sqrt{\frac{Ra}{\sin 2\theta}}$$

From trigonometry (trig), we know that:

$$\sin 2\theta = (\text{using trig identity}) = 2\sin\theta \cos\theta$$

$$\begin{aligned} V_0 &= \sqrt{\frac{Ra}{\sin 2\theta \cos\theta}} \\ &= \sqrt{\frac{25\text{m}(9.8\text{m/sec}^2)}{2\sin(72.3^\circ)(\cos(72.3^\circ))}} = \sqrt{\frac{245 \frac{\text{m}^2}{\text{sec}^2}}{2(.952)(.304)}} = \sqrt{\frac{245 \frac{\text{m}^2}{\text{sec}^2}}{.579}} \\ &= \sqrt{423.1 \frac{\text{m}^2}{\text{sec}^2}} = 20.6\text{m/sec} \end{aligned}$$

Therefore, the launch velocity was 20.6 m/sec

NASA's Reduced Gravity Program (RGP)

Astronauts are in a weightless condition in space, but weightlessness can be created in an aircraft that flies a free fall trajectory, which is a parabola.

The Reduced Gravity Program (RGP) managed by the Johnson Space Center is a research area at NASA that uses a specially configured aircraft to simulate a reduced gravity environment by flying parabolas over the Gulf of Mexico. The Reduced Gravity Program enables scientists, engineers, and astronauts to become accustomed to a microgravity environment. In addition, during each parabola, scientists, engineers, astronauts, or university students can test equipment or hardware that may be used on a future space flight. Each flight includes 40 parabolas and as of 2011, over 140,000 parabolas have been flown in the Program.



Img. 3 Astronaut Satoshi Furukawa in Space Aboard the ISS

Also, some of the scenes from the Apollo 13 movie were shot aboard the KC-135, which was used to fly parabolas. The KC-135, known as, the 'vomit comet,' was retired in 2004 and has been replaced by a Navy C-9, a twin-jet variant of the McDonnell Douglas DC-9.



Img. 4 "NASA 932" Weightless Wonder VI, Vomit Comet Completing a Parabola

Normally this is between 40-50 degrees nose up attitude, and at that point the yoke is pushed forward to reach a 'zero g' condition (takes about 3-4 seconds for zero g to be reached). This forward push on the yoke is matched by a reduction in the throttle position to be at idle throttle when the aircraft reaches zero g. The minimum airspeed seen is usually about 140-160 knots (161-184 mph) and the peak altitude is approximately 9449 meters (31,000 feet) (B).

Note the diagram in Figure 2. The diagram shows a typical parabola flown in The Reduced Gravity Program. The following is a description of how a parabola is created by one of the RGP pilots:

"We start at a "base" altitude of 8229.6 meters (27,000 feet) and airspeed of 250 knots (288 mph). When the test director is ready, and the autopilot is connected to the roll and yaw axes of the aircraft, the aircraft commander will push the nose over and power will be adjusted to reach 7010 meters (23,000 feet) (A) and 350 knots (403 mph) airspeed. At that point, the nose is pulled up at 1.8 g's, power is advanced to max allowable, and this condition is continued until reaching 240 knots (276 mph) airspeed.

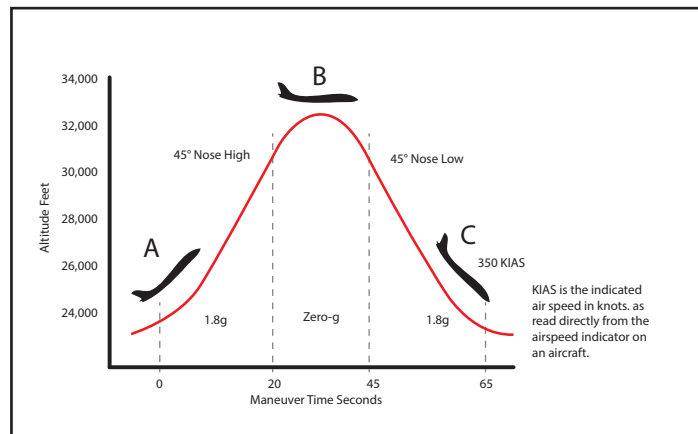


Fig. 2 Flying the parabola

The nose continues to fall through until approximately 35-40 degrees nose down, when the yoke is pulled back and the power advanced to max to get into another 1.8 g pull-up (C). Our lowest altitude is normally (7010 meters) 23,000 feet and highest airspeed is 350 knots (403 mph), and the process begins again."

Note in the diagram that during each parabola, there are 2 periods of more intense gravity (~1.8gs). What does 1.8gs refer to? G or g-force is the force acting on a body due to the acceleration of gravity. Under normal conditions on Earth this force is equal to one-g. If a body experiences a 1.8 g force, it is experiencing a force 1.8 times the normal force of gravity. As an example of a 1.8 g-force, a 50 kilogram person would weigh 90 kilograms (50 kilograms x 1.8gs).

Each of these periods lasts about 20 seconds. As the RGP's aircraft, a Navy C-9, goes over the top of the parabola, there is approximately 20 seconds of what is referred to as reduced gravity or zero-g during this free fall trajectory. As can be seen in *Img. 5*, during this brief period of zero-g passengers can float about the inside of the aircraft. The inside of the aircraft's walls, ceiling and floor has padding as can be seen in the photograph.

The **Background** information has referenced the importance of astronauts flying parabolas during NASA's Reduced Gravity Program to become more familiar in working with various types of equipment in a near zero-g environment. By doing this the astronauts can reduce their reaction time for completing various tasks.

The following two activities will have students measure their reaction time by dropping a meter stick or yardstick, and use a ball launcher to throw a tennis ball to determine different aspects of the trajectory of ball's flight such as the greatest height it attained during its parabolic flight.



Img. 5 University Students Conducting an Experiment on the 'Vomit Comet'

(Photo courtesy of NASA)

Activity 1

Reaction Time

GRADES 5-12

Time Requirement: 1 hour 30 minutes

Materials:

In the Box:

Tape
Meter or yard sticks

Provided by User:

Strips of paper
(1cm by 75cm)

Worksheets:

Acceleration Table Worksheet
(Worksheet 1)
Reaction Time Data
Collection Worksheet
(Worksheet 2)
Reaction Time Bar Graph
Worksheet
(Worksheet 3)

Reference Materials:

None

Key Terms:

Acceleration
Reaction Time
Bar Graph

Objective:

Students will learn about motions and forces, specifically acceleration, by working in pairs to drop a meter stick calibrated to measure reaction time.

Activity Overview:

In this lesson, students will learn how the speed of a falling body increases over time. The concept of acceleration will be introduced by successfully dropping a meter or yard stick over increasingly short periods of time. The students will work in pairs—one student will drop the meter/yard stick and the other person is to catch it between his/her fingers when the fingers are positioned 5 cm (2 inches) apart.

The students will use the equation for a falling body to calculate the distance that an object will fall in .01 second intervals up to .39 seconds. They will use these data to make a calibrated scale that can be pasted on a meter/yard stick.

Next, students will use the calibrated meter/yard stick to determine their reaction time by dropping the meter/yard stick under varying conditions between their fingers. The students will record the results of each drop and then make bar graphs of the data.

They will read and interpret the data on the bar graph and draw conclusions. Through discussion guided by the teacher, students will learn about the importance of training to reduce reaction time.

Activity:

1. **Provide the students with the Acceleration Table Worksheet.** Have the students work in pairs to create the calibration scale. The students are to create a reaction time scale on the long strip of paper.

To begin, have one student find the measurement for acceleration of gravity on the meter/yard stick and the other student draw the line on the strip of paper and label the time on the strip of paper. It is easier to have the 0 seconds time at the bottom of the strip and move upward from there.



2. **Once the reaction time scale has been completed, have the students tape the scale onto a meter/yard stick.** Have them place the 0 sec mark approximately 5cm (2 inches) from the end of the meter/yard stick.
3. **Now the students will work in pairs with one person dropping the meter/yard stick with the pasted reaction time scale for 4 categories of measurement.** Students will drop with eyes open right hand; drop with eyes open left hand; drop with eyes closed right hand and drop with eyes closed left hand. There are to be 3 drops for each student for each of the categories. The students are to record their times on the Reaction Time Data Collection Worksheet.
4. **For each drop of the meter/yard stick, the fingers should be 5 cm apart.** The fingers should be at the 0 second mark on the meter /yard stick. The student is not to move the fingers together until the meter/yard stick is dropped. When their eyes are closed, the fingers should not start to move together until they hear the word 'drop' by the person dropping the meter/yard stick.
5. **Once every team member has completed all of the drops, they are to calculate the average time for the four categories.**
6. **Each student should record their results on the Bar Graph Worksheet by filling in one of the boxes on the worksheet.** The first student to record must shade in the bottom box and if another student has a result that also falls in that range, he or she would shade in the box above the previous one. Students need to be sure and record their results in either the boy or girl column on the worksheet.
7. **Once all of the data has been recorded, have students share their final results with the rest of the class so that they can add them to their worksheet.** Once all the data has been entered, create the bar graphs.



Discussion Points:

1. **Were the reaction time spaces the same width for all of the time intervals that you calculated?**

The spaces are not the same width. The width of a space is impacted by acceleration and time. Since the acceleration rate was the same for all of the reaction times, each width is affected by the square of the time. For example, for the first tenth of a second, the meter/yard stick dropped only .49 cm. The distance traveled between .2 and .3 seconds is 24.5 cm. This result demonstrates the effect of acceleration (shorter distance in less time). If the speed was constant, the distance traveled for each tenth of a second would have been .49 cm.

2. **Which range of the reaction time had the most number of students?**

Answer to this question depends on student data.

3. **Were the reaction times the same for when you had your eyes opened or closed?**

Answer to this question depends on student data. It may be that students reacted more quickly with their eyes open since their bodies are more sensitive to visual stimuli.

4. **What might explain the difference?**

In the case of the right or left hand, the dominate hand can react more quickly than the other hand.

5. **Were the reaction times the same for the boys and girls? If there is a difference, what might be some reasons?**

Answer depends on student data.

6. **Ask the students how training might reduce reaction time and why is this important?**

Have the students think about athletes and how practice enables them to react more quickly to tackle a runner or chase down a fly ball. Also, remind the students that astronauts are given a variety of tests to measure their reaction time. The tests are given under a variety of conditions, for example, after being spun around in a centrifuge or after taking medicine to reduce motion sickness which sometimes has side effects such as drowsiness. Astronauts also train as part of The "Reduced Gravity Program" to become more familiar with microgravity conditions. The "Reduced Gravity Program" was described in the [Background](#) section.

Also, refer to the NASA press release included in the Resources. Note how technology will help solve critical issues in situations that require quick reaction times.

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Motion of an object can be described by its position, direction, speed

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Motion of an object can be described by its position, direction, and speed

Activity 2

Thrown Ball Observation

GRADES 5-12**Time Requirement:** 1 hour 15 minutes**Materials:**In the Box:

Chuckit Ball Launcher
 Stop watch
 Tape measure or
 trundle wheel

Provided by User:

Graph paper

Worksheets:

Thrown Ball Data
 Collection Worksheet
 (Worksheet 4)

Thrown Ball Data
 Analysis Worksheet
 (Worksheet 5)

Reference Materials

None

Key Terms:

Parabola
 Trajectory
 Range
 Vertex

Objective:

Students will learn about motions and forces and transfer of energy as they learn that the trajectory of a thrown tennis ball is a parabola that can vary in shape and size from one throw to the next due to different external factors. The students will use the equation for a falling body and other equations to calculate different aspects of the parabola and trajectory of their thrown tennis ball.

Activity Overview:

This lesson will be conducted both in the classroom and outdoors. This activity requires the students to observe the behavior of a thrown tennis ball as it relates to time and distance the ball traveled. The students will take turns using a Chuckit Ball Launcher to throw a tennis ball. In this lesson, students will observe how different external factors influence the trajectory (parabola) of a thrown tennis ball. As the students will discover in the lesson, the trajectory of the thrown tennis ball is affected by several forces including the ball's weight, the drag caused by air resistance, the angle in which the ball was thrown, the launch velocity, and even its spin. Trajectory problems involving the force of drag or spin rate requires more advanced math and will not be included in this lesson. Also, the influence of air resistance or the height that the ball is released is disregarded so as to make the problems less complex.

Students will record the time and range for each tennis ball throw. They will use this information to solve for the highest point of the trajectory, the launch angle and the release speed of the tennis ball.

Caution: Since students will be throwing a tennis ball during this lesson, it is important to stress the importance of safety. Remind the students not to throw the ball unless their team is ready and to be sure and alert everyone before the tennis ball is thrown.

Activity:***In the Classroom***

1. Before you start the lesson, locate an open area where the students can throw the ball such as the school's baseball or football field.
2. Introduce the lesson by displaying the graphic of the parabola, Galileo and the equation for a falling body. Explain how NASA uses a parabola in their reduced gravity program described in the **Background** section.
3. Discuss the equation for a falling body and use the sample problem to highlight the math involved.
4. Explain the procedure for throwing a ball with the Chuckit Ball Launcher stressing the importance of safety, and distribute the **Ball Throw Data Collection Worksheet**. Explain that each person will make four throws—three with the Ball Launcher and one regular style (student's arm). If there is wind—students will launch one with the wind, another into the wind, and another in a direction perpendicular to which the wind is blowing. The regular throw can be in any direction. If there is no wind, students can make their throws in any direction. Also, point out to the teams that they are to enter the weather data at the time they are doing the ball throws.
5. **Divide the class into teams of seven.** Explain when they do the activity one person will be the thrower, another the timer, while another team member is the data recorder. Two of the team members are to be positioned so that they can accurately spot where the ball hits the ground, and two other team members are to measure the distance from where the ball was thrown to where it hits the ground. The stop watch is to be started when the ball is released and stopped when one of the spotters raises his or her hand to indicate the ball has hit the ground. The time should be given to the recorder and once the distance has been measured, that information is provided to the recorder. Inform the class that it might be easier for one person to complete all three throws and then rotate, and if there is a problem with the throw, redo it. REMIND THE STUDENTS THAT IF THERE IS A PROBLEM, ALERT THE TEACHER IMMEDIATELY.



- Also, remind the class that when they go outdoors, make sure they have all of the necessary equipment to complete the activity—ball launcher, stop watch, tape measure or trundle wheel, and the Ball Throw Data Collection worksheet.

Outside

- Have each team use different areas of the open area where they are throwing the ball. If at a ball field, one team can throw from the first base towards right field, the second team could throw from second base to the center field area, etc.
- Have the teams assume their positions and have the first person throw the tennis ball as far as they can. Record the data for this throw.
- Have the first person rotate to the next position and have the next person throw the tennis ball, etc. Make sure that data is recorded for each throw.
- Once everyone has completed their three throws with the ball launcher, have them throw the ball without the launcher and record the measurements. As before, have a team member record their time and range for the throw.
- Make sure all data is recorded and equipment gathered before returning to the classroom.



Post Throw

Provide each student with [Worksheet 5, Thrown Ball Data Analysis](#) and a sheet of graph paper. Have each student calculate the height of the parabola for each of their throws. Knowing the range and the height of the parabola, the student is to use graph paper to sketch each parabola. The teacher may want the students to determine the launch angle and launch velocity for each throw.

Discussion Points:

- 1. How did your results compare to the other team members' results?**
Results depend on student data.
- 2. How was the trajectory the same for each of your throws? Look at the sketches to answer this question. Please account for differences.**
Launch angle, velocity of the launch and wind direction all have an impact.
- 3. Which of the above type of throws most often gave the optimum or best trajectory for the longest throw for your team? What might be some reasons for this?**
There several reasons the students might propose, such as throwing with the wind enabled the ball to travel farther than when thrown into the wind where the air resistance was greater. In addition, under the same conditions launch angles near 45° will enable a ball to travel farther than a ball launched at any other angle. A ball launched at a 55° launch angle will travel the same distance as a ball launched at a 35° angle with the same launch velocity. Also, a ball launched at a 70° angle will travel the same distance as a ball thrown at a 20° angle with the same launch velocity. Notice how the two angles added together equals 90° .
- 4. Compare and contrast the trajectory of the tennis ball when thrown by hand and with the Ball Launcher. Why are there differences in the two trajectories?**
The Ball Launcher can provide a greater launch velocity than thrown by hand. In almost every case, the Ball Launcher will have the greatest range because of that.
- 5. Explain why the use of math in looking at a parabola provides so much more information than just observing the parabola?**
Most scientists before Galileo never used math to explain their observations. Galileo demonstrated how math can provide a much better explanation for events in nature than can made from just observing an event, describing it and providing an idea to explain the observation.

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Motion of an object can be described by its position, direction, speed

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Motion of an object can be described by its position, direction, speed
- Interactions of energy and matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology



Reference Materials

Glossary

Acceleration:

The rate at which an object changes its velocity. On Earth the acceleration rate due to gravity is 9.8 m/sec^2 .

Axis of Symmetry:

The vertical line that passes through the parabola's vertex. It divides the parabola into two perfect halves.

Equation for a Falling Body:

The equation for a falling body is given as $S = \frac{1}{2} at^2$.

S = distance, a = acceleration due to gravity (9.8 m/sec^2), and t = time.

G-Force:

The force acting on a body due to the acceleration of gravity. Under normal conditions this force is equal to one g . However, a 10 kilogram object undergoing a g -force of $2g$ experiences 20 kilograms of force.

Galileo:

The famous Italian scientist (1564-1642) who made great contributions to science. He was the first person to record astronomical observations with the telescope; conduct experiments with pendulums; and study the motion of objects through experimentation and the use of mathematics.

Gravity:

All objects in the universe, such as Earth, exert a natural force of attraction upon things at or near its surface, and tend to draw them toward its center.

Microgravity:

A condition that results when an object in a gravitational field (such as Earth's gravity) accelerates freely as a result of the gravitational force. Free falling objects such as a satellite on Earth orbit or a sky diver are in a condition of microgravity.

NASA C-98 Aircraft:

The aircraft that NASA currently uses to fly parabolas as part of NASA's Reduced Gravity Program.

This specific aircraft flies parabolic arcs to create short periods of a simulated microgravity environment so that astronauts and others can train to fly missions in a reduced gravity environment.

Parabola:

When an object is thrown upward and lands at a different place, or a baseball is sent over the right field fence, the type of curve that it follows is called a parabola. A parabola looks a lot like the letter U when it is drawn. You can identify an equation for a parabola when either the x or y is squared but not both. $y = x^2 - 8$ is an equation for a parabola.

Range:

The distance the tennis ball travels from the spot where it was thrown to where it landed.

Reaction Time:

The amount of time it takes from when you receive a stimulus to the time you react to it.

Speed:

The measurement of how fast something is moving. The rate of speed is given as the distance traveled per unit of time such as 5 kilometers/hour.

Trajectory:

The path that a moving body, such as a projectile, follows during its flight through space

Fig. 1 Parabola

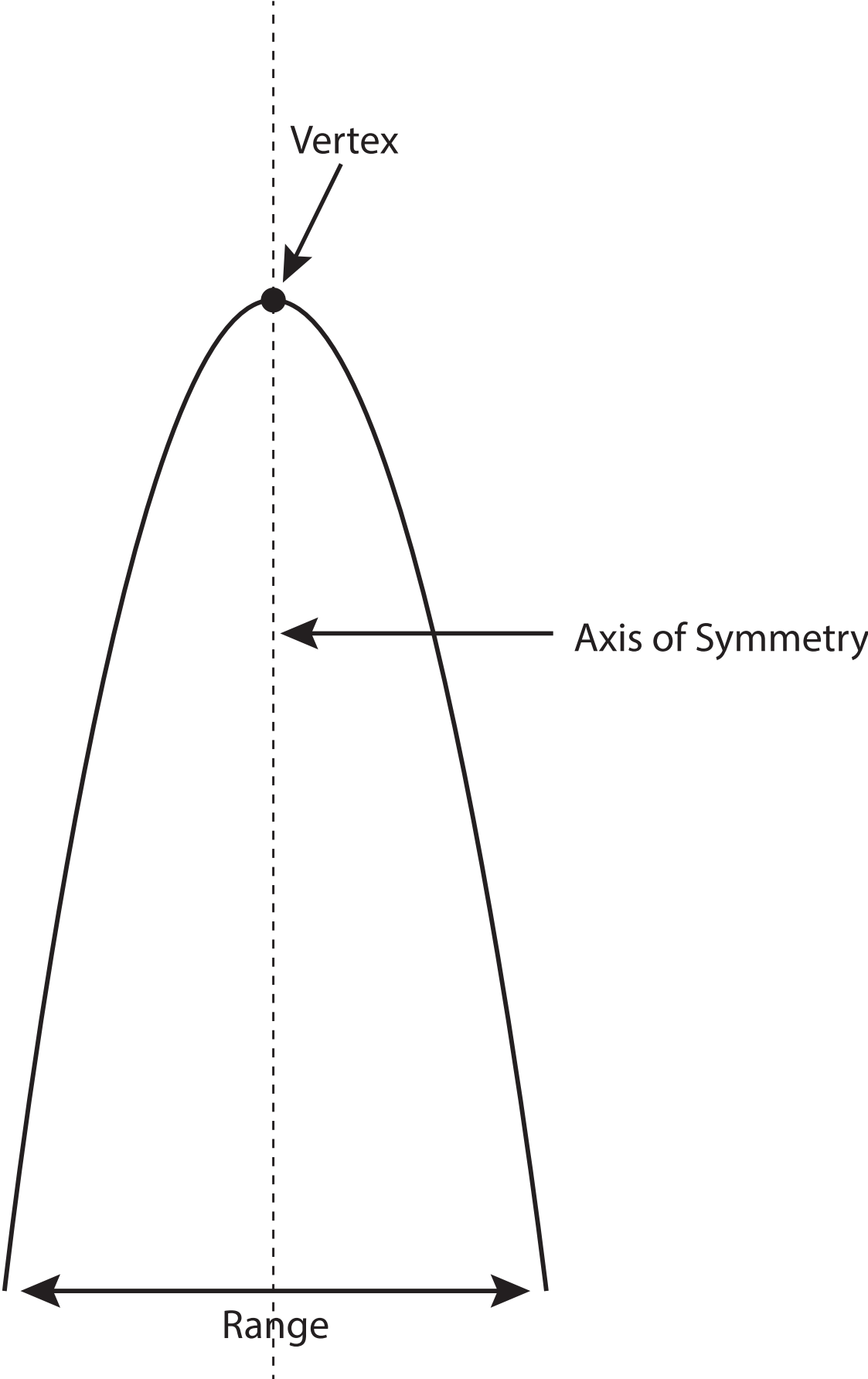
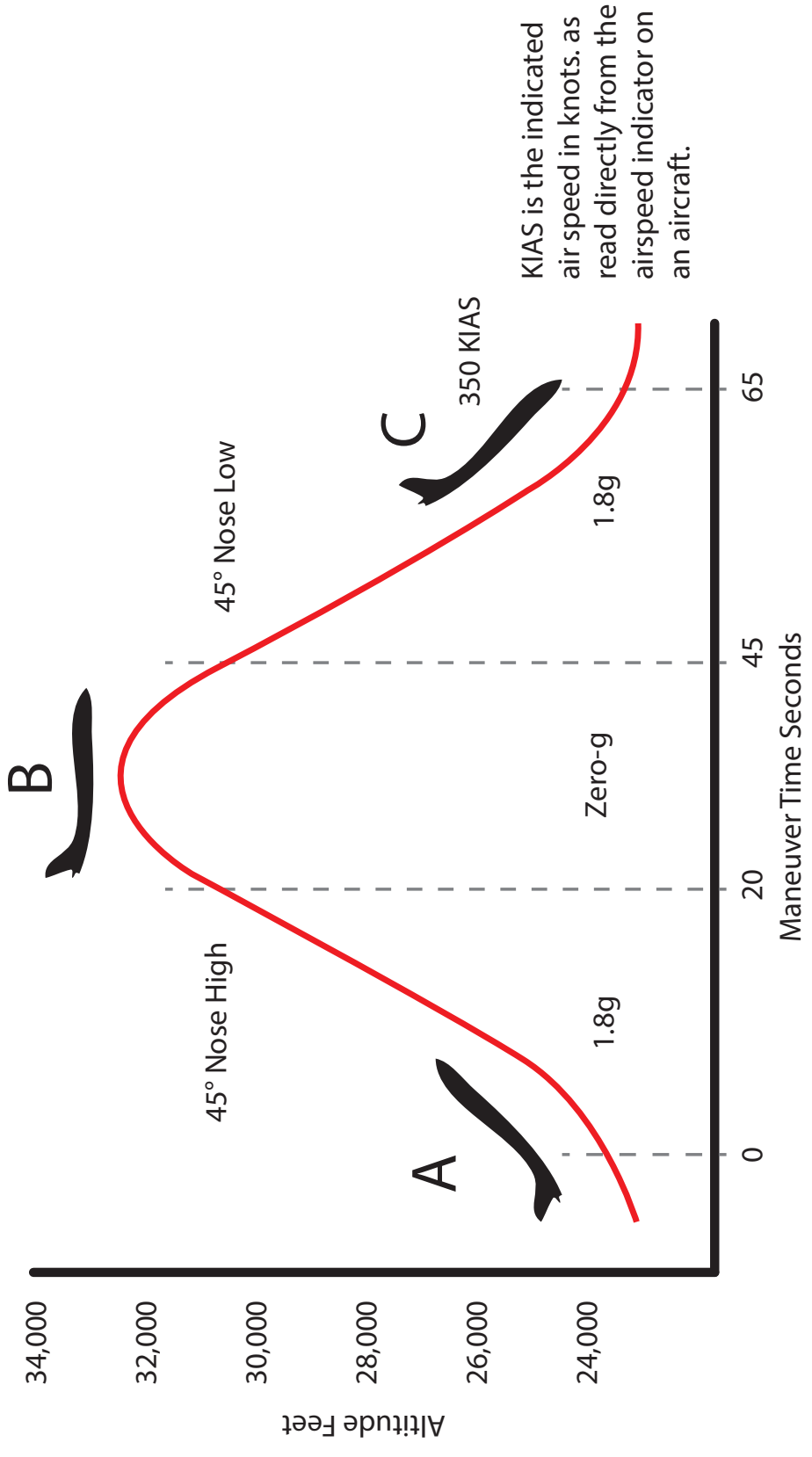


Fig. 2 Flying the parabola



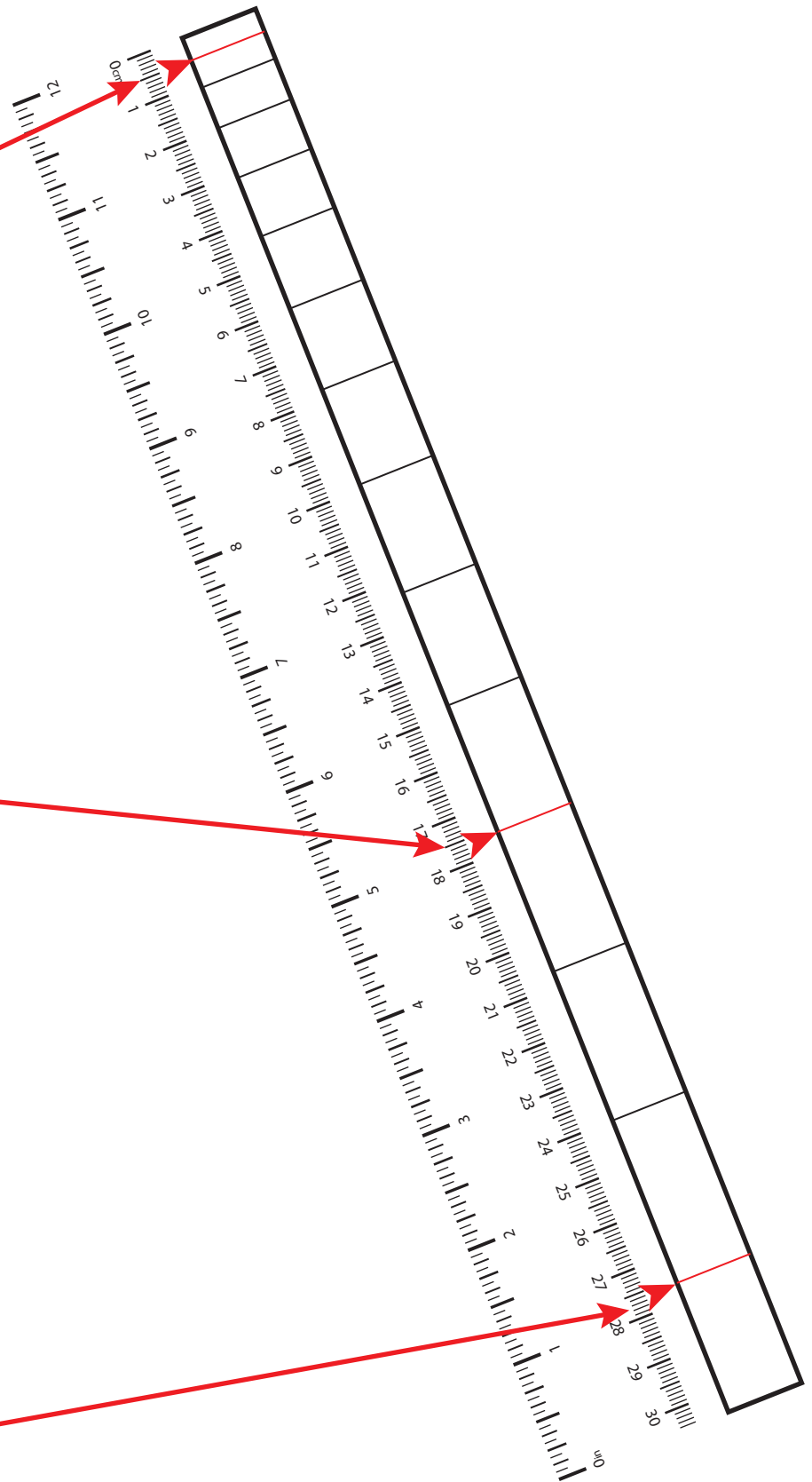


Student Worksheets

Worksheet 1

Acceleration Table

Time in Seconds	Distance in Centimeters	Distance in Inches
.10 sec	.49 cm	2 in
.15 sec	1.1 cm	.4 in
.20 sec	2 cm	.8 in
.25 sec	3.1 cm	1.2 in
.30 sec	4.4 cm	1.7 in
.35 sec	6 cm	2.4 in
.40 sec	7.8 cm	3.1 in
.45 sec	9.9 cm	3.9 in
.50 sec	12.3 cm	4.8 in
.55 sec	14.8 cm	5.8 in
.60 sec	17.6 cm	6.9 in
.65 sec	20.7 cm	8.1 in
.70 sec	24 cm	9.4 in
.75 sec	27.6 cm	10.9 in
.80 sec	31.4 cm	12.4 in
.85 sec	35.4 cm	13.9 in
.90 sec	39.7 cm	15.6 in
.95 sec	44.2 cm	17.4 in
1 sec	49 cm	19.3 in
1.05 sec	54 cm	21.3 in
1.10 sec	59.3 cm	23.3 in
1.15 sec	64.8 cm	25.5 in
1.20 sec	70.6 cm	27.8 in

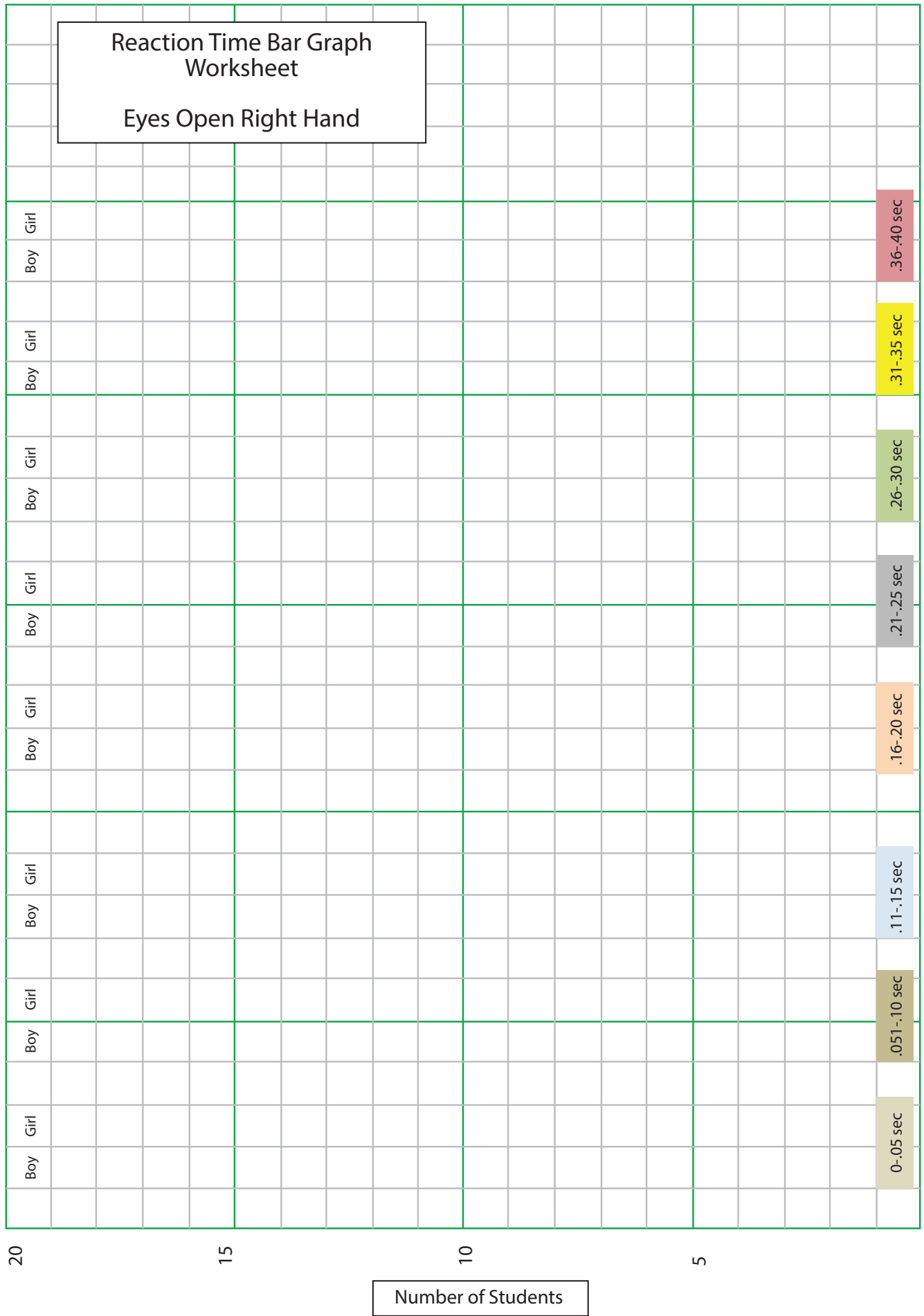


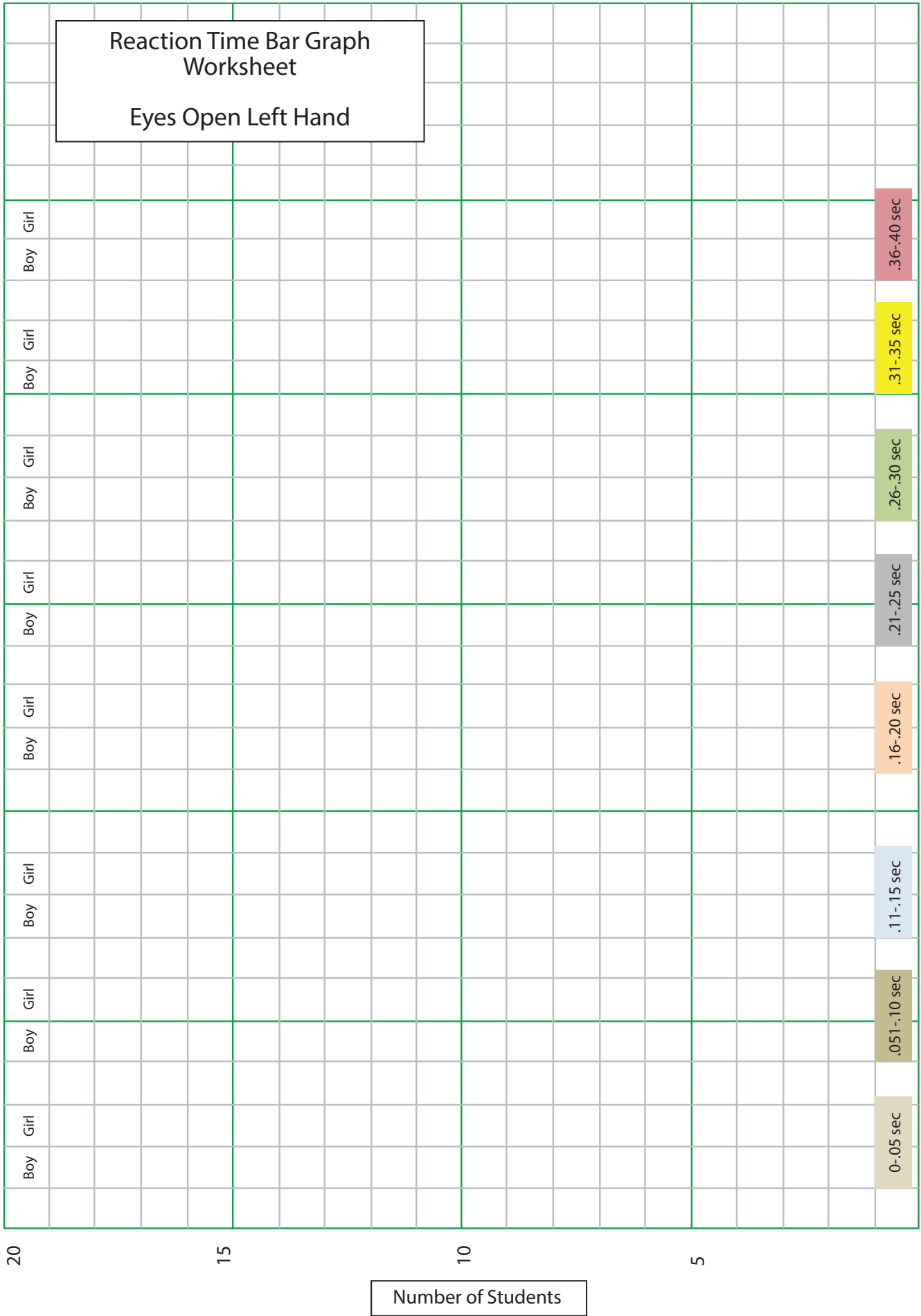
Reaction Time Data Collection Worksheet

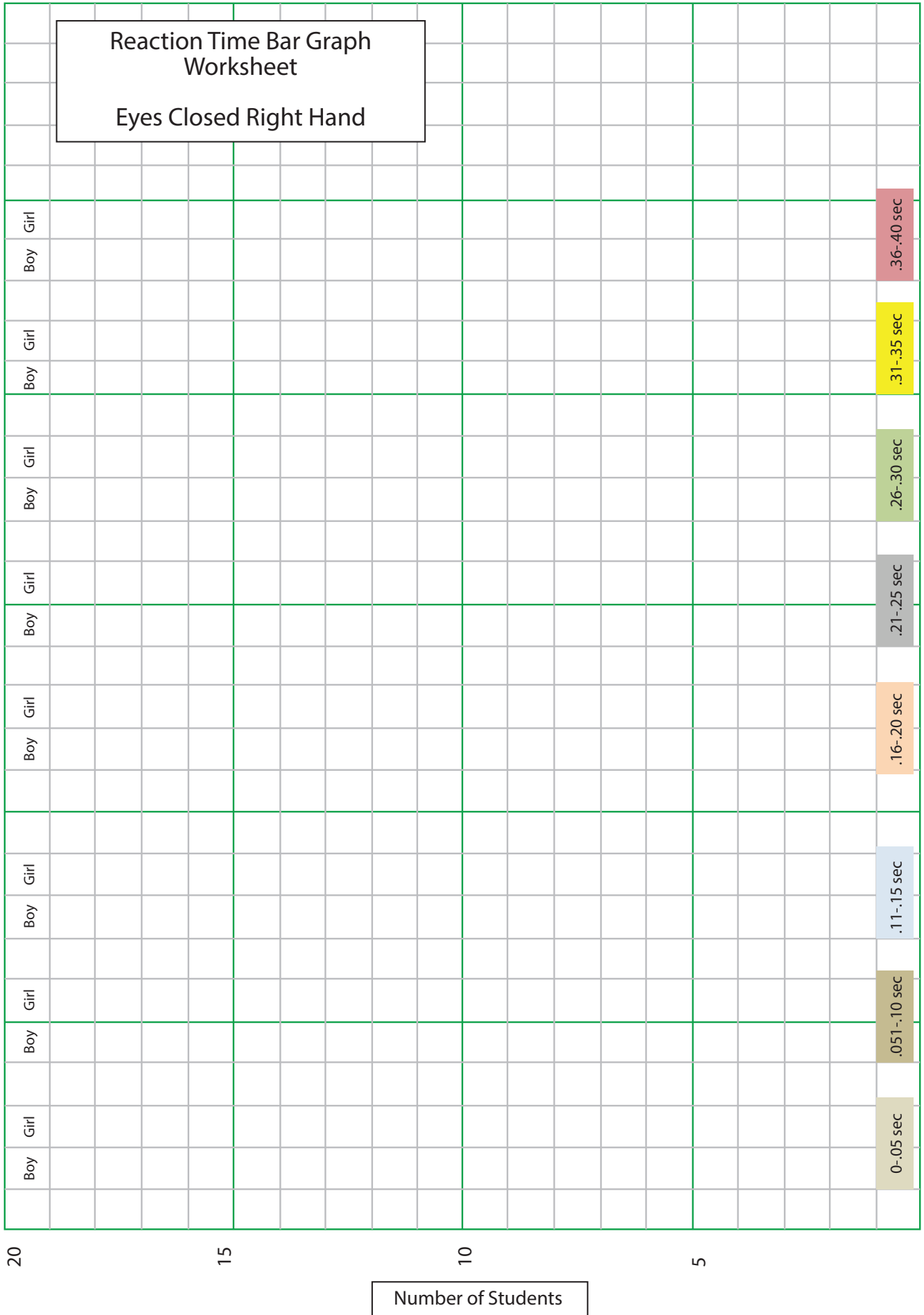
Name of Student	Reaction Time in Seconds Right Hand Eyes Open			Reaction Time in Seconds Right Hand Eyes Closed			Reaction Time in Seconds Left Hand Eyes Open			Reaction Time in Seconds Left Hand Eyes Closed		
	T1	T2	T3	T1	T2	T3	T1	T2	T3	T1	T2	T3
Student 1												
Average Time = $(T1 + T2 + T3) \div 3$												
Student 2												
Average Time = $(T1 + T2 + T3) \div 3$												
Student 3												
Average Time = $(T1 + T2 + T3) \div 3$												
Student 4												
Average Time = $(T1 + T2 + T3) \div 3$												
Student 5												
Average Time = $(T1 + T2 + T3) \div 3$												
Student 6												
Average Time = $(T1 + T2 + T3) \div 3$												

Worksheet 3

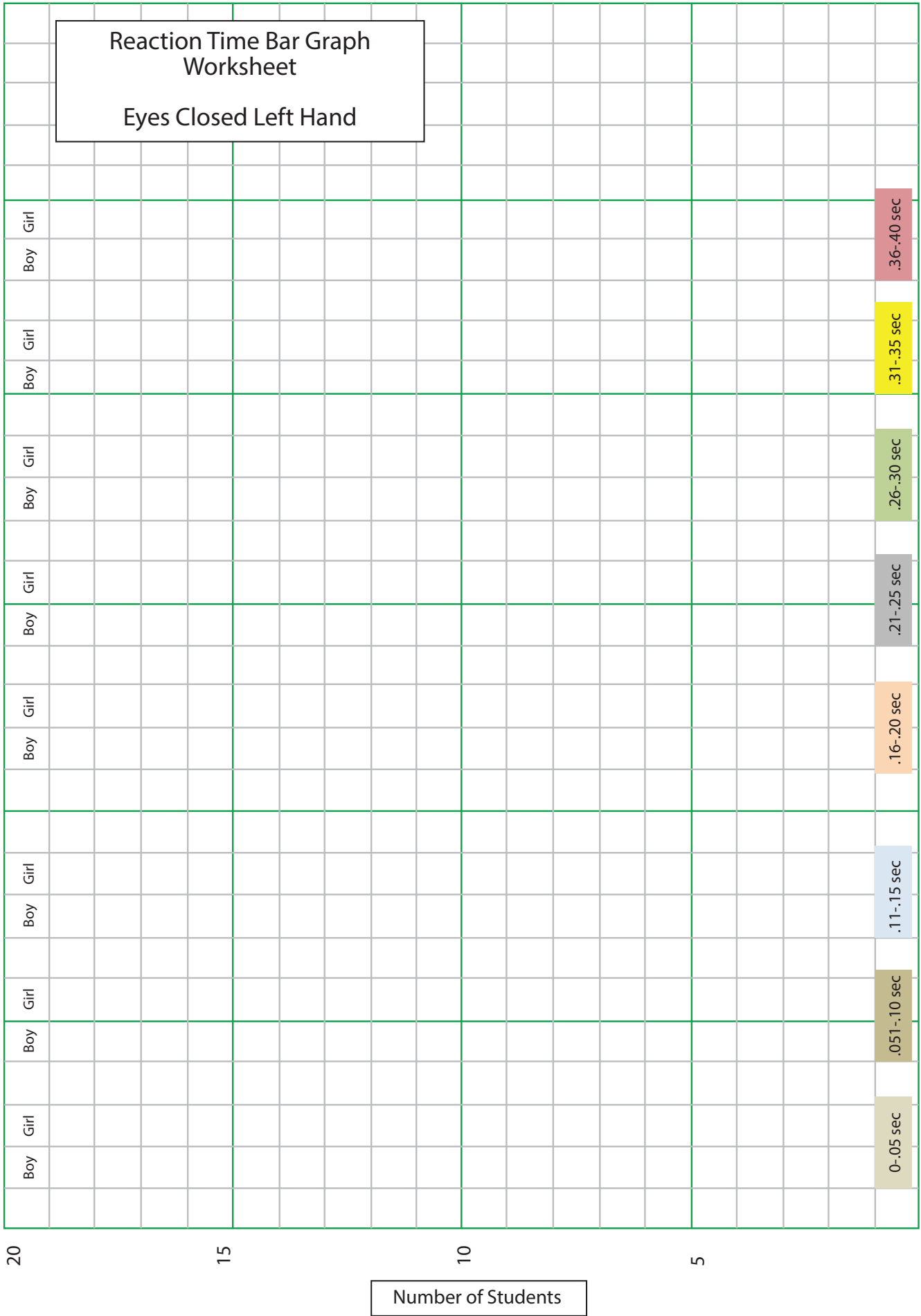
Reaction Time Bar Graph







Reaction Time Bar Graph
Worksheet
Eyes Closed Left Hand



Thrown Ball Data Recording

Worksheet 4

Thrown Ball Data Recording Worksheet						
Name of Student	Throw 1		Throw 2		Throw 3	
Student 1	Time	Range	Time	Range	Time	Range
Student 2						
Student 3						
Student 4						
Student 5						
Student 6						
Indicate for each throw the direction of the throw in reference to the wind. If it is windy, do all three tosses.	With the wind Into the wind No wind If wind, throw perpendicular to the wind. If it is a north wind, throw the ball either to the east or west.		With the wind Into the wind No wind If wind, throw perpendicular to the wind. If it is a north wind, throw the ball either to the east or west.		With the wind Into the wind No wind If wind, throw perpendicular to the wind. If it is a north wind, throw the ball either to the east or west.	

Worksheet 4 (cont.)

Thrown Ball Data Collection

Date: _____ Time: _____

Weather:

Wind Speed: _____ Kilometers Per Hour

Wind Direction: _____

Location of Activity: _____

Name: _____

Ball Launcher Toss 1	Ball Launcher Toss 2	Ball Launcher Toss 3	No Ball Launcher Arm Toss 4
Start Time:	Start Time:	Start Time:	Start Time:
Stop Time:	Stop Time:	Stop Time:	Stop Time:
Total flight time (in seconds):	Total flight time (in seconds):	Total flight time (in seconds):	Total flight time (in seconds):
Range: (in meters)	Range: (in meters)	Range: (in meters)	Range: (in meters)
Circle wind condition related to direction of thrown ball:	Circle wind condition related to direction of thrown ball:	Circle wind condition related to direction of thrown ball:	Circle wind condition related to direction of thrown ball:
Into the wind	Into the wind	Into the wind	Into the wind
With the wind	With the wind	With the wind	With the wind
Perpendicular to wind	Perpendicular to wind	Perpendicular to wind	Perpendicular to wind
No wind	No wind	No wind	No wind
Comments:	Comments:	Comments:	Comments:

Worksheet 5

Thrown Ball Data Analysis

Name: _____

Use the Falling Bodies Equation to determine the height of the parabola for each of the throws.

The formula is:

$S = \frac{1}{2} at^2$. (S = height of parabola, a = acceleration due to gravity (9.8m/sec²), and t = time in seconds)

Height Toss 1: _____

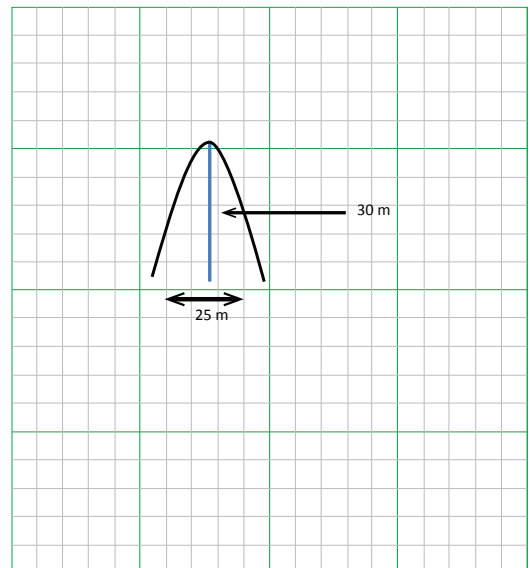
Height Toss 2: _____

Height Toss 3: _____

Height Toss 4: _____

On graph paper, sketch the parabola for each throw.

An example is given: Height 30 meters, range 25 meters.



Solve for other aspects of the ball throw. (As required by the teacher.)

Ball Toss	Launch Angle	Launch Velocity
1		
2		
3		
4		

$$\text{Launch Angle} = \frac{S}{R} = \frac{\tan\theta}{4}$$

Use launch angle to find velocity. If the launch angle is 60° , then you would look up the sin and cos for the 60° in the Launch Velocity Equation.

$$\text{Launch velocity} = V_0 = \sqrt{\frac{Ra}{\sin 2\theta}}$$



Images

Img. 1 Mercury 3 at launch



(Photo courtesy of NASA)

Img. 2 Galileo Galilei by Justus Sustermans (1564-1642)



(Public Domain)

Img. 3 Astronaut Satoshi Furukawa in Space Aboard the ISS



(Image courtesy of NASA)

Img. 4 "NASA 932" Weightless Wonder VI, Vomit Comet



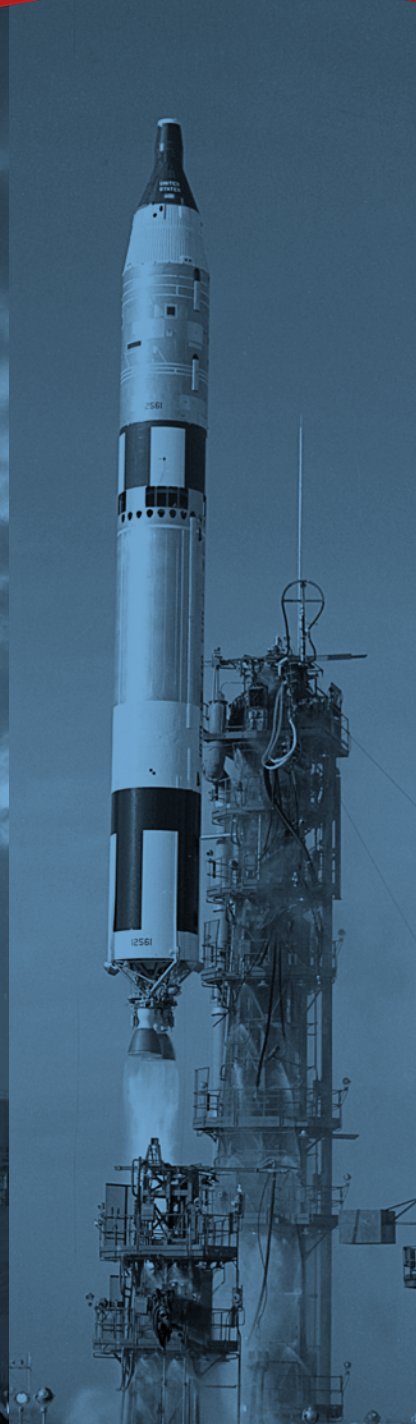
(Photo courtesy of NASA)

Img. 5 University Students Conducting an Experiment on the 'Vomit Comet'

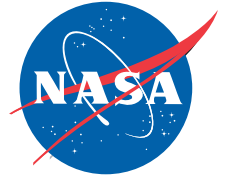


(Photo courtesy of NASA)

Aeronautics
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propulsion



GRADES

9-12

Wind Power



propulsion

Aeronautics
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Wind Power

Lesson Overview

In this lesson, students will explore the power of the wind. Initially students will learn how wind is created by the phenomenon known as convection. Then they will put the power of wind to use with the creation of a wind turbine.

Objectives

Students will:

1. Learn through demonstration how the phenomenon known as convection produces wind.
2. Compete by designing different styles of turbine blade, with the winner being the team that can produce the highest power output.

Materials:

In the Box:

Plastic box
 Food coloring
 Plastic dropper (1 per group)
 PVC Turbine Kits
 Balsa wood strips (4 per group)
 Coroplast strips (4 per group)
 ¼" Dowels (100 total)
 Multimeters (1 per group)

Provided by User:

Water (hot and cold)
 2-4 Risers (thin books or wood blocks)
 Tape or glue
 Cardboard
 Styrofoam cups
 Scissors / craft knives
 Large fan

GRADES 9-12 **Time Requirements:** 4 hours 40 minutes minimum

Background

Early Use of Wind Power

The power of the wind has been put to work for thousands of years, powering the first ships and allowing explorers to discover the hidden corners of the globe. It was Hero of Alexandria (10AD – 70AD) though that invented the first wind powered machine. His device, simply known as “Hero’s Organ”, was exactly that – a wind powered organ similar to the many church organs in use today (Fig. 1).

Over the centuries, people have learned how to put wind power to far greater use than simply for playing music. It has been used to grind wheat for bread, pump water and most recently, generate electricity. The timeline in Figure 2 demonstrates how the technology has evolved over the years.

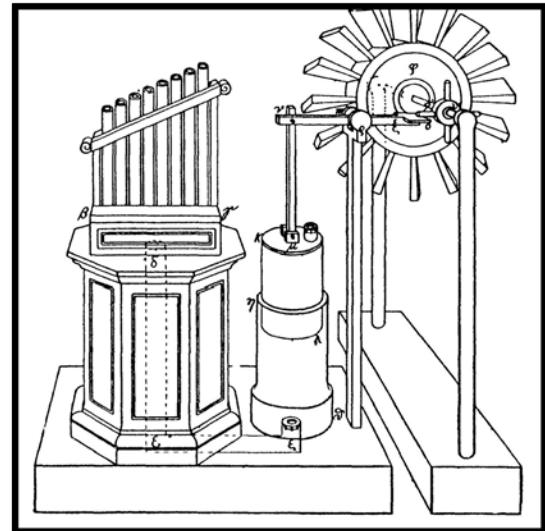


Fig. 1 Hero’s Organ

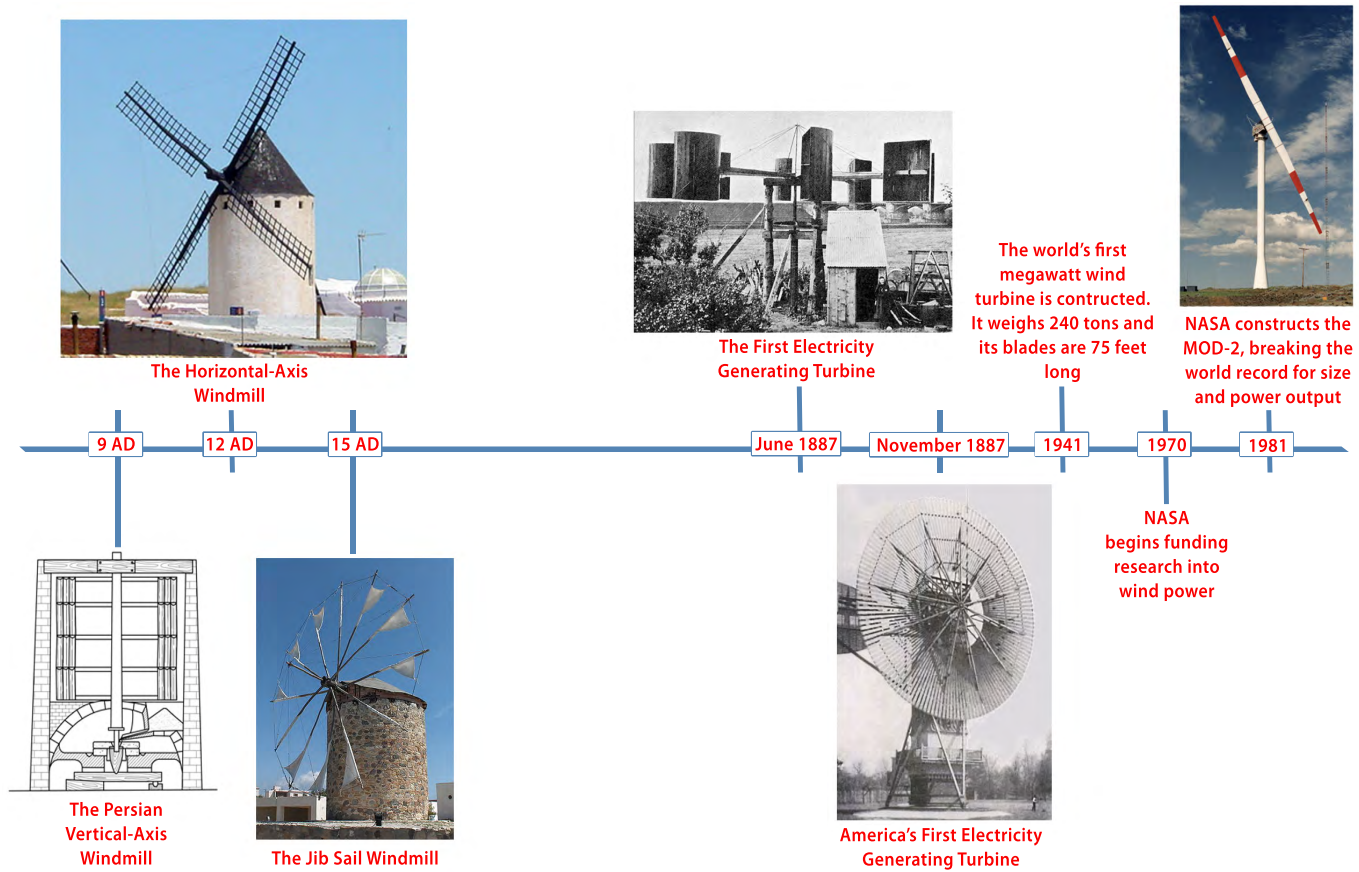


Fig. 2 Wind Power Technology Timeline

The Creation of Wind

Wind is nothing more than the movement of air due to a difference in air pressure and temperature.

The generation of wind begins when energy from the Sun heats a parcel of air. As the air is heated, its molecules become excited and move farther apart, causing the air mass to become less dense than its neighboring cold air mass. This difference in temperature and pressure resulting from the heating process creates instability. In an attempt to return to equilibrium, the colder, denser air moves underneath the warmer, lighter air in order to equalize the pressure between the two air masses. It is this movement of air that we refer to as wind.

To further explain, consider the following analogy. Imagine you are at a party. Room "A" is getting very crowded while the adjacent room "B" is nearly empty (Fig. 3). Some of the people in the crowded room will naturally begin to move to the sparsely occupied room, which in turn brings both rooms to equilibrium (Fig. 4). In this example, the flow of people from one room to the other represents the wind.

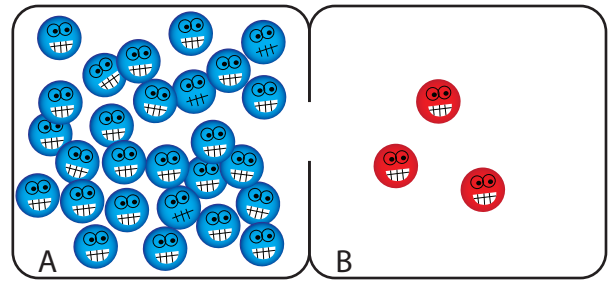


Fig. 3

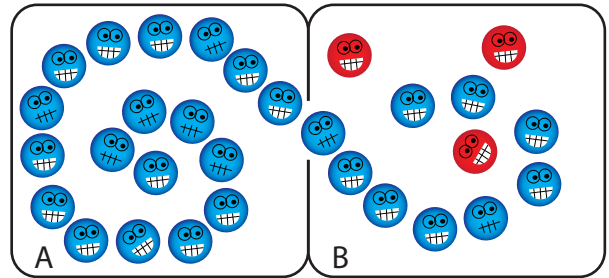


Fig. 4

Measuring Wind Speed

Prior to 1805, there was no consistent way to measure the speed of the wind. One man's "strong gust" was another man's "light breeze". That all changed however when Sir Francis Beaufort, an Irishman in the Royal Navy, developed the Beaufort scale. Initially the scale went from 0 to 12 and measured the effects of the wind on the sails of a ship. This type of scale is classified as an "empirical" scale, meaning that it is based upon observation or experimentation, rather than calculated data. A 0 equated to no movement even with fully extended sails, whereas a 12 required the sails to be completely stowed for safety.

In 1850, the scale was updated to include numbers that corresponded to the number of rotations of an Anemometer (Img. 2), a device with cups to catch the wind. An Anemometer activity is available in the Weather to Fly By lesson of the Museum in a Box series. Another change to the scale was made in 1916, when the use of sails diminished due to the increase in popularity of steam powered ships. People instead began to observe the effects of the wind on waves and land-based phenomena, such as the movement of trees or the smoke from chimneys. Figure 5 shows how the Beaufort scale matured over time.



Img. 2 The Robinson Anemometer

Beaufort number	Description	Wind speed	Wave height	Sea conditions	Land conditions
0	Calm	< 1 km/h (< 0.3 m/s)	0 m	Flat.	Calm. Smoke rises vertically.
		< 1 mph			
		< 1 kn	0 ft		
		< 0.3 m/s			
1	Light air	1.1–5.5 km/h (0.3-2 m/s)	0–0.2 m	Ripples without crests.	Smoke drift indicates wind direction and wind vanes cease moving.
		1–3 mph			
		1–2 kn	0–1 ft		
		0.3–1.5 m/s			
2	Light breeze	5.6–11 km/h (2-3 m/s)	0.2–0.5 m	Small wavelets. Crests of glassy appearance, not breaking.	Wind felt on exposed skin. Leaves rustle and wind vanes begin to move.
		4–7 mph			
		3–6 kn	1–2 ft		
		1.6–3.4 m/s			
3	Gentle breeze	12–19 km/h (3-5 m/s)	0.5–1 m	Large wavelets. Crests begin to break; scattered whitecaps.	Leaves and small twigs constantly moving, light flags extended.
		8–12 mph			
		7–10 kn	2–3.5 ft		
		3.4–5.4 m/s			
4	Moderate breeze	20–28 km/h (6-8 m/s)	1–2 m	Small waves with breaking crests. Fairly frequent whitecaps.	Dust and loose paper raised. Small branches begin to move.
		13–17 mph			
		11–15 kn	3.5–6 ft		
		5.5–7.9 m/s			
5	Fresh breeze	29–38 km/h (8.1-10.6 m/s)	2–3 m	Moderate waves of some length. Many whitecaps. Small amounts of spray.	Branches of a moderate size move. Small trees in leaf begin to sway.
		18–24 mph			
		16–20 kn	6–9 ft		
		8.0–10.7 m/s			
6	Strong breeze	39–49 km/h (10.8-13.6 m/s)	3–4 m	Long waves begin to form. White foam crests are very frequent. Some airborne spray is present.	Large branches in motion. Whistling heard in overhead wires. Umbrella use becomes difficult. Empty plastic garbage cans tip over.
		25–30 mph			
		21–26 kn	9–13 ft		
		10.8–13.8 m/s			

Beaufort number	Description	Wind speed	Wave height	Sea conditions	Land conditions
7	High wind, Moderate gale, Near gale	50–61 km/h (13.9-16.9 m/s)	4–5.5 m	Sea heaps up. Some foam from breaking waves is blown into streaks along wind direction. Moderate amounts of airborne spray.	Whole trees in motion. Effort needed to walk against the wind.
		31–38 mph			
		27–33 kn	13–19 ft		
		13.9–17.1 m/s			
8	Gale, Fresh gale	62–74 km/h (17.2-20.6 m/s)	5.5–7.5 m	Moderately high waves with breaking crests forming spindrift. Well-marked streaks of foam are blown along wind direction. Considerable airborne spray.	Some twigs broken from trees. Cars veer on road. Progress on foot is seriously impeded.
		39–46 mph	18–25 ft		
		34–40 kn			
		17.2–20.7 m/s			
9	Strong gale	75–88 km/h (20.8-24.4 m/s)	7–10 m	High waves whose crests sometimes roll over. Dense foam is blown along wind direction. Large amounts of airborne spray may begin to reduce visibility.	Some branches break off trees, and some small trees blow over. Construction/temporary signs and barricades blow over.
		47–54 mph	23–32 ft		
		41–47 kn			
		20.8–24.4 m/s			
10	Storm Whole gale	89–102 km/h (24.7-28.3 m/s)	9–12.5 m	Very high waves with overhanging crests. Large patches of foam from wave crests give the sea a white appearance. Considerable tumbling of waves with heavy impact. Large amounts of airborne spray reduce visibility.	Trees are broken off or uprooted, saplings bent and deformed. Poorly attached asphalt shingles and shingles in poor condition peel off roofs.
		55–63 mph	29–41 ft		
		48–55 kn			
		24.5–28.4 m/s			
11	Violent storm	103–117 km/h (28.6-32.5 m/s)	11.5–16 m	Exceptionally high waves. Very large patches of foam, driven before the wind, cover much of the sea surface. Very large amounts of airborne spray severely reduce visibility.	Widespread damage to vegetation. Many roofing surfaces are damaged; asphalt tiles that have curled up and/or fractured due to age may break away completely.
		64–72 mph	37–52 ft		
		56–63 kn			
		28.5–32.6 m/s			
12	Hurricane force	≥ 118 km/h (≥ 32.8 m/s)	≥ 14 m	Huge waves. Sea is completely white with foam and spray. Air is filled with driving spray, greatly reducing visibility.	Very widespread damage to vegetation. Some windows may break; mobile homes and poorly constructed sheds and barns are damaged. Debris may be hurled about.
		≥ 73 mph	≥ 46 ft		
		≥ 64 kn			
		≥ 32.7 m/s			

Fig. 5 The Beaufort scale

Wind Turbine Operation

Figure 6 shows the workings of a basic horizontal wind turbine. The blades are connected to a device, known as a governor, which serves two purposes. The first is to adjust the pitch (twist) of the blades to improve performance in varying wind conditions. The second is to control the speed and prevent a dangerous over-speed condition.

The governor is connected to the main shaft which in turn connects the blades to the gearbox. Its purpose is to amplify the speed of the main shaft by converting its immense torque, or turning forces, into additional rotor speed.

The gearbox is finally connected to the generator, a combination of magnets and copper wire. Using the principal of magnetic induction, the copper wire rotates inside a magnetic field, which shifts electrons and ultimately produces electricity (Fig. 7).

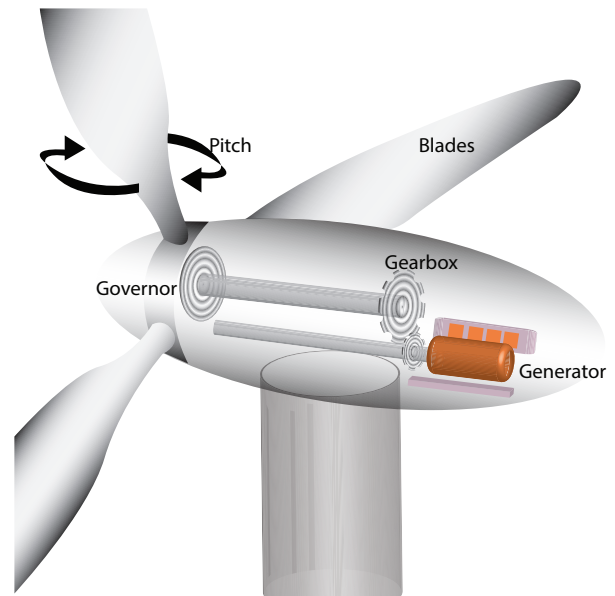


Fig. 6 Wind Turbine Diagram

Blade Design

The design of the wind turbine has changed remarkably over the years. The earliest designs were nothing more than simple pieces of cloth woven between canes. Today though, the use of computers and a better understanding of dynamics have helped us to create much more effective, efficient blade designs.

A turbine blade though can never be 100% efficient. Albert Betz, a German physicist, demonstrated back in 1919 that a blade that is too efficient, or that collects too much of the air, simply cannot turn. He proved, in what became known as Betz's Law, that a blade efficiency of about 59% is the theoretical maximum. In actuality, most commercial devices operate at around 40% efficiency as the 59% theoretical limit is almost unobtainable (Fig 8).

There are many ways to reach this limit but it becomes increasingly more difficult as the size of the blade increases.

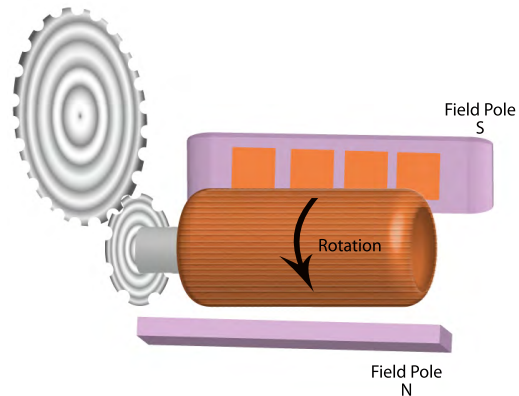


Fig. 7 Turbine Generator Diagram

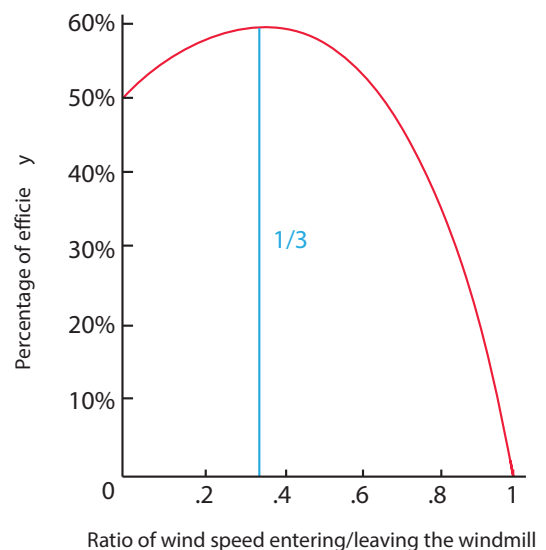


Fig. 8 Betz's Law

Some of the ways engineers are striving towards this 59% goal however are:

- **Aerodynamic blades.** By making a turbine blade in a similar way to an airplane's wing, it not only reduces the drag on the blade as it moves through the air, but uses the areas of high and low pressure to physically pull the blades around.
- **Blade Twisting.** Another technique also used on aircraft is twisting the blade, similar to an airplane's propeller. As the blades turn, the outer edges move significantly quicker than the inner, or root part of the blade due to the greater distance that the outer edge of the blade has to travel. In order to make each part of the blade most effective for its speed, it's twisted to give the tips of the blade a finer pitch and therefore produce less drag.
- **Horizontal / Vertical blades.** For large scale designs, the horizontal blade is a far more efficient design. For smaller locations, or in areas where the direction of the wind changes frequently, a vertical design works better. Similar to an old fashioned barbershop sign, the vertical blade design can collect wind from any direction. Also, due to its aerodynamics, it can be turned by much slower wind speeds, even in just a slight breeze. The drawback however is its inefficiency, with even the best designs capturing a mere 20-30% of the wind's available energy.

Activity 1

Convection Demonstration

GRADES 9-12**Time Requirement: 40 minutes****Materials:**In the Box

Plastic box
Food coloring
Plastic dropper

Provided by User

Very hot water
2-4 Risers
(thin books, woodblocks)
5 Styrofoam cups

Worksheets

None

Reference Materials

None

Key Terms:

Convection
Density
Pressure
Wind

Objective:

In this activity, students will learn through demonstration how the phenomenon known as convection produces wind.

Activity Overview:

Using a combination of hot and cold water, students will learn how the Sun's uneven heating of the Earth creates air masses of varying density and pressure. These air masses move from the high pressure areas to the low pressure areas, creating what is more commonly known as wind. Liquid reacts to these changes in the same manner as air, always trying to maintain a state of equilibrium and in this demonstration, the food coloring will show how these masses move to maintain equilibrium.

WARNING: This activity requires extremely hot water. As such, it should be performed as a demonstration only.

Activity:

- Begin by setting up the demonstration.** First, take four Styrofoam cups and place them upside-down on the risers. The cups should be spaced so that they can fully support the plastic box.
Select risers that are just high enough to allow the fifth cup to slide under one corner of the box.
- Using the **Background** information provided, discuss with the students how wind is created.
- When ready to begin the demonstration, fill the box with at least 6 cm of very cold or refrigerated water and place it on the four Styrofoam cups.



- Next, take the dropper and place a few drops of food coloring on the base of the box in opposite corners. *Be very careful to not cause any turbulence in the water when doing this!*



- Lastly, fill the fifth Styrofoam cup with the hottest water available and place it under one of the corners with the food coloring.



- Have your students watch what happens (Img. 2).



Img. 2 The Convection Phenomenon

Be patient; depending on the temperature of the water, it can take several minutes to see the results.

Discussion Points:**1. What caused the food coloring to move?**

When the hot water was placed underneath the box, it gave off energy in the form of heat, which heated the water in the box. As the water heated it became less dense, which meant that it could be displaced by the adjacent cold water. It is this displacement you saw as the food coloring travelled around the box.

2. How does this relate to wind?

The air around us reacts in the exact same way as the water in the box. As the air is heated by the sun it becomes less dense and is displaced by colder, denser air. This movement of air is what we refer to as wind. If we were somehow able to add food coloring to the air and look down from space, we would see the exact same thing happening with the air as we did with the water in the box.

3. What would happen if we didn't use both extremely hot and cold water?

While the experiment would still work, the effect is most apparent when the temperature differences are greatest. It is no different with air. Larger differences in temperature, and therefore pressure, cause the wind that is created to be stronger.

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Structure and properties of matter
- Interactions of energy and matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

Activity 2

Wind Turbine Design Competition

GRADES 9-12

Time Requirement: 4 hours minimum

Materials:

In the Box

- 3 PVC Turbine Kits
- Balsa wood strips
(4 per group)
- Coroplast strips
(4 per group)
- 100 ¼" Dowels
- 3 Multimeters

Provided by User

- Tape or glue
- Cardboard
- Styrofoam cups
- Scissors / craft knives
- Large fan

Worksheets

- Wind Turbine Power
(Worksheet 1)

Reference Materials

- Wind Turbine
Assembly Instructions
(3 copies, one per group)
- Using The Multimeter
(3 copies, one per group)
- Sample Turbine Blade Designs

Key Terms:

- Voltage
- Wind Turbine

Objective:

Students will compete by designing different styles of turbine blade, with the winner being the team that can produce the highest power output.

Activity Overview:

Wind turbines come in a variety of shapes and sizes. By creating and experimenting with different blade styles, students will learn what blade characteristics harness the greatest wind potential.

Activity:

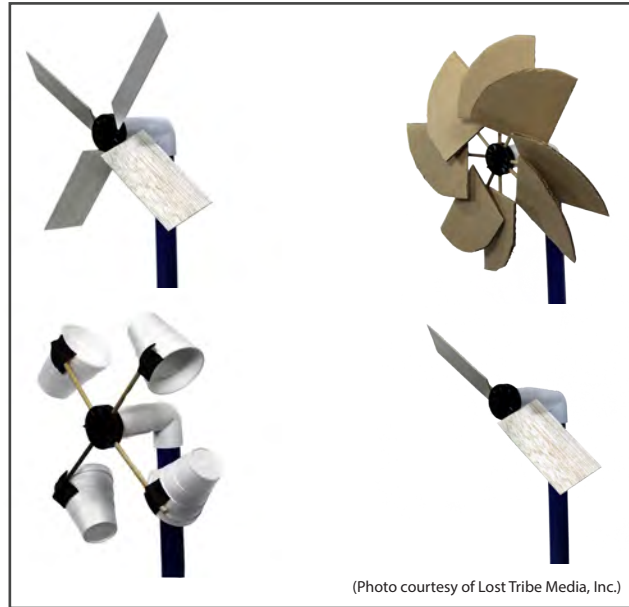
1. Using the **Background** information as needed, discuss with the group how wind turbines create electricity and how there are various styles of turbine blade, each with their own unique qualities.
2. Divide the students into three teams and provide each with their own wind turbine kit and a multimeter.
3. Have each team assemble their wind turbine using the instructions provided in the **Reference Materials** section.
4. Provide each team with a selection of coroplast strips, balsa wood strips, Styrofoam cups, cardboard and any other materials you have available for the creation of the turbine blades.



WARNING: Do not use any sharp or metal materials for turbine blade creation.

5. Ask the students to design their own turbine blades by cutting, gluing and taping as desired.

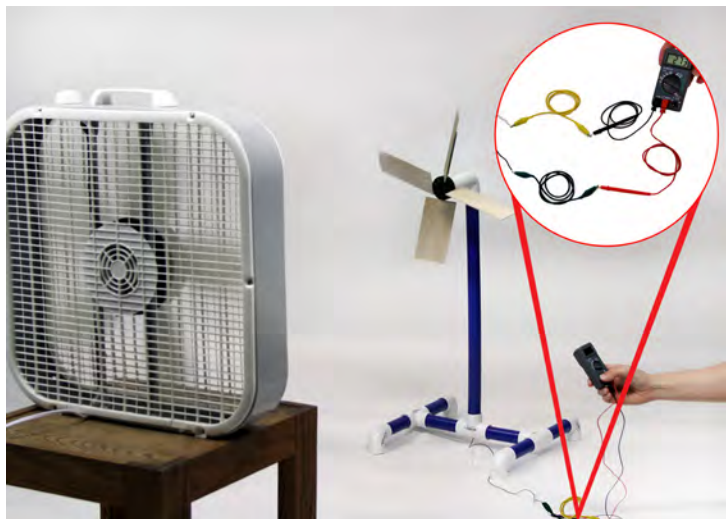
It may be necessary to help younger students get started on this point. You can use the templates provided in the [Reference Materials](#) section or Image 3 below for ideas on blade creation.



Img. 3 Sample Blade Designs

Caution: Blades with a diameter larger than that of the fan will not function.

6. As each team finishes a blade design, have them test its ability to harness the wind's energy by connecting the multimeter to the turbine and blowing on the blades using the fan. See the Multimeter Guide in the [Reference Materials](#) section for information on how to use it correctly.



7. **Have the students record the voltage produced by the turbine as well as a sketch of the blade design on the Wind Turbine Power worksheet.**
8. **Encourage the students to modify or redesign their blades as needed in order to increase the power output.**
9. **After each team has had sufficient time to adjust their blades, compare the results and declare one team the winner!**

Discussion Points:

1. **Why did some designs work better than others?**

It is commonly assumed by students that bigger is always better which is not always the case. Bigger blades may capture more of the airflow but they also require more force in order to move. Smaller, lighter blades may be less effective but also barely need a light breeze in order to start rotating.

2. **What converted the wind into electricity?**

The turbine in our design was a simple electric motor. If electricity was applied to the leads, the motor would have turned the blades. Motors are able to work in more than one way however. By turning the shaft, as we did using the blades, it generated electricity. In real world designs though, the generator is specifically designed for converting mechanical energy into electricity.

3. **What else could have been done to generate more electricity?**

In commercial designs, the turbine blades are connected to a gearbox. This gearbox allows the pitch of the blade to change, just like an airplane propeller, in order to improve its performance. Additional things such as twisting the blade or shaping it more like an aircraft wing would have also yielded improved performance.

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Structure and properties of matter
- Interactions of energy and matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology



Reference Materials

Glossary

Convection:

The circulation or movement of a liquid or gas, caused by the transfer of heat

Density:

The compactness of the molecules within a body of matter; a body that is more dense has more tightly packed molecules

Pressure:

The application of a force against an object

Wind:

The name given to the movement of an air mass

Voltage:

The force produced by an electrical energy, expressed in volts

Wind Turbine:

A device designed to capture the kinetic energy of wind and convert it into electrical or mechanical energy

Fig. 1 Hero's Organ

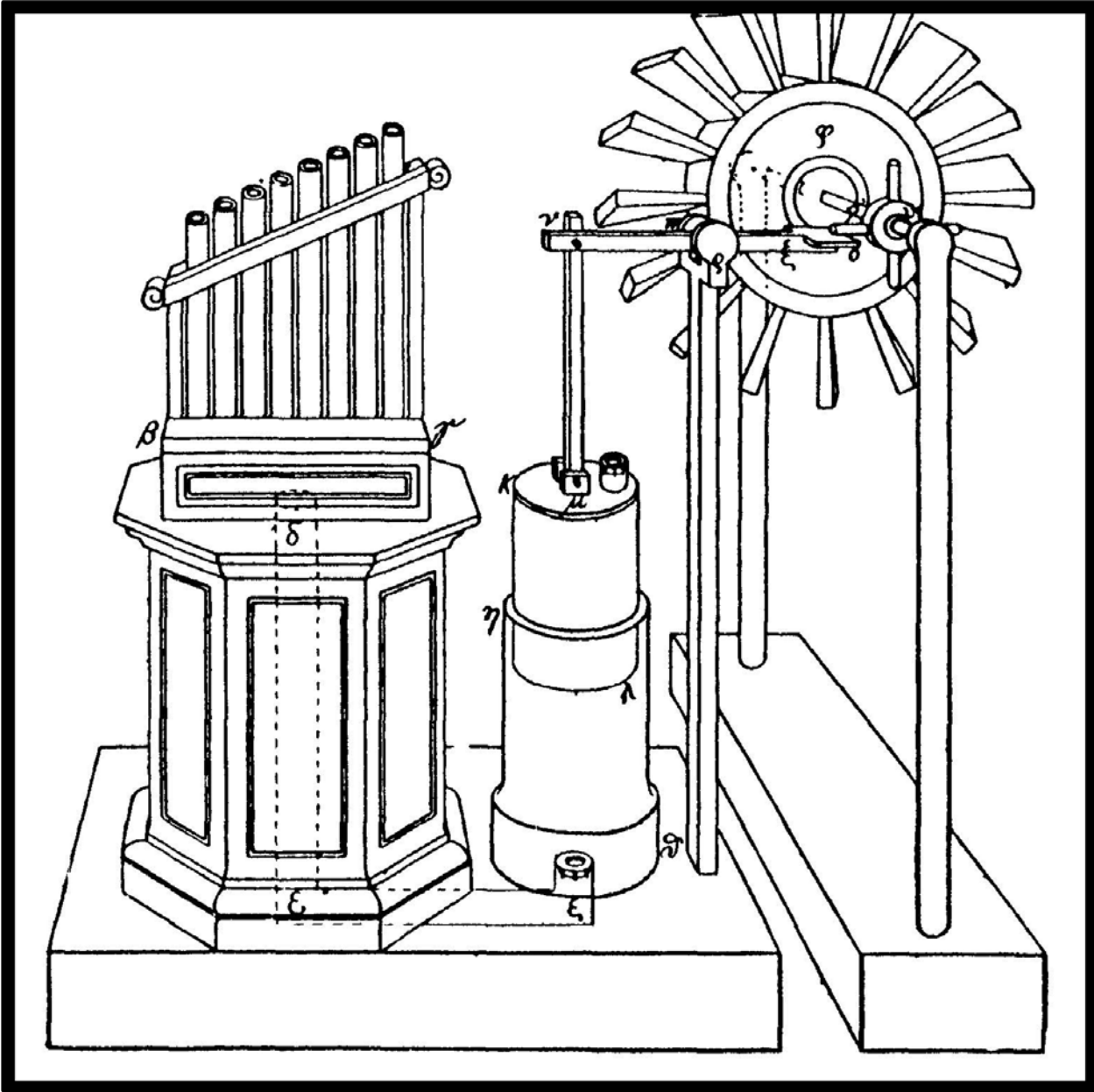


Fig. 2 Wind Power Technology Timeline

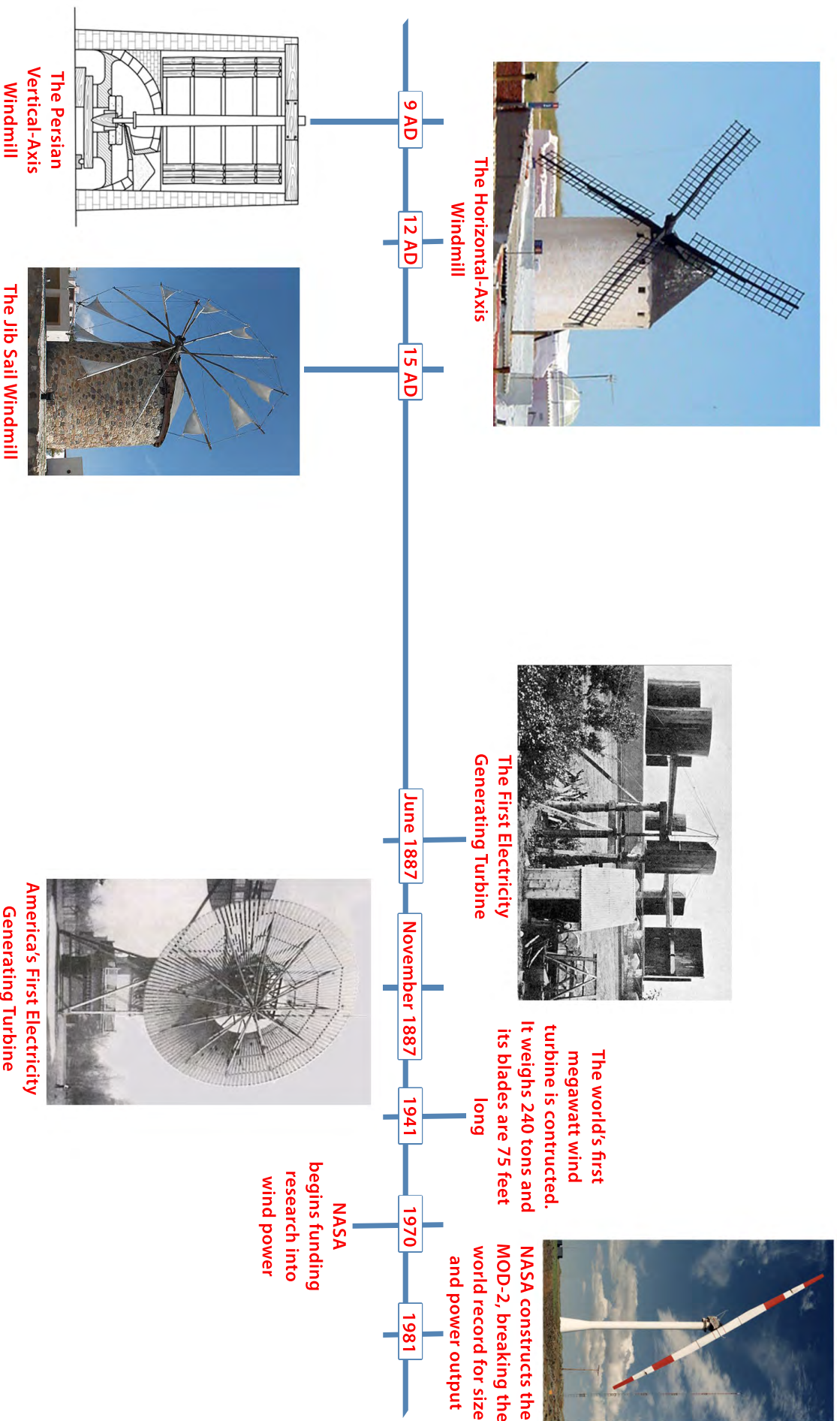


Fig. 3

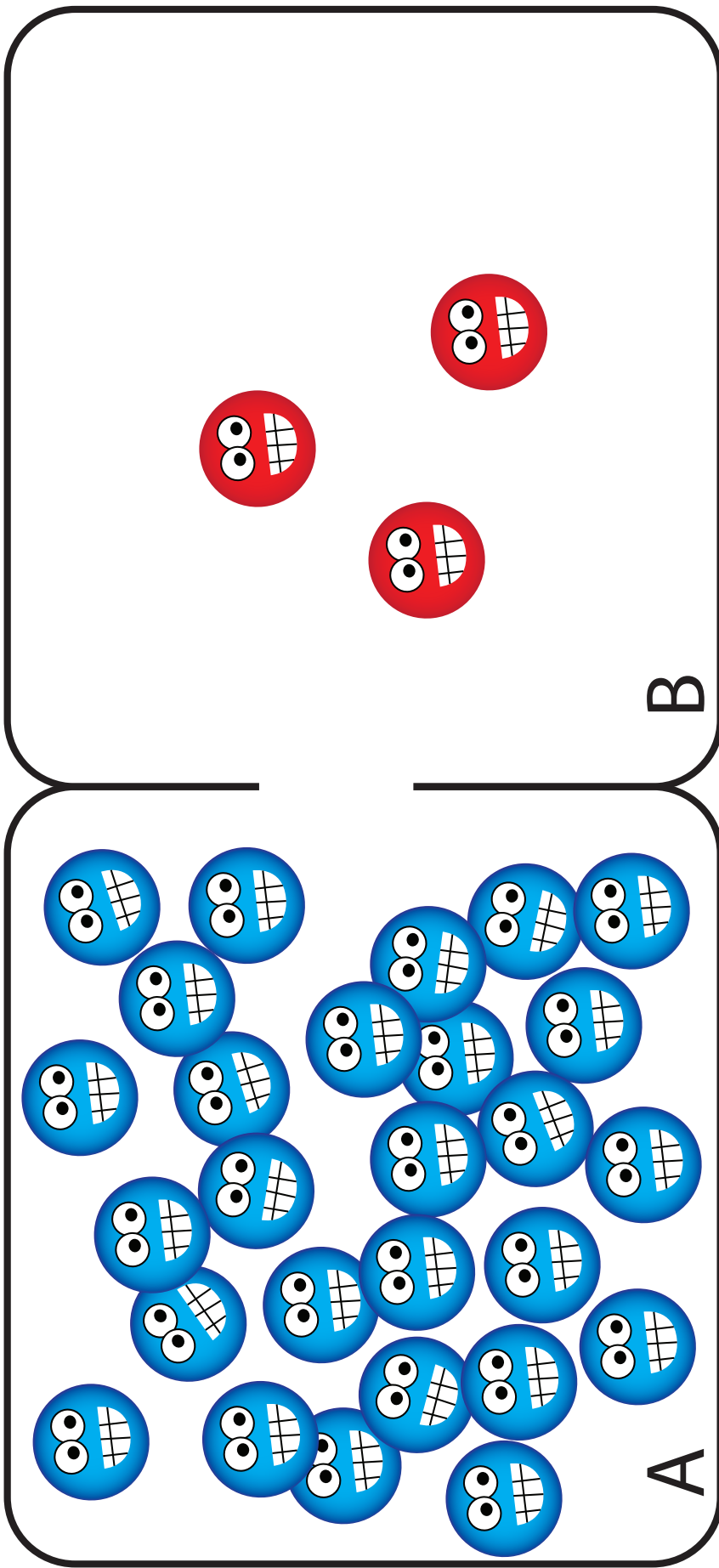


Fig. 4

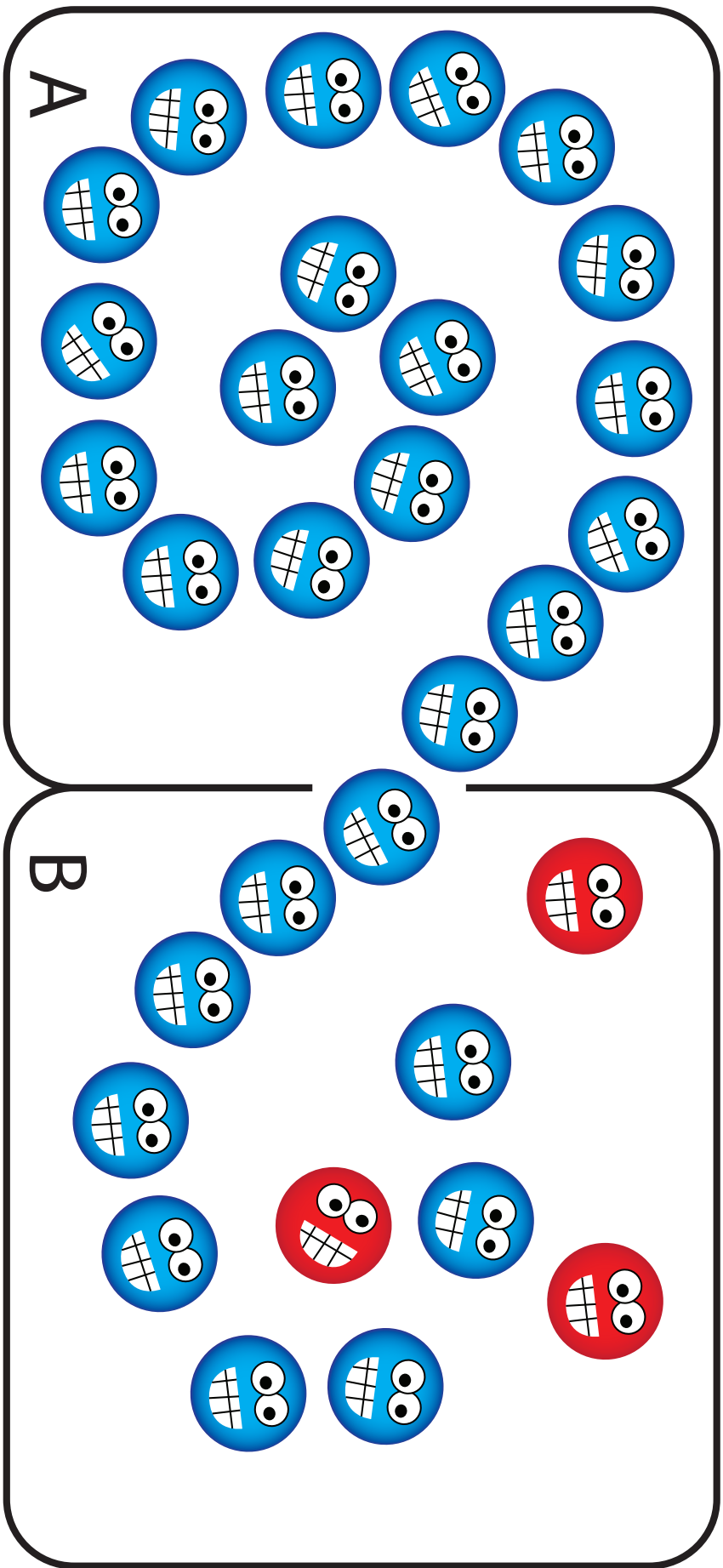


Fig. 5 The Beaufort scale

Beaufort number	Description	Wind speed	Wave height	Sea conditions	Land conditions
0	Calm	< 1 km/h (< 0.3 m/s)	0 m	Flat.	Calm. Smoke rises vertically.
		< 1 mph			
		< 1 kn	0 ft		
		< 0.3 m/s			
1	Light air	1.1–5.5 km/h (0.3-2 m/s)	0–0.2 m	Ripples without crests.	Smoke drift indicates wind direction and wind vanes cease moving.
		1–3 mph	0–1 ft		
		1–2 kn			
		0.3–1.5 m/s			
2	Light breeze	5.6–11 km/h (2-3 m/s)	0.2–0.5 m	Small wavelets. Crests of glassy appearance, not breaking.	Wind felt on exposed skin. Leaves rustle and wind vanes begin to move.
		4–7 mph	1–2 ft		
		3–6 kn			
		1.6–3.4 m/s			
3	Gentle breeze	12–19 km/h (3-5 m/s)	0.5–1 m	Large wavelets. Crests begin to break; scattered whitecaps.	Leaves and small twigs constantly moving, light flags extended.
		8–12 mph	2–3.5 ft		
		7–10 kn			
		3.4–5.4 m/s			
4	Moderate breeze	20–28 km/h (6-8 m/s)	1–2 m	Small waves with breaking crests. Fairly frequent whitecaps.	Dust and loose paper raised. Small branches begin to move.
		13–17 mph	3.5–6 ft		
		11–15 kn			
		5.5–7.9 m/s			
5	Fresh breeze	29–38 km/h (8.1-10.6 m/s)	2–3 m	Moderate waves of some length. Many whitecaps. Small amounts of spray.	Branches of a moderate size move. Small trees in leaf begin to sway.
		18–24 mph	6–9 ft		
		16–20 kn			
		8.0–10.7 m/s			
6	Strong breeze	39–49 km/h (10.8-13.6 m/s)	3–4 m	Long waves begin to form. White foam crests are very frequent. Some airborne spray is present.	Large branches in motion. Whistling heard in overhead wires. Umbrella use becomes difficult. Empty plastic garbage cans tip over.
		25–30 mph	9–13 ft		
		21–26 kn			
		10.8–13.8 m/s			

Beaufort number	Description	Wind speed	Wave height	Sea conditions	Land conditions
7	High wind, Moderate gale, Near gale	50–61 km/h (13.9-16.9 m/s)	4–5.5 m	Sea heaps up. Some foam from breaking waves is blown into streaks along wind direction. Moderate amounts of airborne spray.	Whole trees in motion. Effort needed to walk against the wind.
		31–38 mph			
		27–33 kn	13–19 ft		
		13.9–17.1 m/s			
8	Gale, Fresh gale	62–74 km/h (17.2-20.6 m/s)	5.5–7.5 m	Moderately high waves with breaking crests forming spindrift. Well-marked streaks of foam are blown along wind direction. Considerable airborne spray.	Some twigs broken from trees. Cars veer on road. Progress on foot is seriously impeded.
		39–46 mph			
		34–40 kn	18–25 ft		
		17.2–20.7 m/s			
9	Strong gale	75–88 km/h (20.8-24.4 m/s)	7–10 m	High waves whose crests sometimes roll over. Dense foam is blown along wind direction. Large amounts of airborne spray may begin to reduce visibility.	Some branches break off trees, and some small trees blow over. Construction/temporary signs and barricades blow over.
		47–54 mph			
		41–47 kn	23–32 ft		
		20.8–24.4 m/s			
10	Storm Whole gale	89–102 km/h (24.7-28.3 m/s)	9–12.5 m	Very high waves with overhanging crests. Large patches of foam from wave crests give the sea a white appearance. Considerable tumbling of waves with heavy impact. Large amounts of airborne spray reduce visibility.	Trees are broken off or uprooted, saplings bent and deformed. Poorly attached asphalt shingles and shingles in poor condition peel off roofs.
		55–63 mph			
		48–55 kn	29–41 ft		
		24.5–28.4 m/s			
11	Violent storm	103–117 km/h (28.6-32.5 m/s)	11.5–16 m	Exceptionally high waves. Very large patches of foam, driven before the wind, cover much of the sea surface. Very large amounts of airborne spray severely reduce visibility.	Widespread damage to vegetation. Many roofing surfaces are damaged; asphalt tiles that have curled up and/or fractured due to age may break away completely.
		64–72 mph			
		56–63 kn	37–52 ft		
		28.5–32.6 m/s			
12	Hurricane force	≥ 118 km/h (≥ 32.8 m/s)	≥ 14 m	Huge waves. Sea is completely white with foam and spray. Air is filled with driving spray, greatly reducing visibility.	Very widespread damage to vegetation. Some windows may break; mobile homes and poorly constructed sheds and barns are damaged. Debris may be hurled about.
		≥ 73 mph			
		≥ 64 kn	≥ 46 ft		
		≥ 32.7 m/s			

Fig. 6 Wind Turbine Diagram

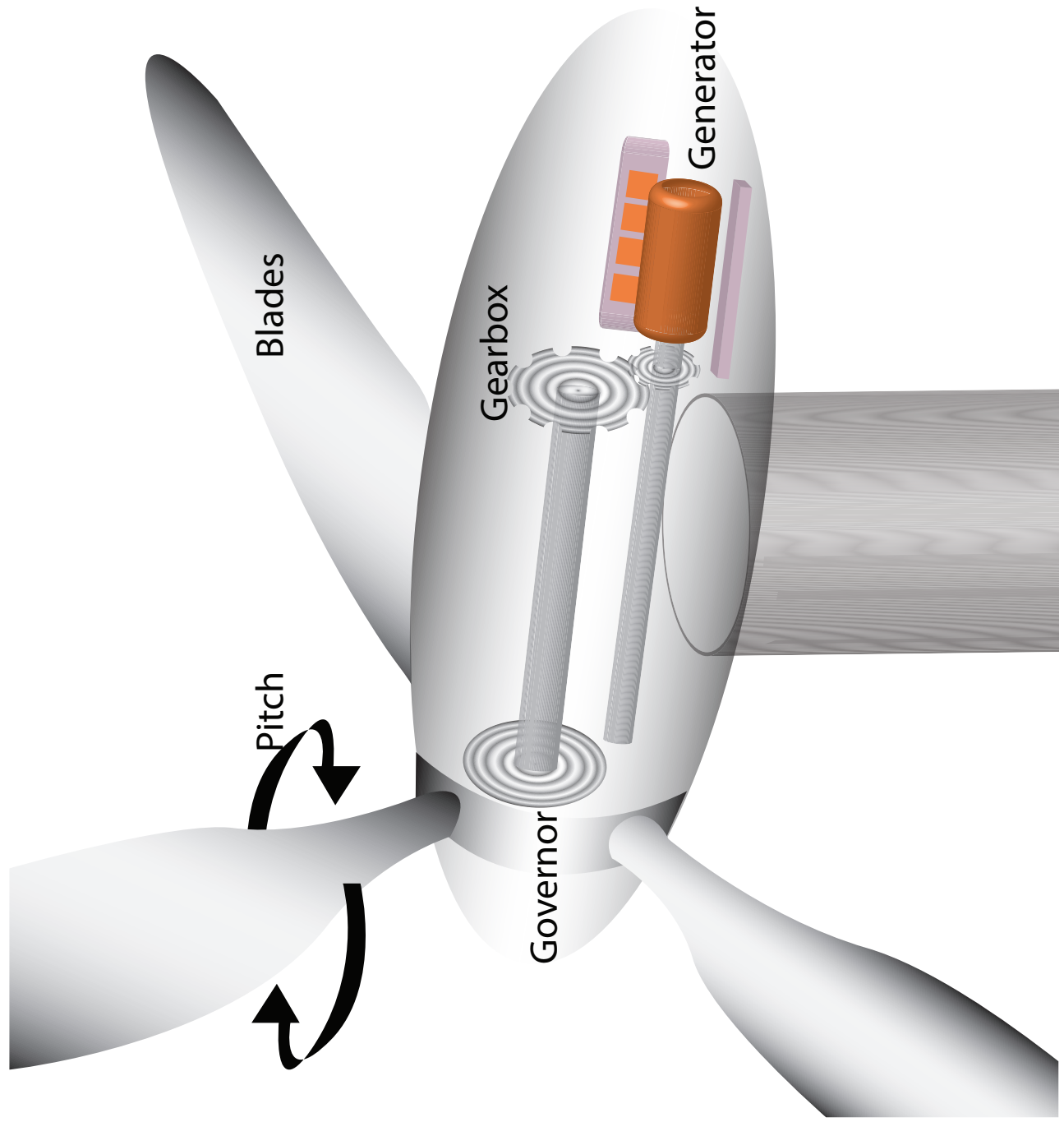


Fig. 7 Technology Generator diagram

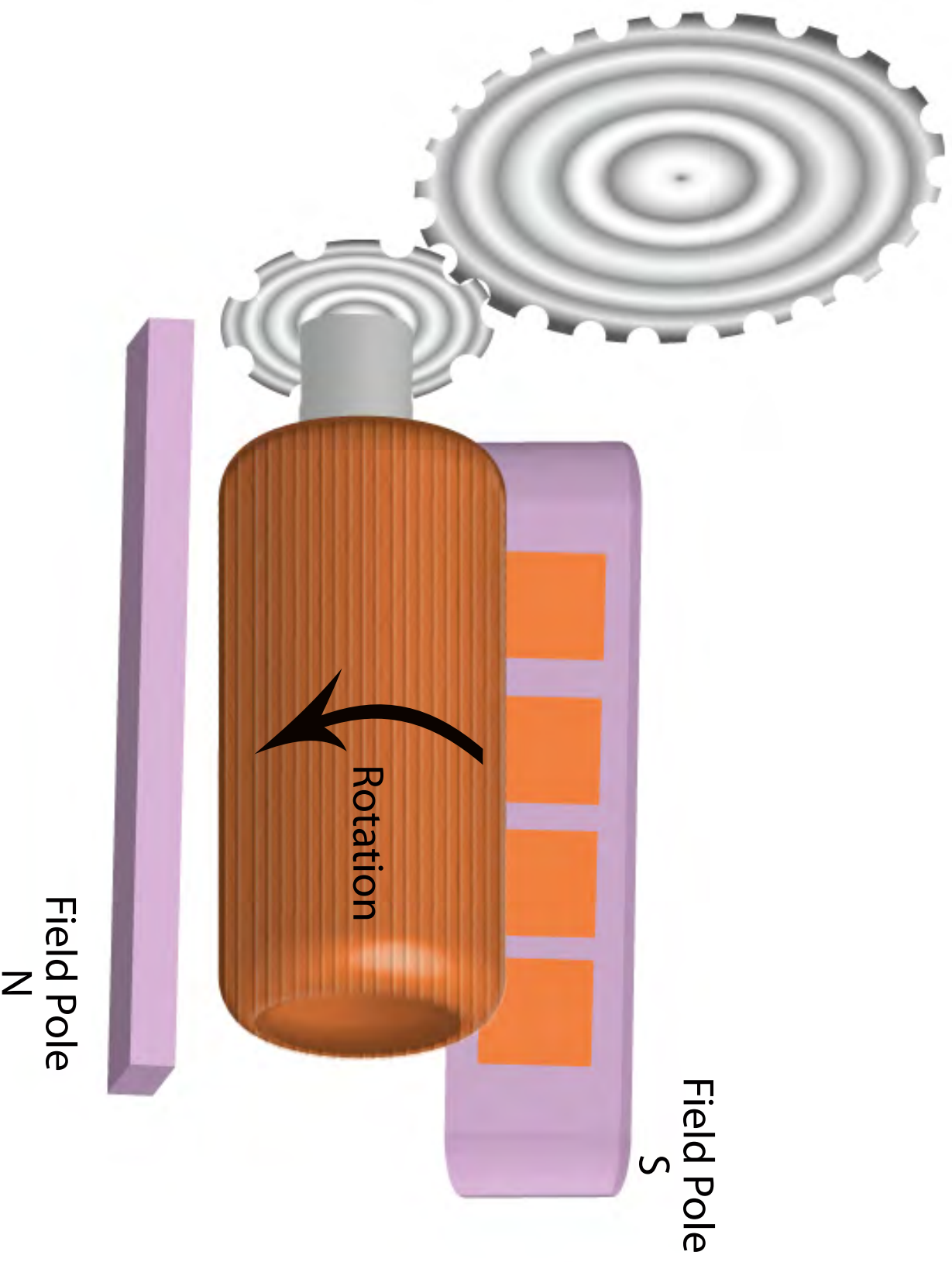
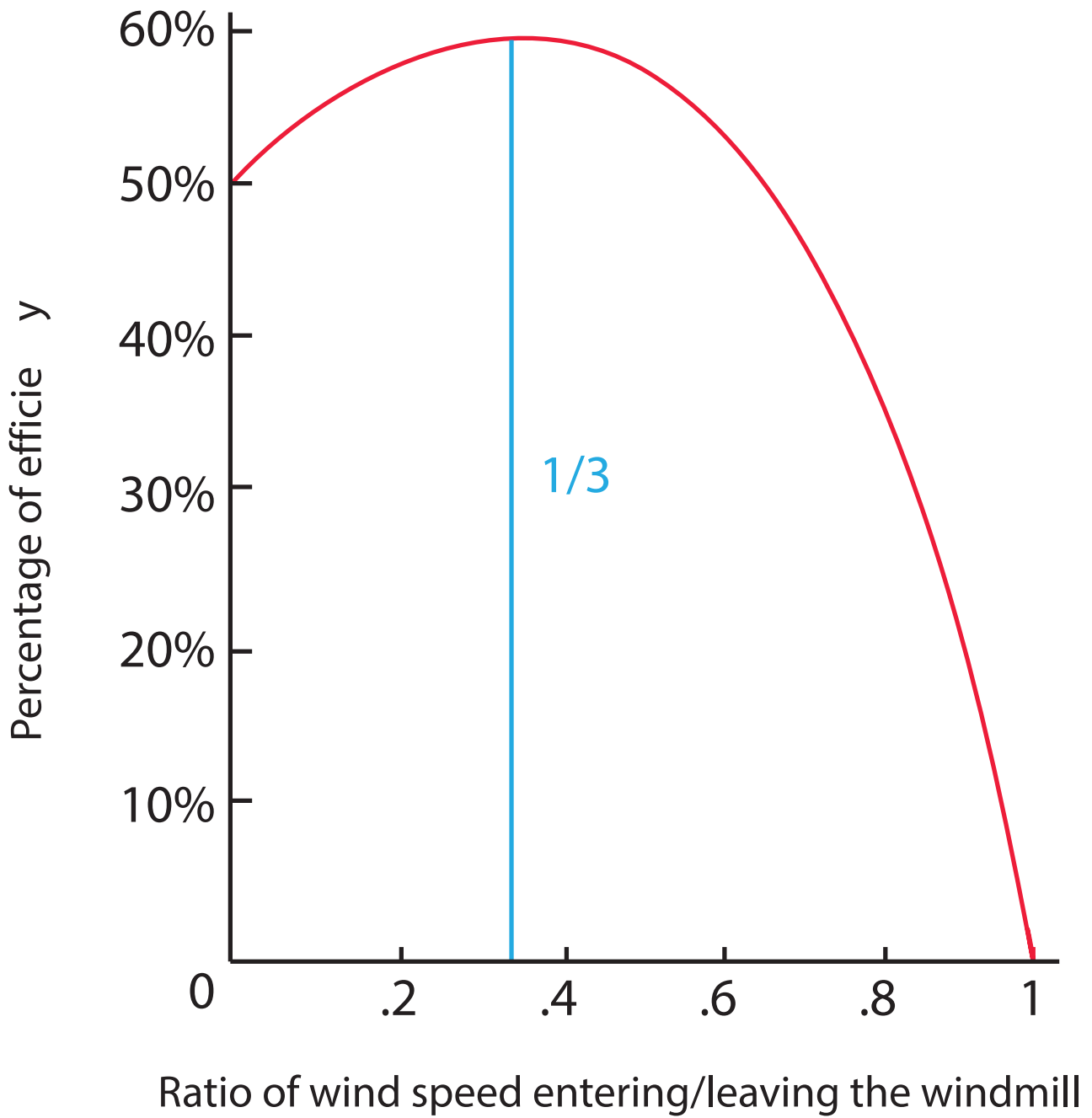


Fig. 8 Betz's Law



Wind Turbine Assembly Instructions

Assembling The Base:

1. Assemble the PVC pieces according to the diagram on the right.
2. Use the T-pieces without holes to join the sides of the base to the center. In the very center of the base, use the T-piece with the hole drilled in it. This hole will allow the wires from the motor to pass through.



Assembling The Hub:

1. Wrap a 1/2 inch by 18 inch piece of tape around the motor to ensure a snug fit.
2. Push the three pieces of PVC pipe together to form one solid piece.
3. Run the wires of the motor through the pipe as shown.
4. Secure the motor in the coupler, it should fit very snugly; you may add or remove tape to attain the best fit.
5. Press the crimping hub onto the drive shaft, this should also fit snugly.

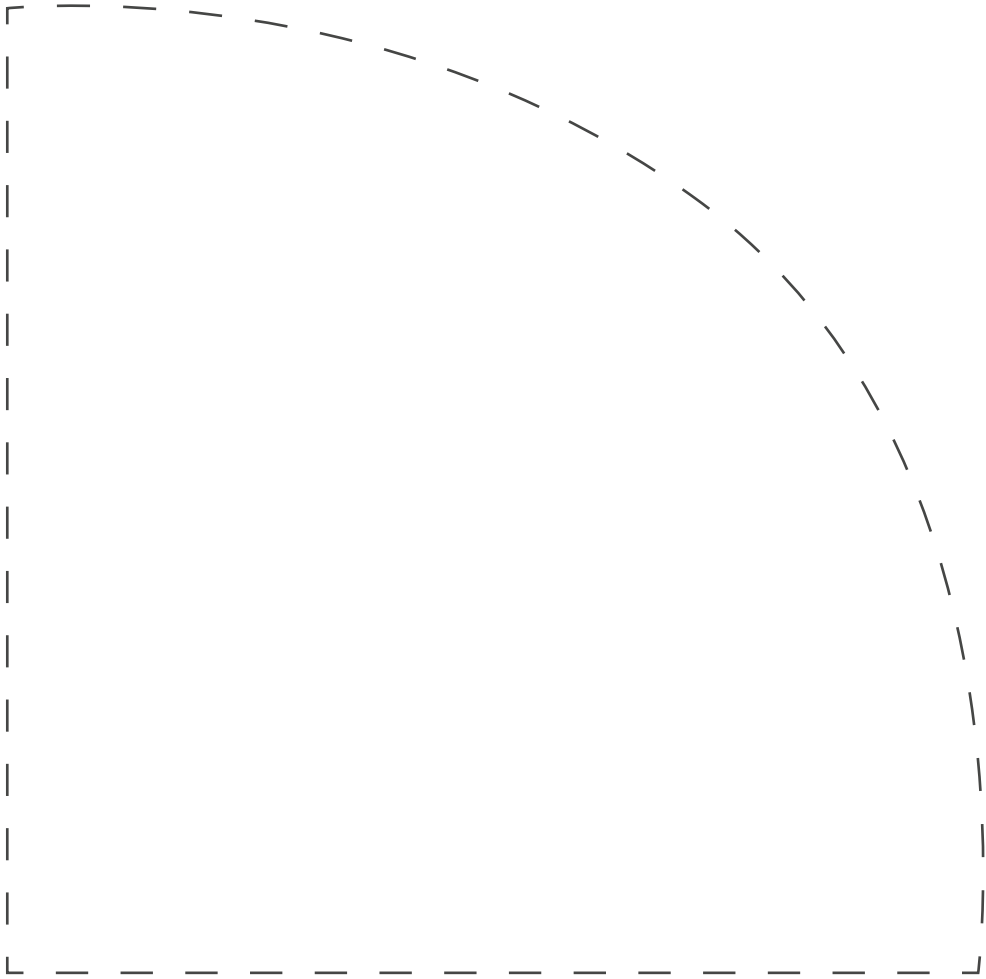


Using The Multimeter

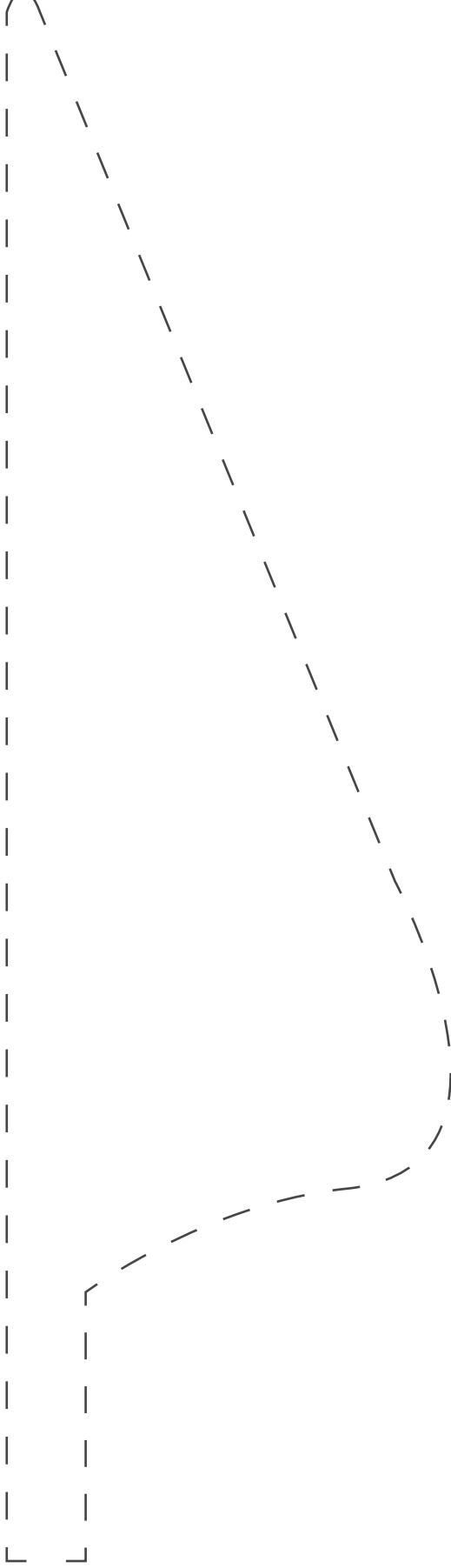
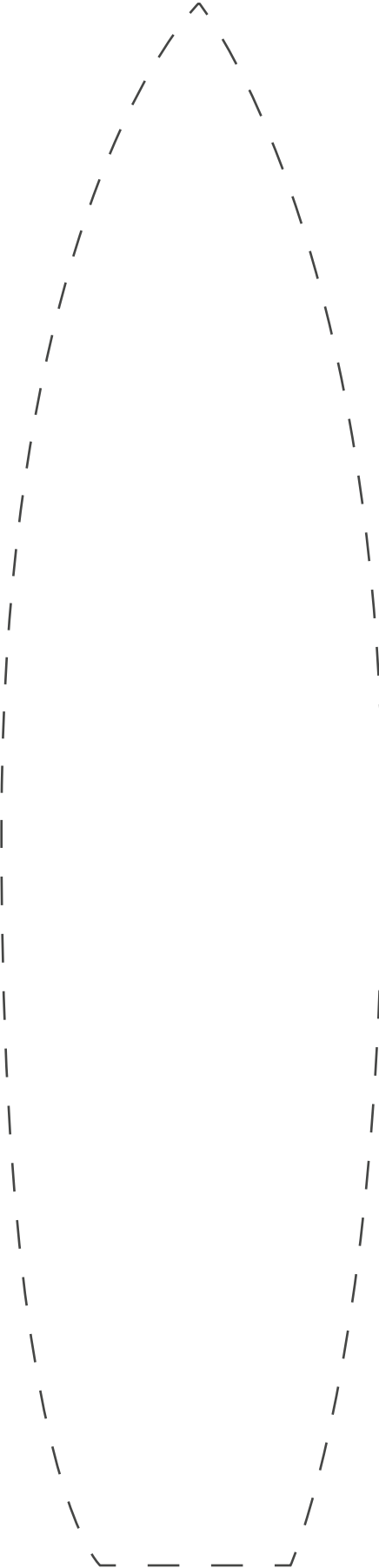
1. Attach the leads to the multimeter. To measure voltage, attach the black lead to the COM port and the red lead to the V Ω MA port.
2. Using alligator clips, attach the multimeter leads to the wind turbine's motor wires (the wires emerging from the base of the structure). Attach the black lead to the red wire and red lead to the white wire.
3. Turn the multimeter dial counterclockwise to the 2000 m position. This will display measurements in thousandths of a volt.
4. If the multimeter does not display any numbers (including 0), when the dial is moved out of the OFF position, you may need to replace the 9V battery.



Sample Turbine Blade Designs 1



Sample Turbine Blade Designs 2 and 3





Student Worksheets

Worksheet 1

Wind Turbine Power

Sketch a picture of your blade design and record the voltage generated in the table below.

Blade Design 1	Volts: <input type="text"/>
Blade Design 2	Volts: <input type="text"/>
Blade Design 3	Volts: <input type="text"/>

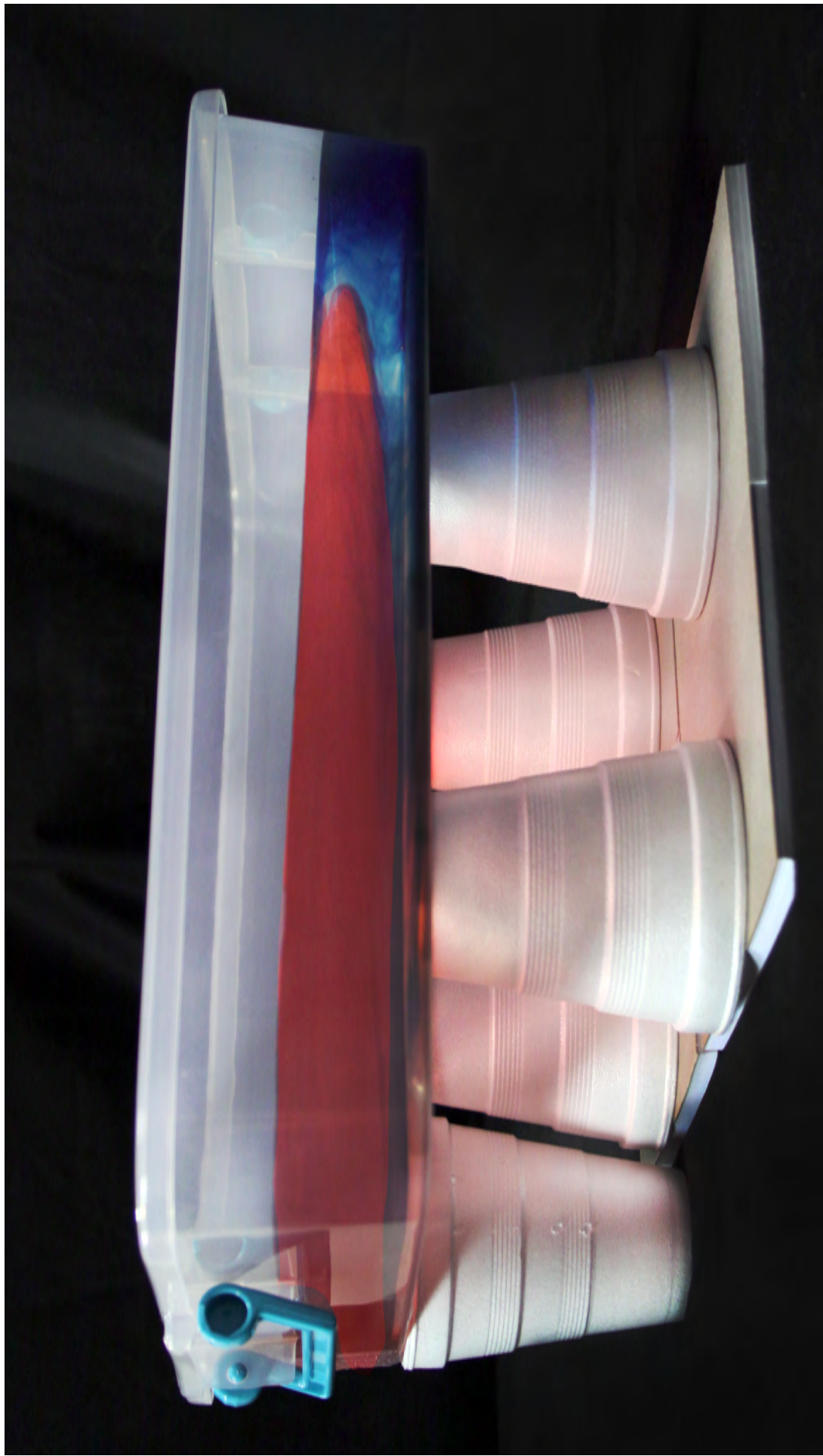


Images

Img. 1 The Robinson Anemometer

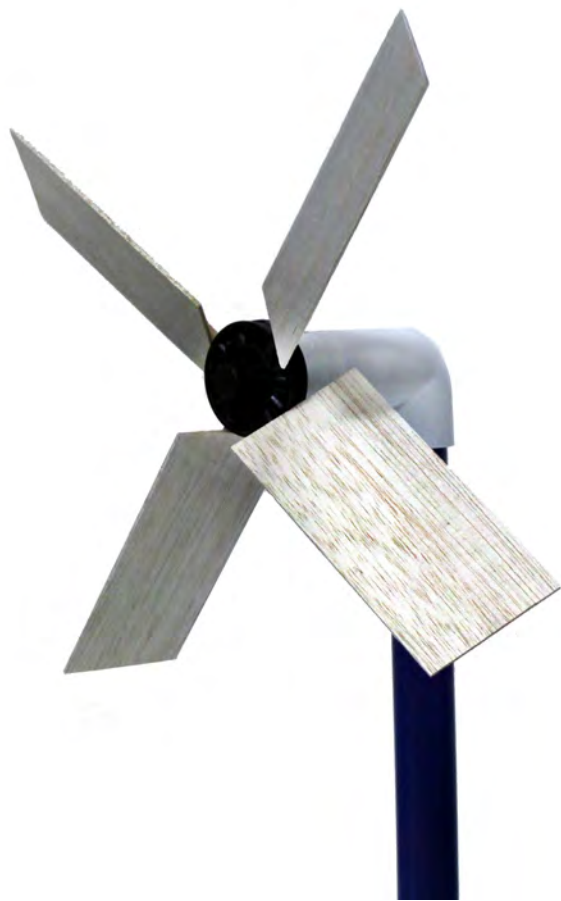


Img. 2 The Convection Phenomenon



(Photo courtesy of Lost Tribe Media Inc.)

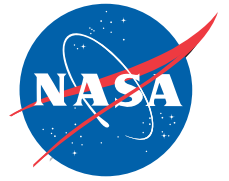
Img. 3 Sample Blade Designs



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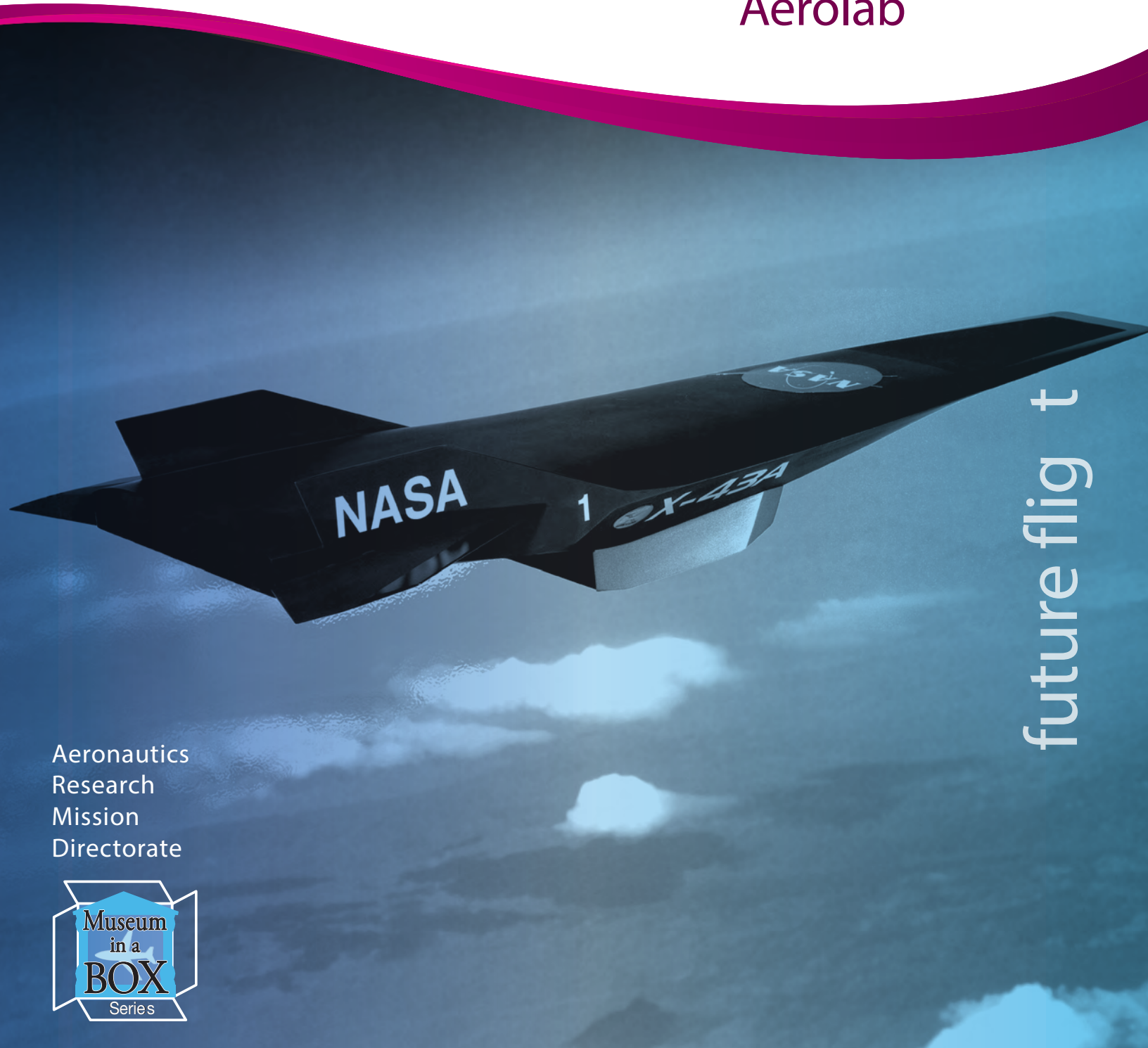
propulsion



GRADES

5-12

Aerolab



future flight

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(Photo courtesy of NASA - www.nasaimages.org)

Aerolab

Lesson Overview

Aerolab is a hands-on activity designed to introduce students to the concepts behind flight. Through experimentation, students will discover the effects of weight and drag on an aircraft, as well as explore how changes in thrust make a big difference in aircraft performance.

Objectives

Students will:

1. Learn how forces such as lift, weight, thrust and drag can affect an aircraft in flight.

Materials:

In the Box

2 Jetstream Model Airplanes
 Pylon Kit
 5:1 Winder
 Sil-Slick Rubber Lube
 Pipette
 Safety glasses (2 pairs)
 Stop watch
 Tape measure

Provided by User

Yarn (25" – 50")
 Tape
 2 1-cent coins
 Trash can / bucket / cardboard box

GRADES

5-12

Time Requirements: 3 hours

Background

Prior to beginning this activity, it is highly advisable to watch the Aerolab DVD included in the Museum in a Box. It explains in detail the set-up and operation of the Jetstream model airplane, highlights the activity below, as well as provides videos for the students, giving them a better understanding of the concepts presented.

The Forces of Flight

Every vehicle, whether an airplane, helicopter or rocket, is affected by four opposing forces: Thrust, Lift, Drag and Weight (Fig. 1). It is the job of aircraft designers to harness these forces and use them in the most advantageous way possible.

A force can be thought of as a push or pull in a specific direction. It is a vector quantity, which means a force has both a magnitude (amount) and a direction.

The information in this section refers specifically to fixed-wing aircraft such as gliders and airplanes. While helicopters use the same basic principles, the physics are somewhat different.

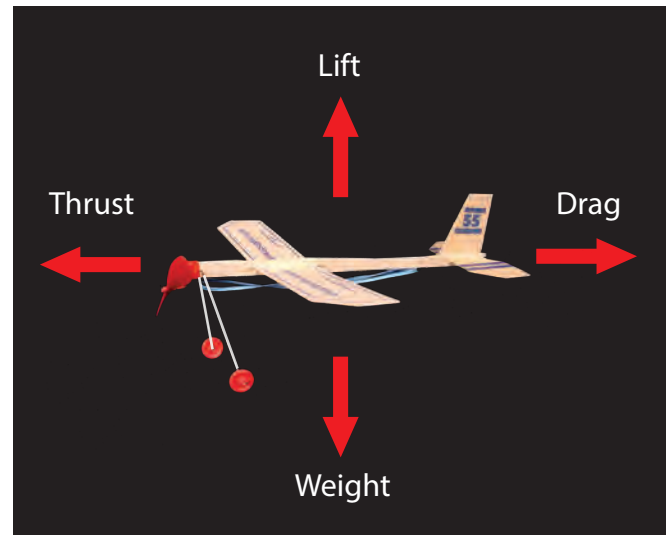


Fig. 1 Four forces of flight

Thrust

Thrust is produced by an aircraft's propulsion system or engine. The direction of the thrust dictates the direction in which the aircraft will move. For example, the engines on an airliner point backward, which means that generally speaking, the airplane's thrust vector will always point forwards. (Reverse thrust simply uses metal components known as clamshells to reverse the thrust vector.) The magnitude of the thrust depends on many factors such as the number and type of engine, the environment, and the throttle or thrust setting.

It is important to note that the job of the engine is just to propel the aircraft, not to lift it. The wings perform the task of lifting, not the engines.

Lift

Lift is generated by the motion of air passing over the aircraft's wings. Its direction is always perpendicular to the flight direction and its magnitude depends on several factors including the shape, size and velocity of the aircraft. Unlike thrust, lift is divided into two components, horizontal and vertical. In straight and level (cruise) flight (Fig. 2), 100% of the lift vector is vertical, or straight upwards, while in turning flight, some of the lift is directed horizontally, which helps the aircraft turn (Fig. 3). In addition, some lift, around 10% of the total in a typical airliner, is generated by the fuselage due to its aerodynamic shape.

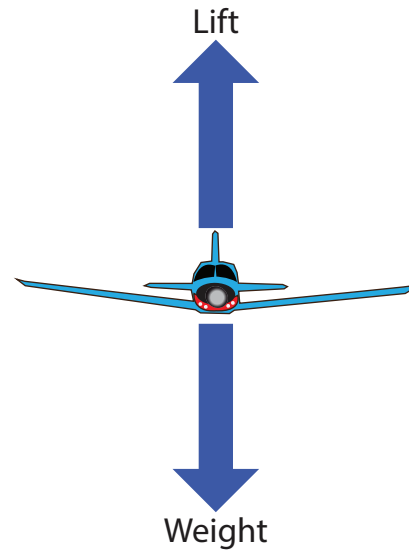


Fig. 2 Forces of straight and level flight

Drag

Drag is simply resistance of the aircraft against the air. There are three types of drag which affect aircraft:

Parasitic Drag: The resistance to movement created just by trying to pass an object through the air. It can be thought of as the same feeling a runner might experience when running into a strong wind. Just the act of physically pushing through the air creates resistance which must be overcome to move forwards.

Interference Drag: The drag caused by two different airflows meeting. This is commonly seen where the wing is attached to the fuselage of an aircraft.

Form Drag: The drag caused by the design of an aircraft. While the body of an aircraft may be extremely smooth and aerodynamic, the many radio antennas attached to it are not. These antennas create drag in a similar way to sticking a hand out of a car window. The car is aerodynamic, but the hand is not.

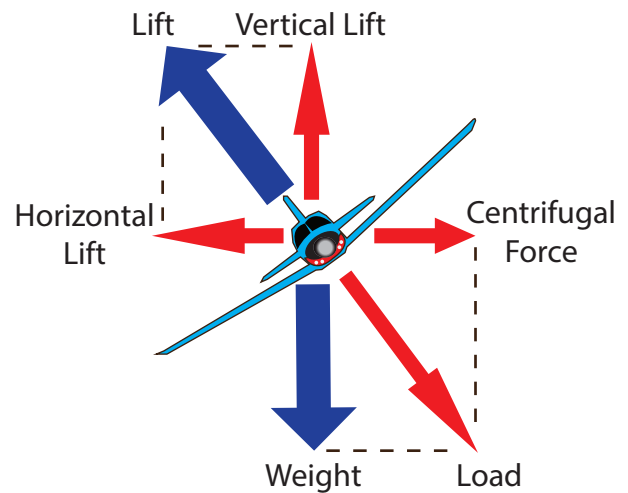


Fig. 3 Forces of turning flight

Weight

Weight is a force that is always directed toward the center of the earth due to gravity. The magnitude of the weight is the sum of all the airplane parts, plus the fuel, people and cargo. While the weight is distributed throughout the entire airplane, its effect is on a single point called the center of gravity. When an aircraft is loaded, it is vital that its center of gravity remain within certain limits. An aircraft that is too nose- or tail-heavy will either not fly, or be so difficult to control that it becomes too dangerous to try.

The Forces In Flight

While each of the forces is independent of the other, in flight they work opposite each other. For example, the primary role of thrust is to overcome drag, while the primary role of lift is to overcome weight. In actuality however, it is much more complicated. When the aircraft is in cruise flight, not climbing, descending, or changing speed, the forces are equal. This means that the total thrust equals the total drag, while the total lift equals the total weight. In a climb however, lift must be greater than weight, just as thrust must be greater than drag when accelerating.

For more detailed information on the forces of flight, please reference the Museum in a Box lesson "Four Forces".

Activity 1

The AeroLab Model Airplane

GRADES**5-12****Time Requirement:** 3 hours**Materials:**In the Box

2 Jetstream Model
Airplanes
Pylon Kit
5:1 Winder
Sil-Slick Rubber Lube
Pipette
2 Safety glasses
Stop watch
Tape measure

Provided by User

Yarn (12" – 24")
Tape
2 1-cent coins
Trash can / bucket /
cardboard box

Worksheets

AeroLab Flight Data
(Worksheet 1)

Reference Materials

Jetstream Assembly
Instructions

Key Terms:

Leading Edge
Trailing Edge

Objective:

Students will learn how forces such as drag, weight and thrust can affect an aircraft in flight.

Activity Overview:

In this lesson, students will learn how external forces can affect an aircraft in flight by comparing the data from an unmodified Jetstream model airplane with one that has been altered by the students. These modifications will vary depending on the items at hand and the time available, but will include adding extra weight or increasing thrust.

Activity:

Before beginning this activity, assemble one of the Jetstream planes using the assembly instructions provided in the [Reference Materials](#) section. This will provide students with a visual example prior to building their own. For groups larger than 4 students, it may be beneficial to build both airplanes ahead of time. This way one plane can be modified by the first group of students while another group experiments with the other.

For best results, this activity requires a large, open area, preferably with a non-carpeted floor, such as a gymnasium or cafeteria.



Img. 1 X-31 Enhanced Fighter Maneuverability Demonstrator aircraft
(Photo courtesy of NASA - www.nasaimages.org)

WARNING: This activity uses a rubber band wound to a high tension. It is recommended that the students involved with the winding process wear the safety glasses included with the kit.

1. Using the **Background** information provided, explain the four forces of flight and how each force affects an airplane's ability to fly. Also, discuss the difference between kinetic energy and potential energy. If you would like to cover these topics in greater detail, consider completing the Museum in a Box lesson "Four Forces".
2. Next, divide the class into groups of 4 students and assign the following roles to the members of each group:

Winder: This person will be responsible for winding the rubber band precisely 1,000 times, unless otherwise specified by the activity.

Timer: This person will be responsible for recording the flight time, which is the moment the airplane leaves the floor surface until the wheels first touch down again.

Launcher: This person will be responsible for physically launching the Jetstream.

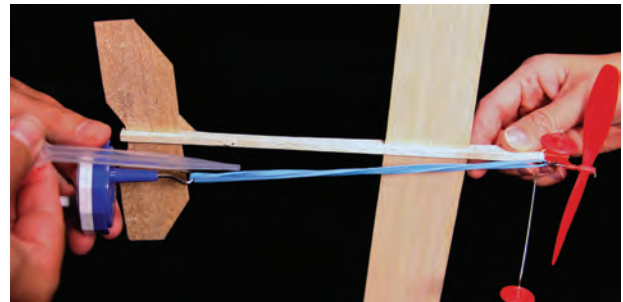
Marker: This person will record the points of takeoff and touchdown, as well as counting the complete laps made by the airplane. Marking the points of take-off and touchdown with tape will assist in visually determining partial laps.

It is recommended that the students trade roles for each subsequent launch of the airplane.

3. If not completed beforehand, have the students assemble the Jetstream model airplane and pylon using the assembly instructions provided in the **Reference Materials** section.
4. Explain to the students how to correctly launch the airplane, demonstrating if desired.

- a. Place a few drops of rubber lube onto the rubber band and wind it 1,000 times (200 turns of the winder) using the 5:1 winding tool. The lube prevents the rubber from becoming sticky due to the heat generated during the winding process.

The gearing inside the winding tool makes 5 complete turns of the rubber band for each rotation of the handle. This means that the students only have to turn the winder's handle 200 times to achieve the required 1,000 turns on the rubber band.



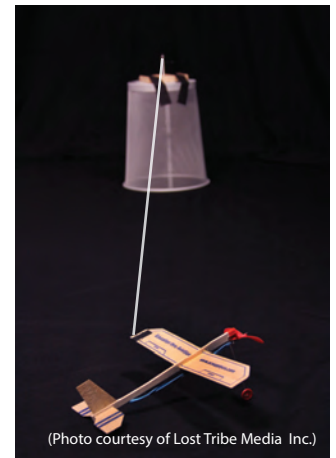
- b. While holding firmly onto the airplane, attach the paperclip from the pylon to the center of the left wing. Apply a small piece of tape if desired to hold it securely in place.



- c. Pull the string taught and point the nose of the airplane slightly away from the pylon. *It is a common mistake of students to have the airplane pointed inwards. This causes the airplane to fly towards the center, hitting the trash can and failing to launch.*

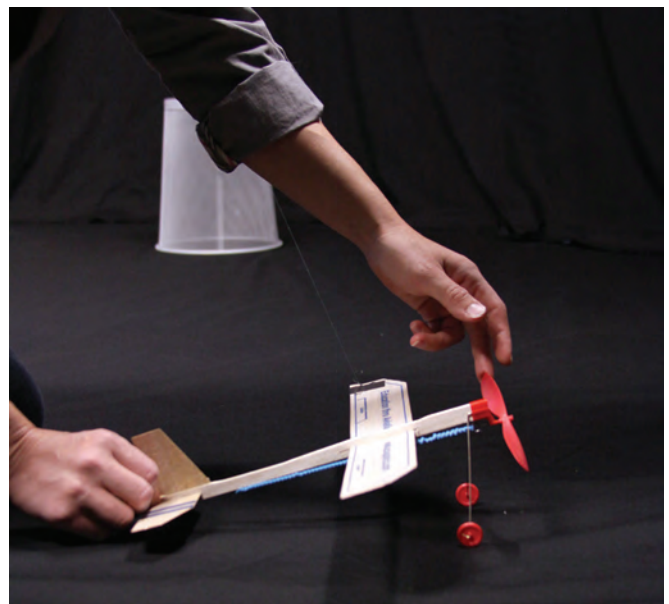


Img. 2 Correct launch position



Img. 3 Incorrect launch position

- d. Release the propeller first while still holding onto the tail. This allows the propeller to accelerate to the correct speed.
- e. Finally, let go of the tail of the airplane and watch it fly!



5. **Have the students perform three launches of an unmodified airplane.** Record the time the airplane remains in the air (Time Airborne) and the number of laps it makes in the “Unmodified Aircraft” table of the worksheet. For accuracy, it is important that the time be started only when the airplane becomes airborne and stopped when it first touches back down. Use pieces of tape to mark the points on the ground where the airplane takes off and lands. Be sure to only count the laps where the airplane is in the air (Fig. 4). The students should also record the takeoff distance in terms of laps.

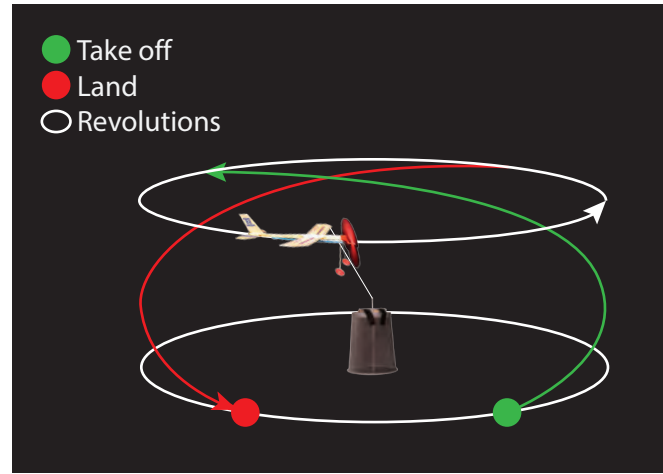
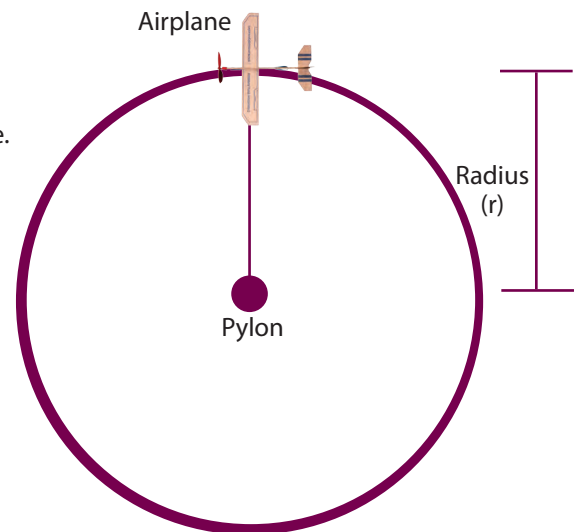


Fig. 4 Aircraft flight path

6. **Have the students complete their worksheets as follows.**

The calculations below are based upon our experiments. Your numbers will vary.

- a. Measure and record the radius of the flight path at the top of the worksheet. This is the distance from the end of the string attached to the pylon to the center of the airplane's fuselage.
- b. Calculate the distance the plane travels during one lap of the flight path. This is the circumference of the circle that the airplane makes when it flies. Record your results on the second line of the worksheet.



Distance traveled in one revolution = $2\pi r$, where (r) is the radius and $\pi = 3.14$. In our example the radius is 2 meters.

$$2 \times \pi \times \text{Radius} = \text{Circumference (in meters)}$$

$$2 \cdot \pi \cdot 2 \text{ meters} = 12.56\text{m}$$

Sample Data for Calculations

Launch Number	Takeoff Distance (in laps)	Takeoff Distance (in meters)	Time Airborne (in seconds)	Laps Flown
1	0.3	3.77 m	15 sec	6.1
2	0.4	5.02 m	13.5 sec	5.8
3	0.3	3.77 m	17.3 sec	6.5
Average	0.33	4.19 m	15.3 sec	6.1

- c. Calculate the takeoff distance in meters and record the results on your worksheet.
To find the takeoff distance, multiply the estimated number of laps the plane traveled before becoming airborne by the distance of one lap (the circle's circumference).

$$\text{Takeoff Distance (in laps)} \times \text{Circumference} = \text{Takeoff Distance (in meters)}$$

$$0.3 \cdot 12.56\text{m} = 3.77\text{m}$$

- d. Calculate the average takeoff distances, time airborne and number of laps for the three launches.
To find the average, add the values for each launch together, then divide by the number of launches (three). Do this for each measurement taken (Takeoff Distances, Time Airborne, Laps Flown).

$$\frac{\text{Sum of Takeoff Distance (in meters)}}{3} = \text{Average Takeoff Distance (in meters)}$$

$$\frac{(3.77 + 5.02 + 3.77)}{3} = 4.19\text{ m}$$

- e. Find the average distance the airplane flew during each trial.

$$\text{Average Number of Laps Flown} \times \text{Circumference} = \text{Average Distance Flown}$$

$$6.1 \cdot 12.56\text{m} = 76.62\text{m}$$

f. Calculate the airplane's average airspeed for all three trials.

$$\frac{\text{Average Distance Flown}}{\text{Average Time Airborne}} = \text{Average Airspeed}$$

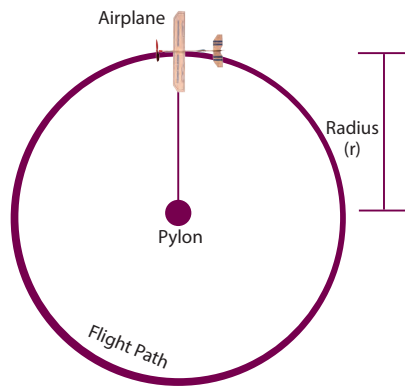
$$\frac{76.62\text{m}}{15.3\text{ sec}} = 5.01\text{ m/s}$$

Below is an example of a completed worksheet.

Worksheet 1 Example:

Radius of flight path (distance from pylon to fuselage center): 12.56m

Circumference (distance traveled in one lap) = $2\pi r$: 3.77m



$$\text{Number of Laps} \cdot \text{Circumference} = \text{Average Distance Traveled}$$

$$\frac{\text{Average Distance Flown}}{\text{Average Time Airborne}} = \text{Average Airspeed}$$

$$\pi = 3.14$$

Unmodified Aircraft

Launch Number	Takeoff Distance (in laps)	Takeoff Distance (in meters)	Time Airborne (in seconds)	Laps Flown
1	0.3	3.77 m	15 sec	6.1
2	0.4	5.02 m	13.5 sec	5.8
3	0.3	3.77 m	17.3 sec	6.5
Average	0.33	4.19 m	15.3 sec	6.1

Average distance flown: 76.62m

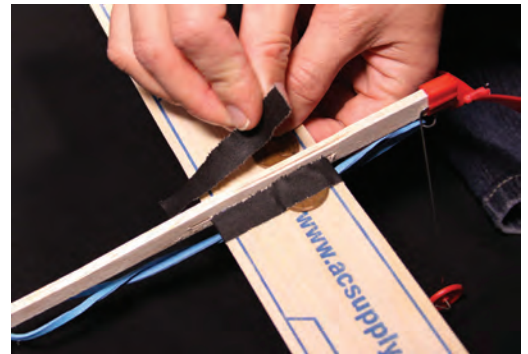
Average airspeed: 5.01m/s

7. **Repeat steps 5 & 6 multiple times, modifying the airplane as specified below.** For each modification perform three launches, recording the data onto the worksheet and completing the speed and distance calculations.

Modification 1 - Additional weight: Tape a 1-cent coin to the right wing by the fuselage.



Modification 2 - Additional weight: Tape a second 1-cent coin to the left wing by the fuselage.



Modification 3 - Additional drag: Tape short lengths of yarn to the wing tips. (Remove both pennies prior to launching the aircraft.)



Modification 4 - Reduced thrust: Launch an unmodified airplane using just 600 turns (120 turns of the winder).

Modification 5 - Additional thrust: Launch an unmodified airplane using 1,200 turns (240 turns of the winder).

Caution: Do not exceed 1,200 turns. The rubber band included in the kit will snap.

8. **If time permits, have students suggest other airplane configurations and repeat the experiment.** Such ideas might include taping small objects on top of the wings or fuselage, adding weight to the tail, etc.

Discussion Points:

1. Why did we perform each experiment three times?

One of the main problems with this kind of experiment is the uncontrollable variables that come into play. The time the plane is held before being released, the tension on the string, the friction of the floor surface, the delay between seeing the plane take off and pressing the button on the stopwatch and other factors all contribute to a less than perfectly accurate reading. By performing each experiment 3 times we average out this inaccuracy and arrive at a far more precise number than can be achieved with a single test alone.

2. What happened to the plane when weight was added to the wings?

It should have been discovered that the plane covered less distance when additional weight was added to the wings, although the speed of the aircraft was approximately the same. It should have also been noted that the plane traveled much further before becoming airborne.

3. What caused this loss of performance?

Newton’s second law of motion states that Force = Mass • Acceleration, or F=MA. In our experiments, this equates as follows:

Force: *Generated by the rubber band turning the propeller, which remains constant at 1,000 turns.*

Mass: *The total mass of the airplane plus any of the modifications.*

Acceleration: *An increase in speed over time. Acceleration is measured as change in velocity/time, in m/s², but for this experiment we are expressing it in terms of the distance required for the plane to achieve take-off speed.*

Since the force applied remained constant and the mass increased, the only variable that could compensate for the change was acceleration. This decreased due to the added weight and is why it took longer for the plane to become airborne. This also left less energy available for cruise flight, meaning that the total distance flown was significantly less.

FORCE = MASS • ACCELERATION (distance needed to accelerate to takeoff speed)

	Force (thrust generated by twisted rubber band)	Mass	Distance needed to accelerate to takeoff speed
Unmodified airplane	1,000 turns	13.3 grams	3.15 meters
1 Penny Airplane	1,000 turns	16.5 grams	6.3 meters
2 Pennies Airplane	1,000 turns	19.7 grams	9.5 meters

4. **What happened when yarn was added to the wings?**

Adding yarn to the rear, or trailing edge, of the wing caused additional drag. This meant that the plane had to work harder to move through the air, expending its energy sooner and therefore covering less distance. It should have been noted that the speed of the airplane was also approximately one-half meter per second slower.

5. **What effect did reducing the airplane's thrust have on its performance?**

Reducing the number of turns on the rubber band reduced the airplane's potential energy. This reduction caused both a shorter and slower flight. At 600 turns, the aircraft should have flown approximately one quarter of the distance when compared to the 1,000 turn experiment, as well as flown nearly one-half meter per second slower.

6. **What effect did increasing the airplane's thrust have on its performance?**

Increasing the number of turns on the rubber band increased the airplane's potential energy. This caused both a longer and faster flight. At 1,200 turns, the aircraft should have flown approximately 20% further when compared to the 1,000 turn experiment, as well as flown nearly one-half meter per second faster.

7. **How could we improve this airplane in order to increase its performance?**

While students' answers will vary, the main ways to improve aircraft performance are to either increase its thrust, or reduce its weight or drag. This could be achieved by using additional rubber bands, which provide more potential energy and therefore more thrust. Drag could be reduced by sanding the wings until extremely smooth, or by rounding its leading edges - the front edge of the wing.

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Properties and changes of properties in matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Structure and properties of matter
- Interactions of energy and matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL MATH STANDARDS K-12

NUMBER AND OPERATIONS

- Understand numbers, ways of representing numbers, relationships among numbers, and number systems
- Understand meanings of operations and how they relate to one another
- Compute fluently and make reasonable estimates

ALGEBRA

- Represent and analyze mathematical situations and structures using algebraic symbols
- Use mathematical models to represent and understand quantitative relationships

MEASUREMENT

- Understand measurable attributes of objects and the units, systems, and processes of measurement
- Apply appropriate techniques, tools, and formulas to determine measurements.

DATA ANALYSIS AND PROBABILITY

- Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them

PROCESS

- Problem Solving
- Communication
- Connections
- Representation



Reference Materials

Glossary

Leading Edge:

The front edge of an aircraft's wing

Trailing Edge:

The rear edge of an aircraft's wing

Fig. 1 Four forces of flight

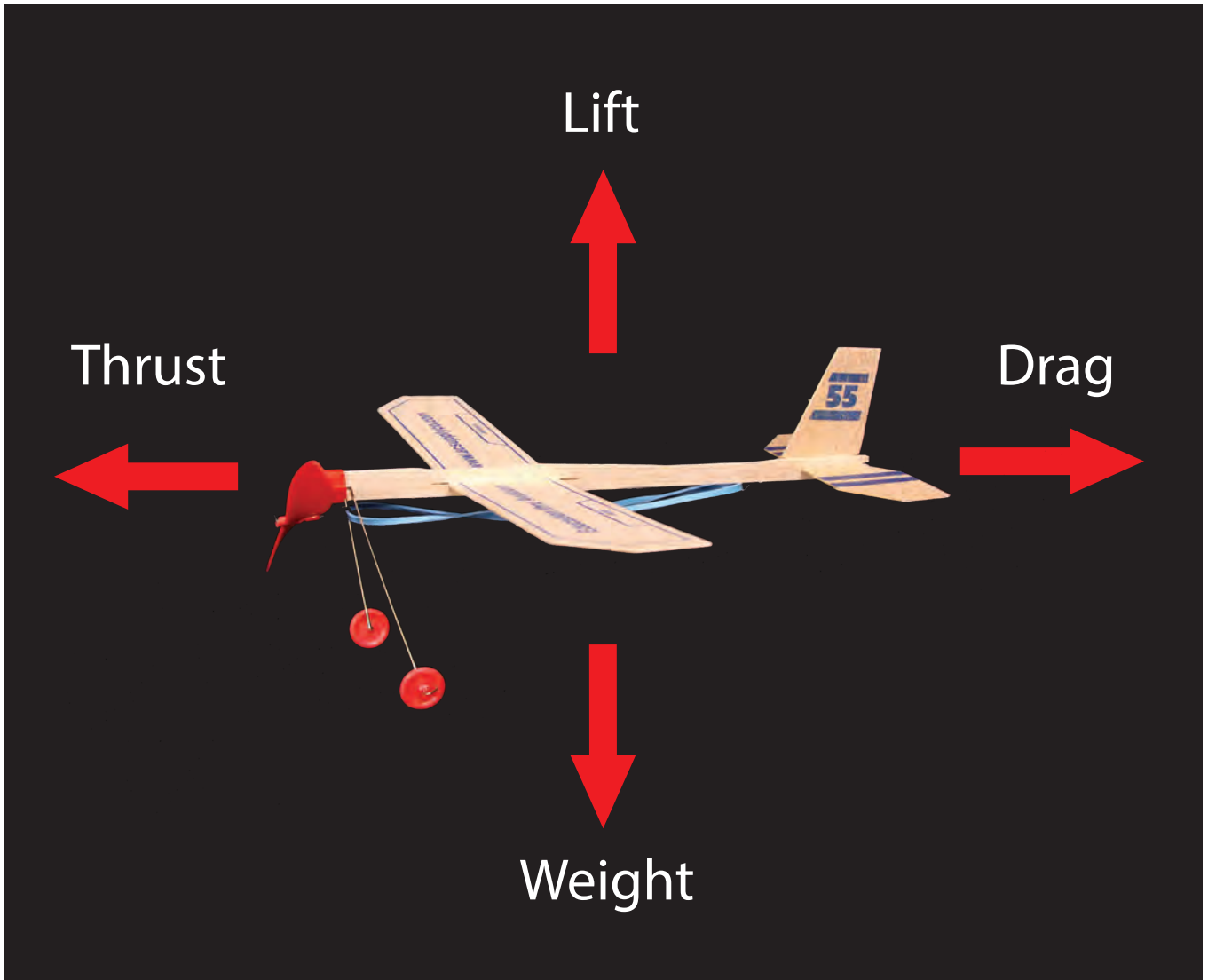


Fig. 2 Forces of straight and level flight

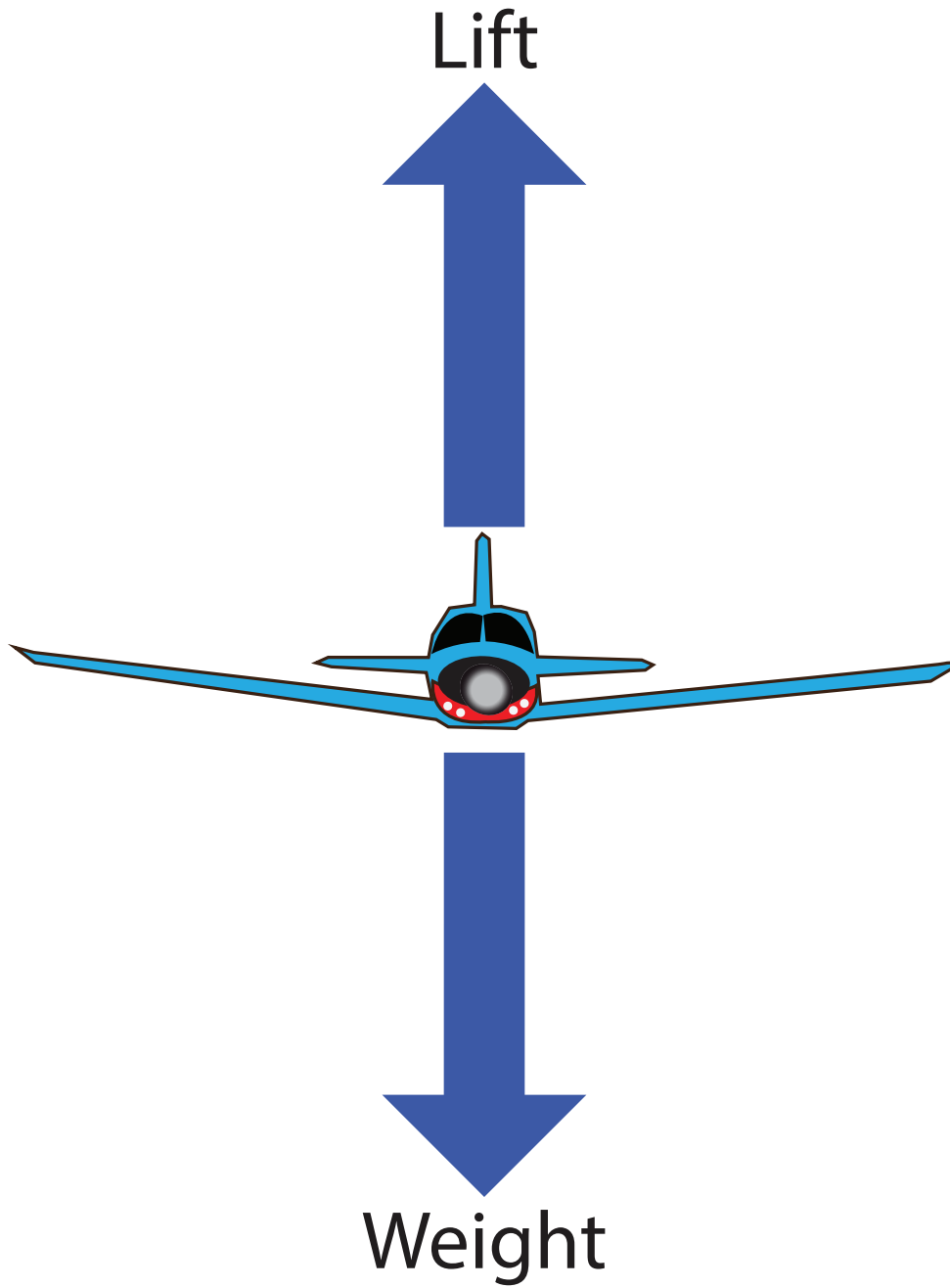


Fig. 3 Forces of turning flight

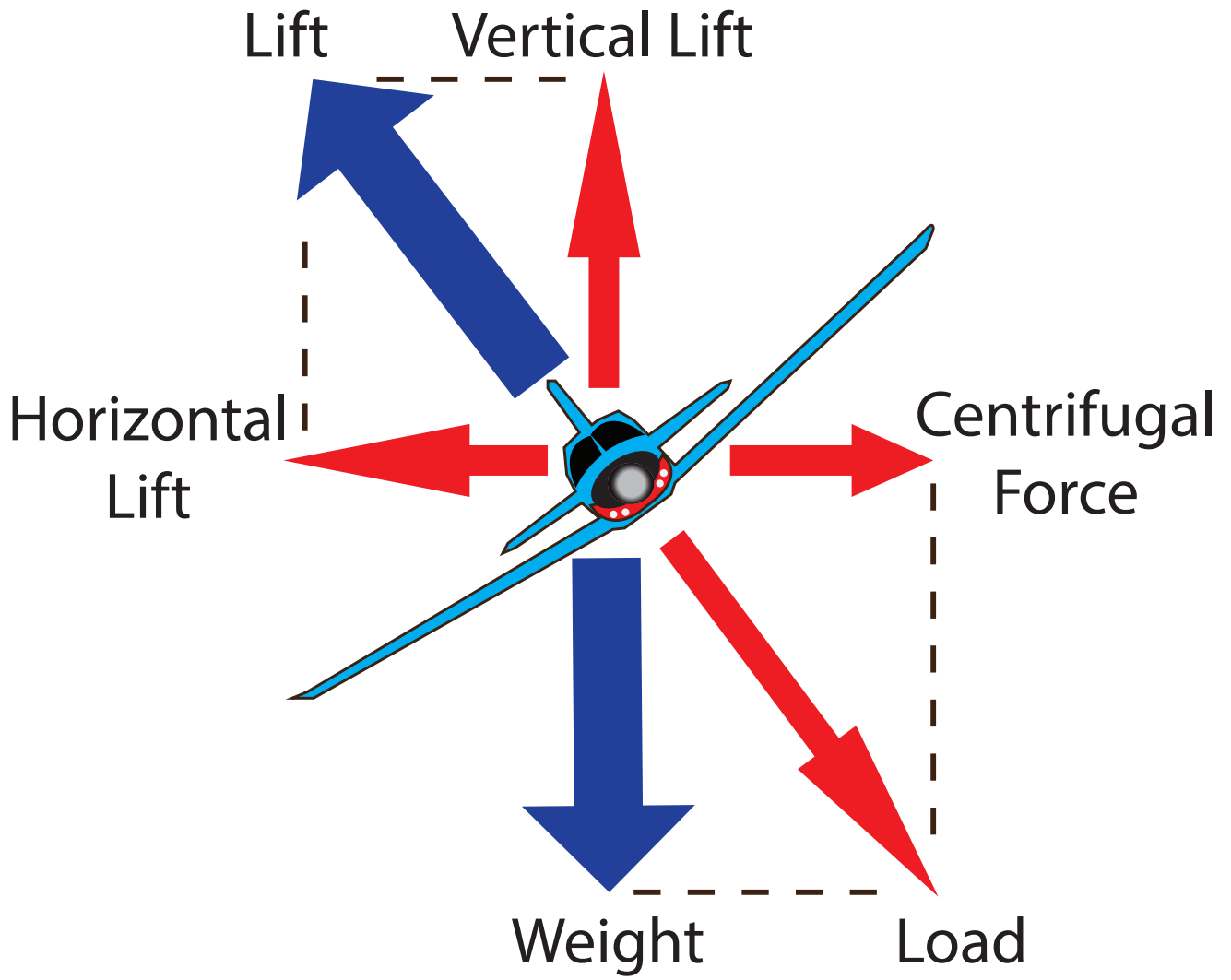
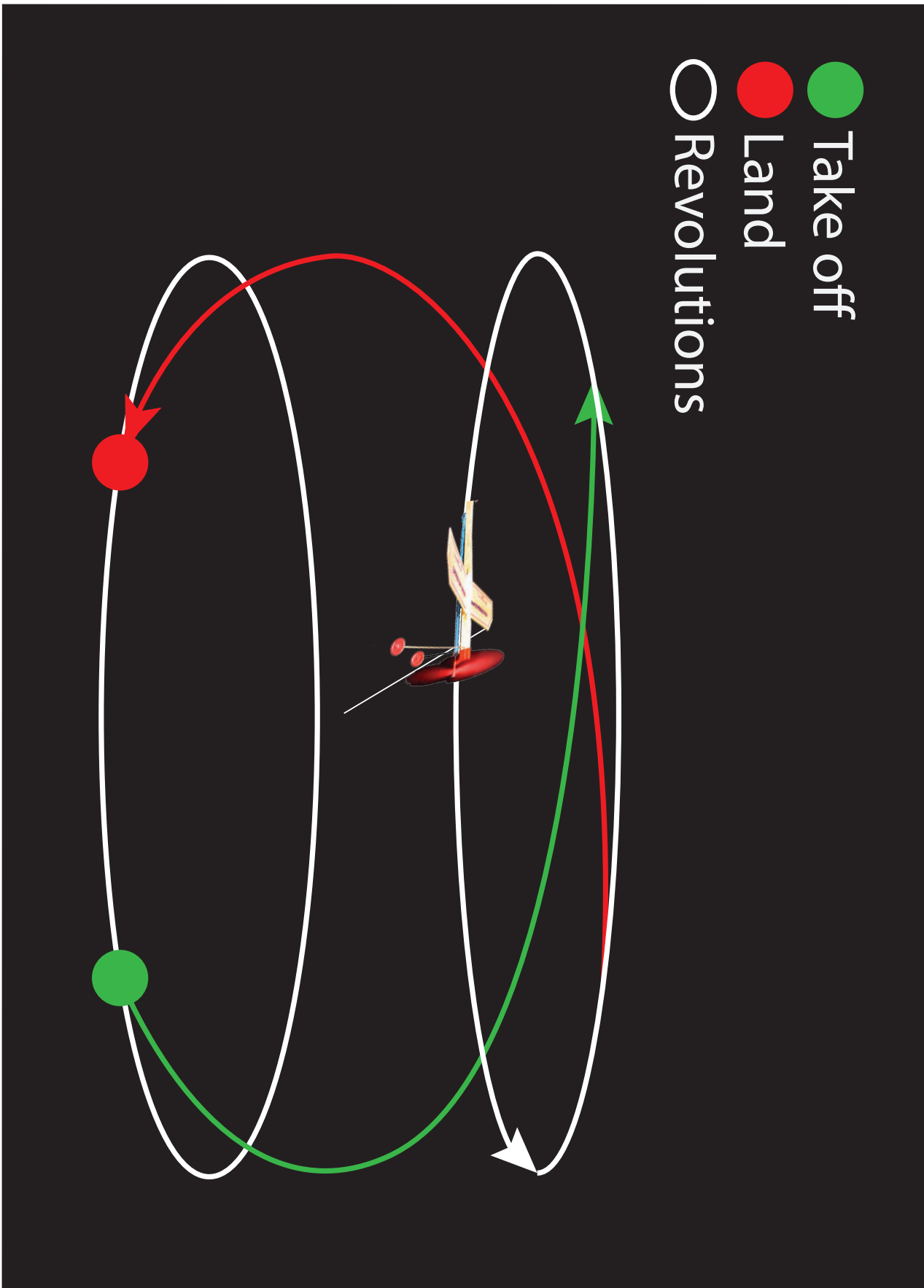
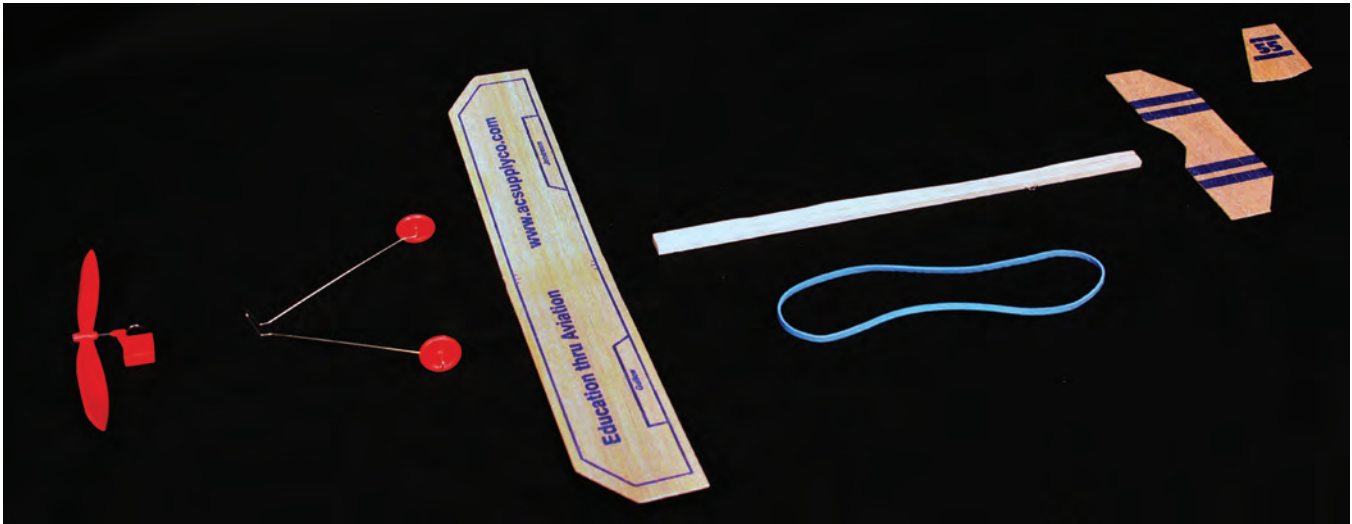


Fig. 4 Aircraft flight path



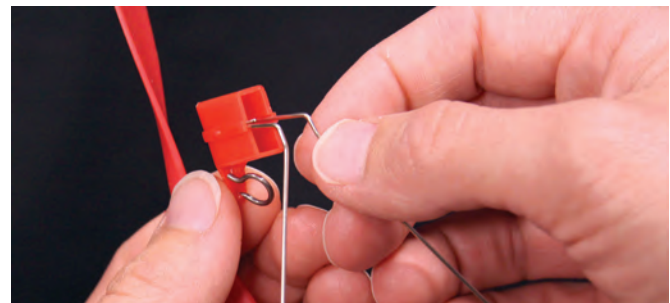
Jetstream Assembly Instructions



1. Before assembling the Jetstream model airplane, inspect the wings and ensure they are in line and curved slightly upwards. The wings should not be twisted or otherwise damaged; if they are, discard the kit and use another.



2. Insert the landing gear (wheels) into the propeller assembly.

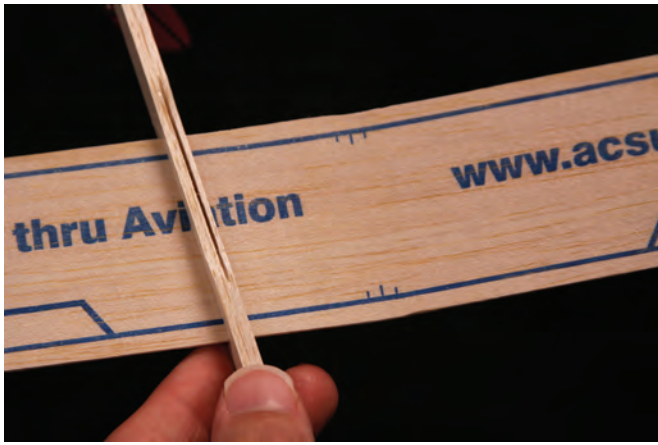


3. Insert the fuselage (the body of the plane) into the slot in the propeller assembly behind the landing gear. Ensure the metal hook on the fuselage is located at the rear of the airplane and is pointing downward.



4. Carefully slide the wings into the slot in the fuselage until centered. The body of the plane should sit between the blue hash marks on the wings.





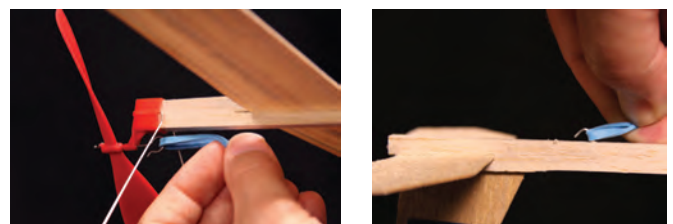
- Slide the horizontal stabilizer into the slot on the side of the fuselage.



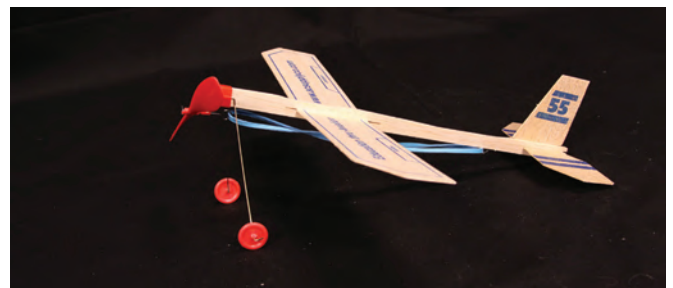
- Place the vertical stabilizer into the slot on the top of the fuselage.



- Attach one end of the rubber band onto the propeller's hook, and one end to the hook on the body.



Your aircraft is now ready for flight!





Student Worksheets

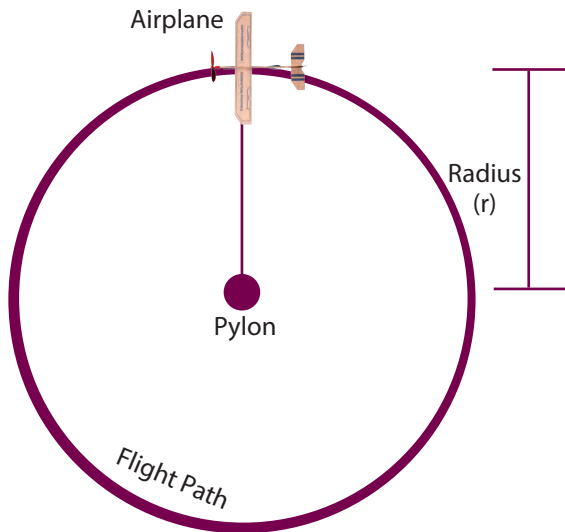
Worksheet 1

Aerolab Flight Data

Record the number of revolutions your plane makes in the table below.

Radius of flight path (distance from pylon to fuselage center): _____

Circumference (distance traveled in one lap) = $2\pi r$: _____



Number of Laps • Circumference = Average Distance Traveled

$$\frac{\text{Average Distance Flown}}{\text{Average Time Airborne}} = \text{Average Airspeed}$$

$\pi = 3.14$

Unmodified Aircraft

Launch Number	Takeoff Distance (in laps)	Takeoff Distance (in meters)	Time Airborne (in seconds)	Laps Flown
1				
2				
3				
Average				

Average distance flown: _____

Average airspeed: _____

Worksheet 1 continued Aerolab Flight Data

Modification #1: Additional Weight (1 cent)

Launch Number	Takeoff Distance (in laps)	Takeoff Distance (in meters)	Time Airborne (in seconds)	Laps Flown
1				
2				
3				
Average				

Average distance flown: _____

Average airspeed: _____

Modification #2: Additional Weight (2 cents)

Launch Number	Takeoff Distance (in laps)	Takeoff Distance (in meters)	Time Airborne (in seconds)	Laps Flown
1				
2				
3				
Average				

Average distance flown: _____

Average airspeed: _____

Modification #3: Additional Drag

Launch Number	Takeoff Distance (in laps)	Takeoff Distance (in meters)	Time Airborne (in seconds)	Laps Flown
1				
2				
3				
Average				

Average distance flown: _____

Average airspeed: _____

Worksheet 1 continued **Aerolab Flight Data**

Modification #4: Reduced Thrust (600 turns)

Launch Number	Takeoff Distance (in laps)	Takeoff Distance (in meters)	Time Airborne (in seconds)	Laps Flown
1				
2				
3				
Average				

Average distance flown: _____

Average airspeed: _____

Modification #5: Additional Thrust (1,200 turns)

Launch Number	Takeoff Distance (in laps)	Takeoff Distance (in meters)	Time Airborne (in seconds)	Laps Flown
1				
2				
3				
Average				

Average distance flown: _____

Average airspeed: _____

Modification # _____ :

Launch Number	Takeoff Distance (in laps)	Takeoff Distance (in meters)	Time Airborne (in seconds)	Laps Flown
1				
2				
3				
Average				

Average distance flown: _____

Average airspeed: _____

Modification # _____ :

Launch Number	Takeoff Distance (in laps)	Takeoff Distance (in meters)	Time Airborne (in seconds)	Laps Flown
1				
2				
3				
Average				

Average distance flown: _____

Average airspeed: _____

Modification # _____ :

Launch Number	Takeoff Distance (in laps)	Takeoff Distance (in meters)	Time Airborne (in seconds)	Laps Flown
1				
2				
3				
Average				

Average distance flown: _____

Average airspeed: _____

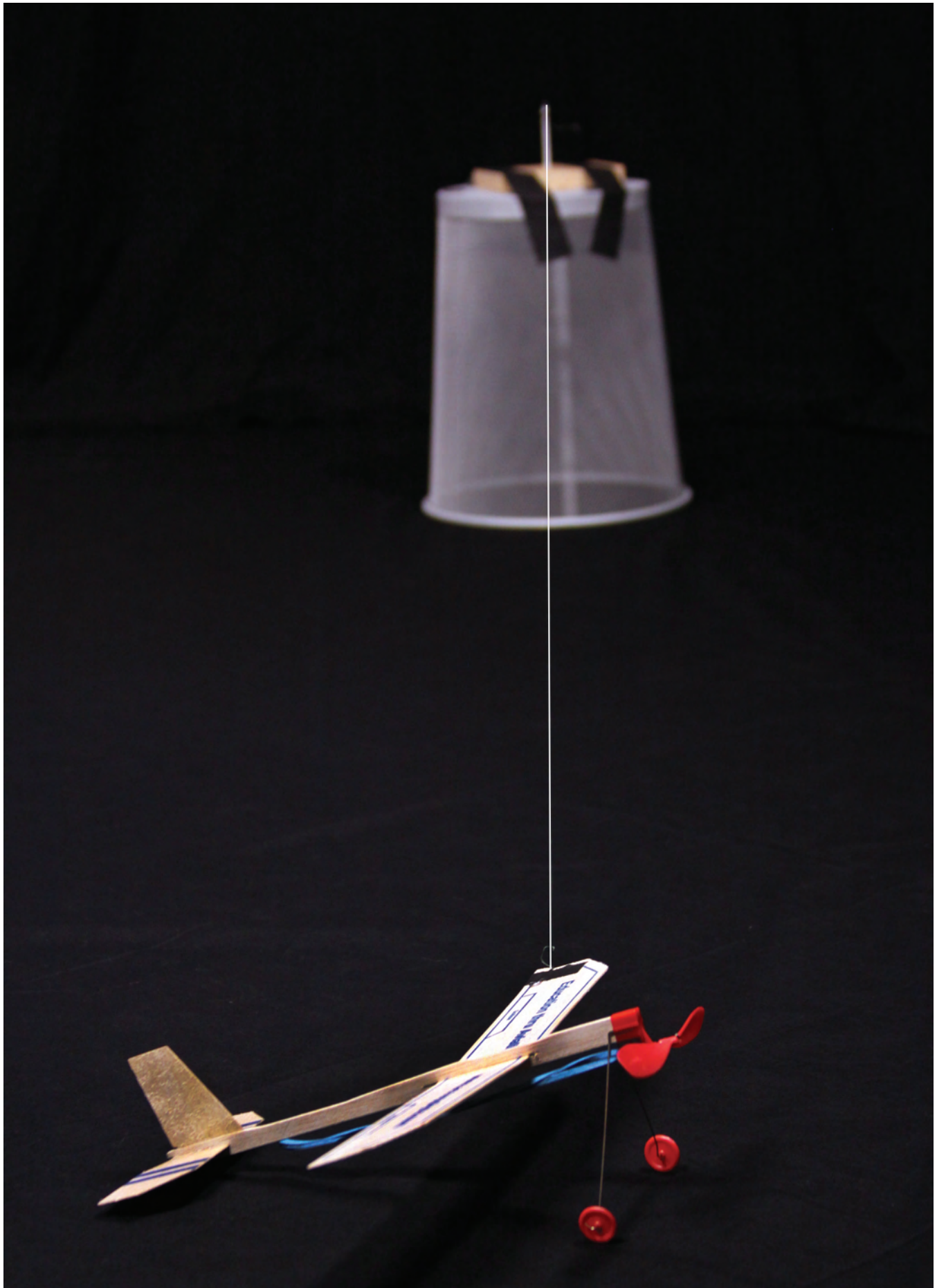


Images

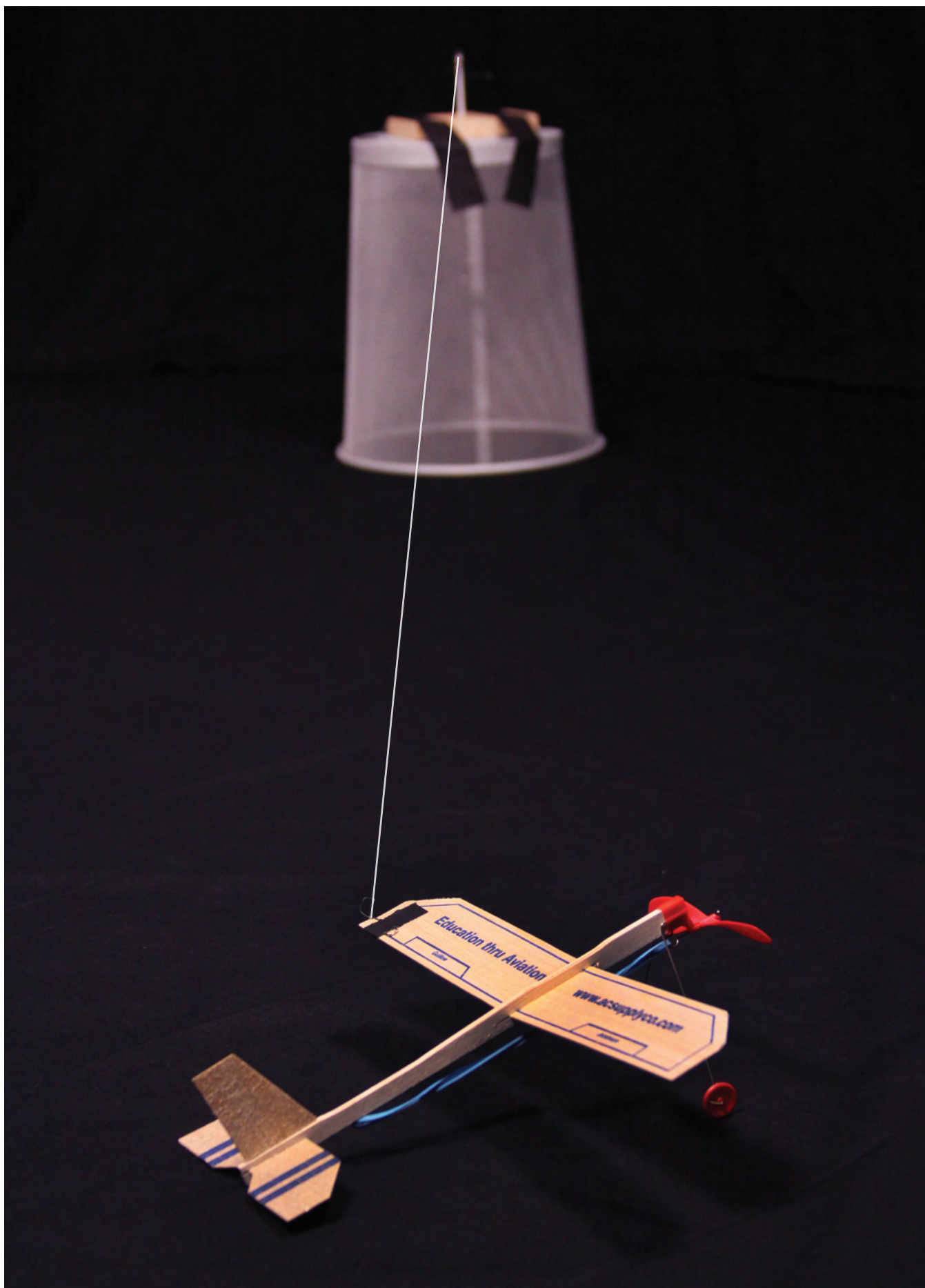
Img. 1 X-31 Enhanced Fighter Maneuverability Demonstrator aircraft



Img. 2 Correct launch position



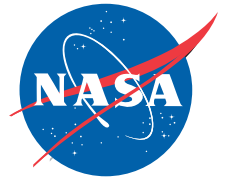
Img. 3 Incorrect launch position



Aeronautics
Research
Mission
Directorate



future flight



5-12

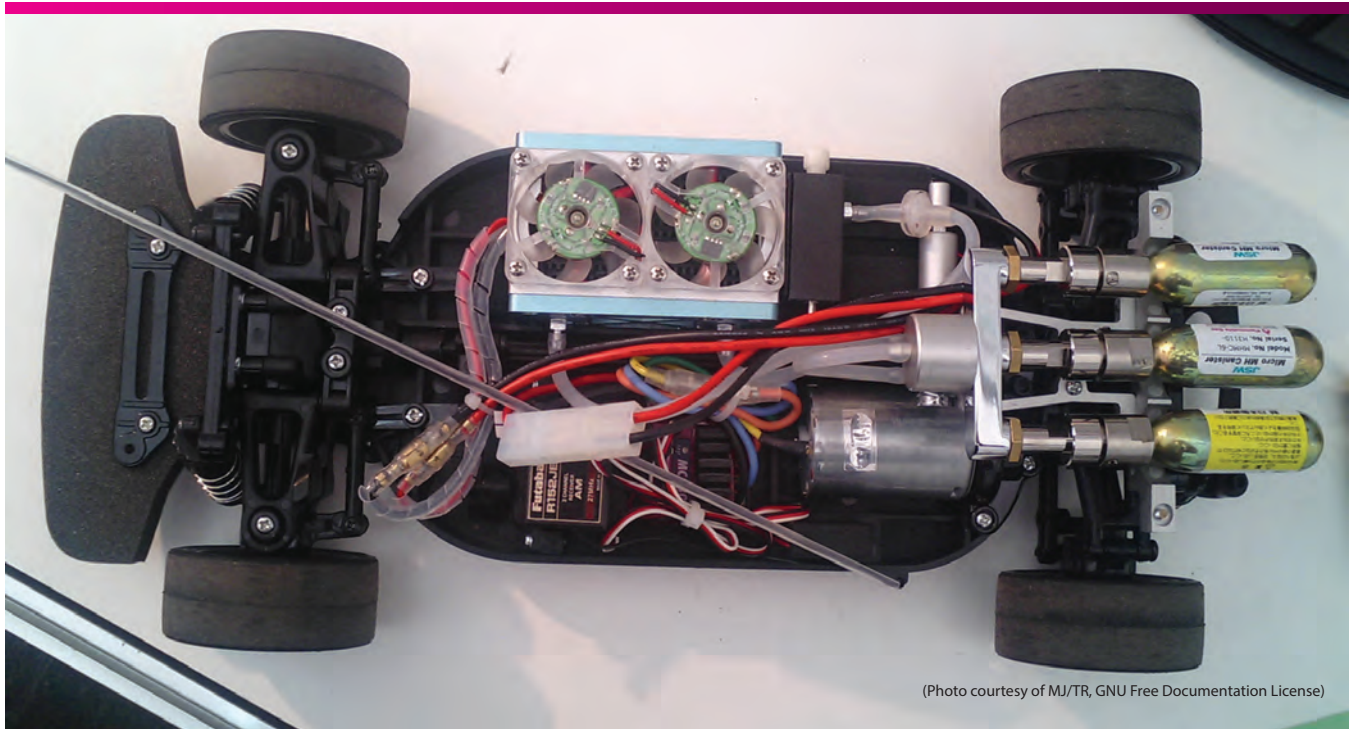
Fuel Cell Activity



future flight

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(Photo courtesy of MJ/TR, GNU Free Documentation License)

Fuel Cell Activity

Lesson Overview

By observing this demonstration, students will learn about properties and changes in matter as water is converted into its elemental components using solar electricity and a fuel cell. They will also learn how the same fuel cell creates electricity by converting hydrogen and oxygen into water.

Objectives

Students will:

1. Discover how a hydrogen fuel cell can power a small car.

Materials:

In the Box

- Thames & Kosmos™ Fuel Cell Car & Experiment Kit
- Safety goggles (1 pair)
- Philips head screwdriver
- Small knife or scissors
- Metric ruler

Provided by User

- Sunlight / lamp
- Distilled water

GRADES

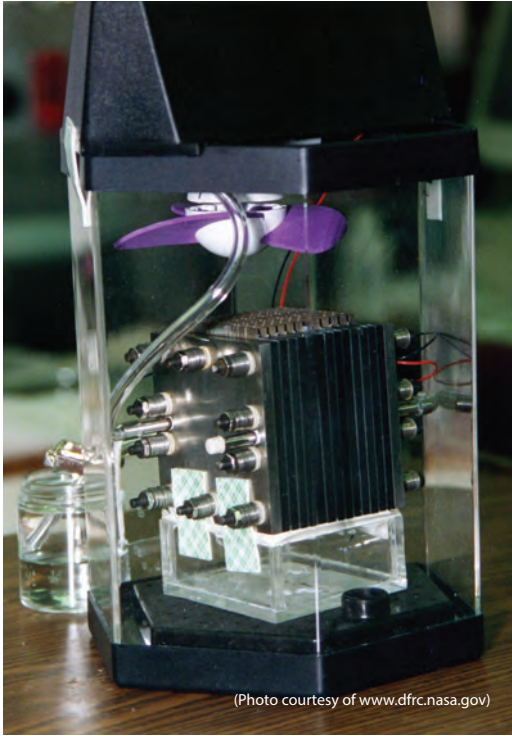
5-12

Time Requirements: 1 hour

Background

An Introduction to the Fuel Cell

The ability to produce power without damaging the environment is a continuing challenge. Fossil fuels like gasoline, natural gas and coal all come from non-renewable sources and when burned, they increase the levels of air pollution and may harm the environment. Batteries, such as those found in flashlights and MP3 players, have limited lifetimes and often end up being disposed of in landfills which over time leach hazardous chemicals into



(Photo courtesy of www.dfrc.nasa.gov)

the earth. There are many environmentally friendly alternatives available today, such as solar, wind, geothermal and hydroelectric power. These power sources often depend on a power grid for the distribution of electricity. Fuel cells however are different. They have near-zero emissions, are quiet and efficient, can work in almost any environment and do not need a grid for distribution. It can also operate in a temperature that is lower than the cell's normal operating temperature.

A fuel cell combines a fuel, such as hydrogen, with an oxidizer (oxygen) to produce electrical power. It works in a similar way to a battery but it never runs down or needs to be recharged. Like a battery which has a positive and negative end, a fuel cell has two electrodes: the positive (cathode) and the negative (anode), both of which are separated by an electrolyte, similar to the gel in a standard battery. With the battery however, one of the electrodes is slowly eroded as electricity is produced whereas in a fuel cell, the electrode is not. This means the cell can produce electricity for as long as fuel and oxidizer are available.

NASA's Glenn Research Center in Cleveland, Ohio has been at the center of NASA's fuel cell research and development since 1963. It helped to develop the fuel cells that were the primary source of power on the Space Shuttle fleet as well as develop fuel cells for electric vehicles and energy-storage systems.

Fuel cells may soon be seen in many areas of our lives. For example, they may replace the auxiliary power unit (APU) on commercial aircraft, which provides electricity when the engines are not operating. They could also be used in cars or personal electronics. They are even being considered for use on future missions to Mars and beyond.

Much work must still be done before fuel cells can be used in long range spacecraft, primarily because of the need to operate in extreme low pressure environments and low temperatures for extended durations. When perfected though, the technology will enable new space exploration as well as provide fuel savings, quieter operation and reduced environmental emissions.

For further information on the design, physics and operation of the hydrogen fuel cell, please refer to page 78 in the Thames & Kosmos® Fuel Cell Lab Manual included in the Museum in a Box.

Activity 1

Fuel Cell Car Demonstration

GRADES 5-12**Time Requirements:** 1 hour**Materials:**In the Box

Thames & Kosmos™ Fuel Cell Car & Experiment Kit

Safety goggles (1 pair)

Philips head screwdriver

Small knife or scissors

Metric ruler

Provided by User

Sunlight / lamp

Distilled water

Worksheets

None

Reference Materials

None

Key Terms:H₂O

Electrolysis

Fuel cell

Objective:

Students will discover how a hydrogen fuel cell can power a small car.

Activity Overview:

By observing this demonstration, students will learn how water is converted into its elemental components using solar electricity and a fuel cell. They will also learn how the same fuel cell creates electricity by converting hydrogen and oxygen into water.

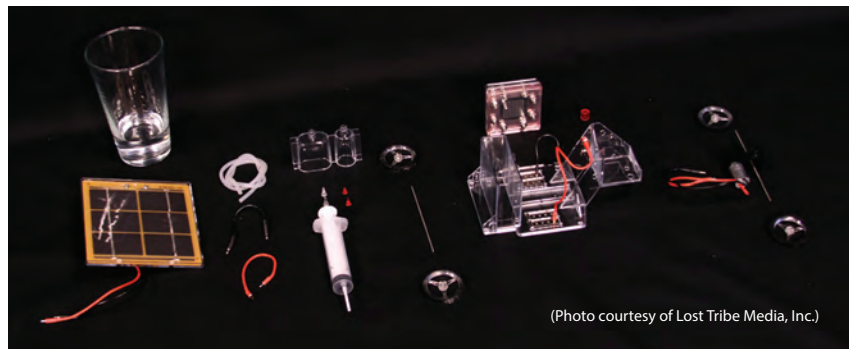
Activity:

Caution: *The fuel cell kit contains many small, easily breakable parts. It is important to exercise caution during both the setup and the demonstration.*

Caution: *At no time should the fuel cell be disassembled. It contains a very delicate Nafion foil plate which WILL be destroyed unless opened in laboratory conditions.*

WARNING: The fuel cell used in this kit creates hydrogen, a highly explosive gas. While the kit cannot produce enough gas to create a large explosion, care must be taken to avoid working near heat sources or open flame. Before starting this demonstration, read ALL of the safety information contained on pages 3 and 41 of the Thames & Kosmos® Fuel Cell Lab Manual included in the Museum in a Box.

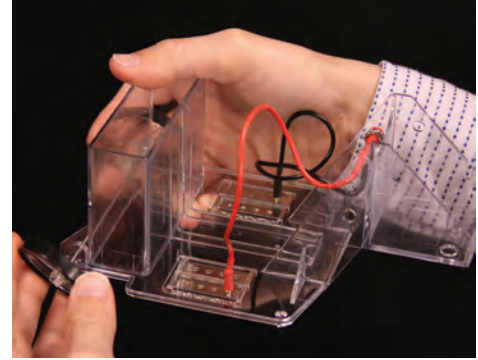
The kit will require time to build and charge prior to the demonstration. It takes approximately 30 minutes to assemble the vehicle itself, with an additional 30 minutes required to charge the gas tanks and demonstrate the vehicle moving.



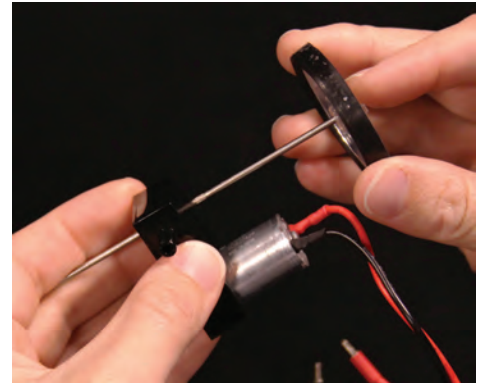
Img. 1 Exploded view of Fuel Cell Car Kit

Assemble the car as follows:

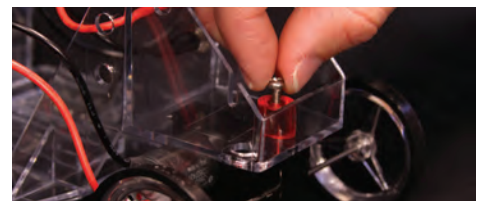
- a. Pass a metal axle through the holes in the rear of the body and attach a wheel to each end.



- b. Attach a wheel to each end of the axle on the motor assembly.



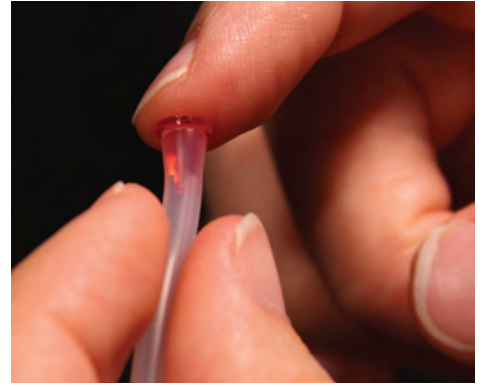
- c. Attach the motor assembly to the body of the car using the Phillips screw and spacer.



- d. If necessary, cut the rubber hose into the following lengths: 1 of 6cm, 2 of 5cm, 2 of 17cm. It is important to be accurate when cutting the hose.



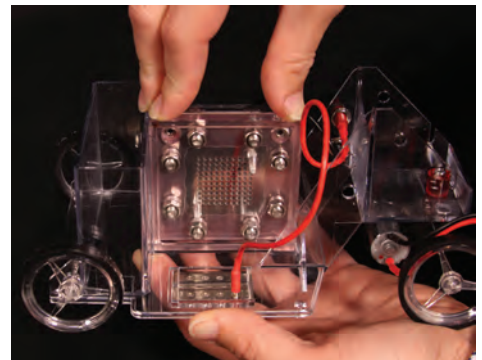
- e. Plug one end of each of the 5cm hoses using the red plugs provided.



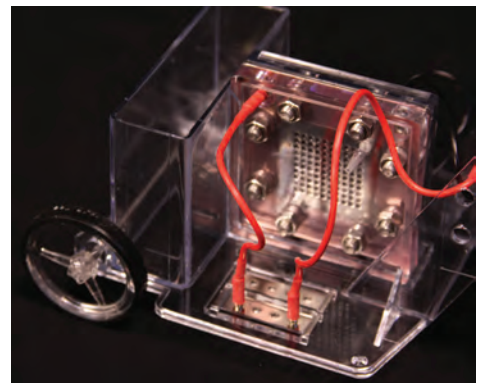
- f. Plug one end of each of the 17cm hoses using the transparent plugs provided.



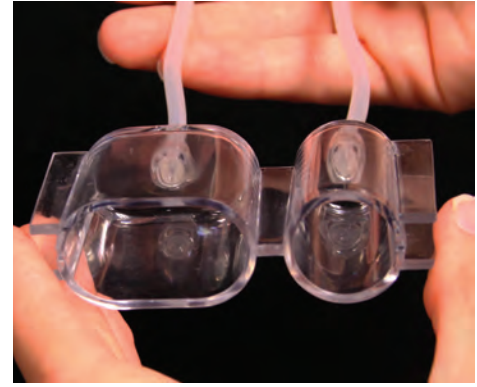
- g. Insert the fuel cell into the slot provided in the car, ensuring that the red side is facing the right side of the car.



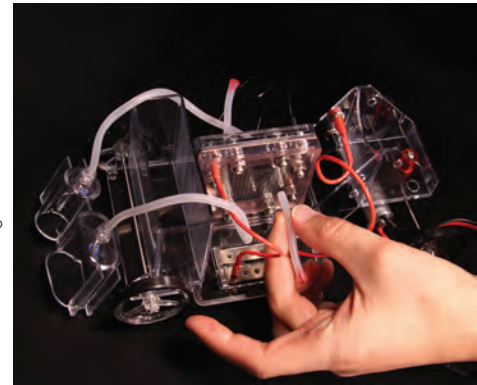
- h. Place one end of the red wire into the hole in the red side of the fuel cell; insert the other end of the wire into the hole next to it on the body of the car. Do the same with the black wire on the opposite side.



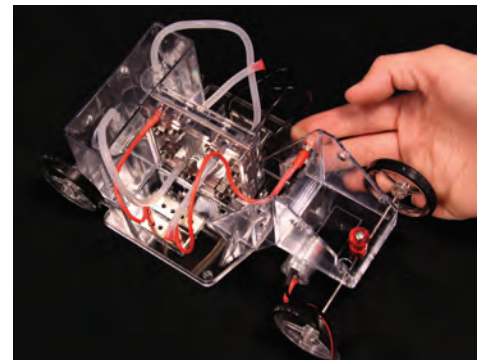
- i. Pass the 17cm hoses (with transparent plugs) through the bottom of the gas tanks and pull until each transparent plug is firmly secured in the hole at the top of the tank.



- j. Attach the hose from the larger tank to the port on the bottom of the red side of the fuel cell, while the hose from the smaller tank connects on the opposite side. Attach the 5cm hoses to the top ports. *You will notice that the fuel cell has a red and a blue side. The red side is referred to in the Thames & Kosmos® Fuel Cell Lab Manual as the "Hydrogen" side, while the blue side is the "Oxygen" side.*



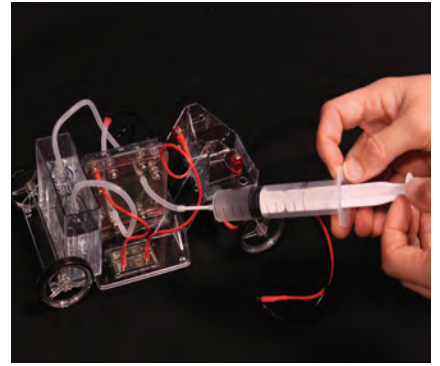
- k. Place the gas tank assembly into the carrier on the back of the car, ensuring that the hydrogen tank (the larger tank) is on the right side of the vehicle.



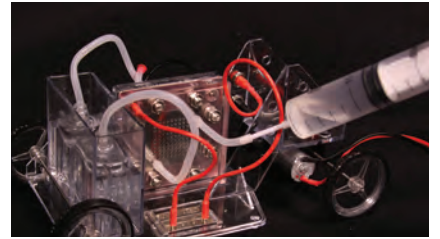
- l. Carefully pour distilled water into the water tank on the back of the vehicle, filling it full. It is important to ONLY use distilled water. Regular tap water contains minerals which will damage the fuel cell.



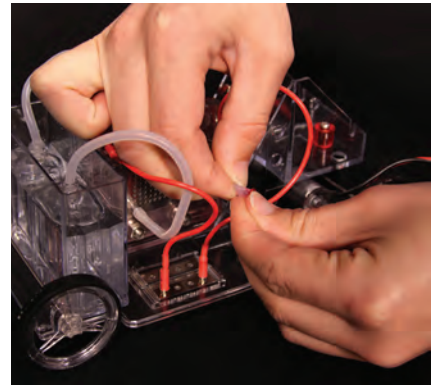
- m. Remove the red plug from the end of one of the short 5cm hoses and then carefully insert the tip of the syringe into the end of the hose. This will be a snug fit. Next, slowly draw backwards on the plunger to pull water from the tank into the fuel cell.



Caution: Do not let the tank fully empty. The purpose of this step is to remove all air from the system! It may be necessary to disconnect the syringe, push forwards on the plunger to empty it and then reconnect more than once to fully draw all the air out of the fuel cell.



- n. Once the syringe has filled with water, disconnect and immediately reconnect the red plug. It may help to pinch the tube to prevent air from re-entering the system.
- o. Repeat the process on the other side of the fuel cell.



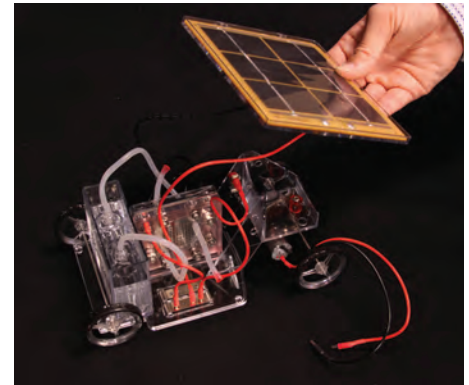
By this stage, you have a completely assembled car that is ready to use. The remaining steps will convert the water into its individual components of hydrogen and oxygen, then convert them back into water, generating electricity in the process. It may be beneficial for the students to start the demonstration at this point, which will take an additional 30 minutes to complete. As you complete each step, explain what is happening to the students.

1. Use the assembled fuel cell car as follows to demonstrate to the students how the fuel cell generates electricity:

- a. Connect the wires of the solar panel to the car, ensuring that the red wire connects to the red side, the black wire to the black side. Place the assembly under a lamp, or near a sunny window. There is no need to mount the solar panel to the car.

Once the wires to the solar panel are connected, electricity is powering the fuel cell, converting the water into its base elements, hydrogen and oxygen.

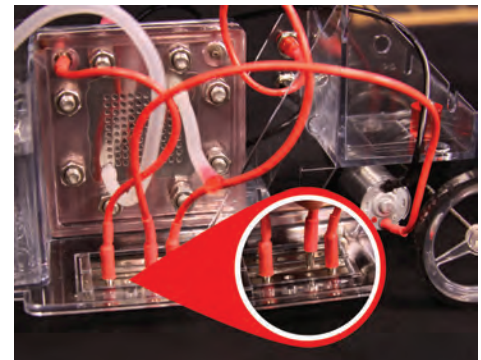
This separation of hydrogen and oxygen is called electrolysis. It takes approximately 15 minutes for the fuel cell to fill the gas tanks completely, at which time you can move on to the next step.



- b. Disconnect the solar panel and set it to one side.
It is likely that your students are already familiar with solar power. Therefore it is important to demonstrate that it is completely detached and no longer producing electricity.

- c. Attach the wires from the motor to the plug holes in the body. Connect the red wire to the right side of the car, the black wire to the left.

At this point the fuel cell begins to work in the opposite direction, taking the hydrogen and oxygen gases and converting them back into water. As this happens, electricity is produced which powers the motor.



- d. Place the car on the ground and let it go!

Discussion Points:**1. What just happened?**

The fuel cell is a two-way device; it can either produce gas from water, or water from gas. In step (2a), we used the fuel cell to convert water, or H_2O , into its base elements, hydrogen and oxygen, which were stored in the tanks on the back of the car. After disconnecting the solar panel, which provided the source of electricity needed to power the conversion, the production of gas stopped and the fuel cell started to consume gas instead. As the cell converted the gases back into H_2O , it also produced electricity, which then powered the motor in the car.

2. What does H_2O mean?

H_2O is the chemical formula for the compound we commonly call water. In the case of distilled water, each molecule contains 2 hydrogen atoms and 1 oxygen atom. Every substance can be described this way. For example, table salt is $NaCl$, or one part Sodium (Na) to one part Chlorine (Cl).

3. Why does the water have to be distilled? What does that mean?

Think of a typical bottle of spring water. It says right on the label that it contains “minerals which are important to health,” which is true. Unfortunately, what is good for humans and animals isn’t good for fuel cells. Minerals, which are very small crystals found in drinking water, clog the fuel cell and prevent it from working.

Distilling is a process where a liquid, water in our case, is heated to the point of evaporation (steam). That steam is collected on a cooled surface where it condenses again back into liquid water. This is the distilled water that can be used by the fuel cell. As the mineral crystals could not be carried in the steam, the distilled water is 100% pure H_2O , with no additional minerals.

This demonstration is just one of many experiments that can be performed using this kit. The other activities available with the Fuel Cell kit are listed below. Detailed instructions can be found in the Thames & Kosmos® Fuel Cell Lab Manual.

- 1. Page 50 / Experiment 9: Splitting of Water Through Electrolysis**
In this experiment, students will make an electrode and apply a small electrical current to water in order to witness the separation of the oxygen and hydrogen molecules.
- 2. Page 52 / Experiment 10: Test to Demonstrate Presence of Hydrogen**
Continuing on from Experiment 9, students will collect the gas bubbles created and test to see if the gas reacts to an open flame .
- 3. Page 54 / Experiment 11: Calibration of the Gas Tanks**
Students will use a graduated syringe to calibrate the scale on the gas/water tanks.
- 4. Page 57 / Experiment 12: Assembly and Filling of the Fuel Cell**
Similar to the fuel cell activity just completed, in Experiment 12 students assemble a fuel cell and prepare it for use.
- 5. Page 59 / Experiment 13: Splitting of Water in the Fuel Cell**
Similar to the fuel cell activity just completed, in Experiment 13 students convert water into hydrogen and oxygen.
- 6. Page 60 / Experiment 14: Qualitative Gas Analyses: Test to Demonstrate Presence of Hydrogen, Glow Test to Prove Presence of Oxygen**
This experiment expands on the skills learned in Experiment 10, testing the different gasses produced by the fuel cell and determining their properties.
- 7. Page 61 / Experiment 15: Quantitative Measurement of Gas Generation Rates**
Having discovered that the fuel cell produces gas, students will now determine the rate at which gas is produced.
- 8. Page 65 / Experiment 16: Electrical Measurement of the Electrolysis: Determination of Current and Voltage**
In this experiment, students will measure the voltage and current output of the solar panel being used to perform the electrolysis.

9. **Page 66 / Experiment 17: Efficiency of Water Electrolysis**
Students will use the numbers discovered in Experiment 16 to calculate the efficiency of solar electrolysis.
10. **Page 68 / Experiment 18: Influence of Light and Shade on the Splitting of Water**
Students will adjust the amount of light hitting the solar panel and note the change in the rate of electrolysis.
11. **Page 70 / Experiment 19: A Game of Patience: Complete Splitting of all the Water in the Fuel Cell**
Students will measure the amount of time it takes for electrolysis to generate 24ml of hydrogen gas.
12. **Page 71 / Experiment 20: Another Math Problem: How much Water was there in the Fuel Cell**
Using math, students will determine how much water can be created with 24ml of hydrogen and 12ml of oxygen.
13. **Page 72 / Experiment 21: Solar Splitting of Water, is it better than with the Lamp?**
Students will compare the difference in efficiency of a solar panel using either a lamp or the Sun.
14. **Page 72 / Experiment 22: How long does the Gas Remain in the Tank?**
Students will discover the porous nature of plastics and discover that it is a poor choice for long term storage of gasses.
15. **Page 76 / Experiment 23: It moves!**
Experiment 23 contains many of the steps just completed in this demonstration.
16. **Page 80 / Experiment 24: Starting the Motor**
Students will discover how the electric motor used to power the car can also be used as a generator.
17. **Page 81 / Experiment 25: Another Way of Turning**
Students will use the electricity produced by the electric motor to provide electricity to the electrolysis process.
18. **Page 82 / Experiment 26: Measurements on the Generator**
In this experiment, students will continue to measure and analyze the output of the electric motor.
19. **Page 83 / Experiment 27: Range of the Car**
By tethering the car to a post, students will measure the distance traveled on a single tank of fuel.

20. **Page 84 / Experiment 28: An Airy Matter**
Students will discover how the efficiency of the fuel cell is affected by the use of regular air as opposed to the 100% oxygen supply.

21. **Page 85 / Experiment 29: A Crane with Hydrogen Drive**
Students will build a crane powered by the fuel cell motor and measure the amount of weight it can lift.

22. **Page 86 / Experiment 30: What is the Power of the Crane?**
Students will calculate the mathematical performance of the crane built in Experiment 29.

23. **Page 87 / Experiment 31: Energy Delivered by the Crane**
Students will calculate the energy of the crane from Experiments 29 and 30 in Joules.

24. **Page 88 / Experiment 32: Measurement of No-load Voltage, Operating Voltage and Short Circuit Current of the Fuel Cell**
In this experiment, students will measure the voltage output of the fuel cell in a variety of situations.

25. **Page 90 / Experiment 33: Efficiency of the Fuel Cell**
Students will calculate the mathematical efficiency of the fuel cell.

26. **Page 93 / Experiment 34: Hybrid Solar Hydrogen Car**
By combining the power of both the fuel cell and solar panel, students will explore how to extend the range of their vehicle.

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Properties and changes of properties in matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Structure and properties of matter
- Interactions of energy and matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology



Reference Materials

Glossary

Electrolysis:

The process by which a direct electrical current (DC) is used to force a non-spontaneous chemical reaction

Fuel cell:

A device that converts chemical energy from a fuel into electricity through a chemical reaction with oxygen or oxidizing agent

H₂O:

The chemical name for pure water, which is comprised of two parts hydrogen to one part oxygen

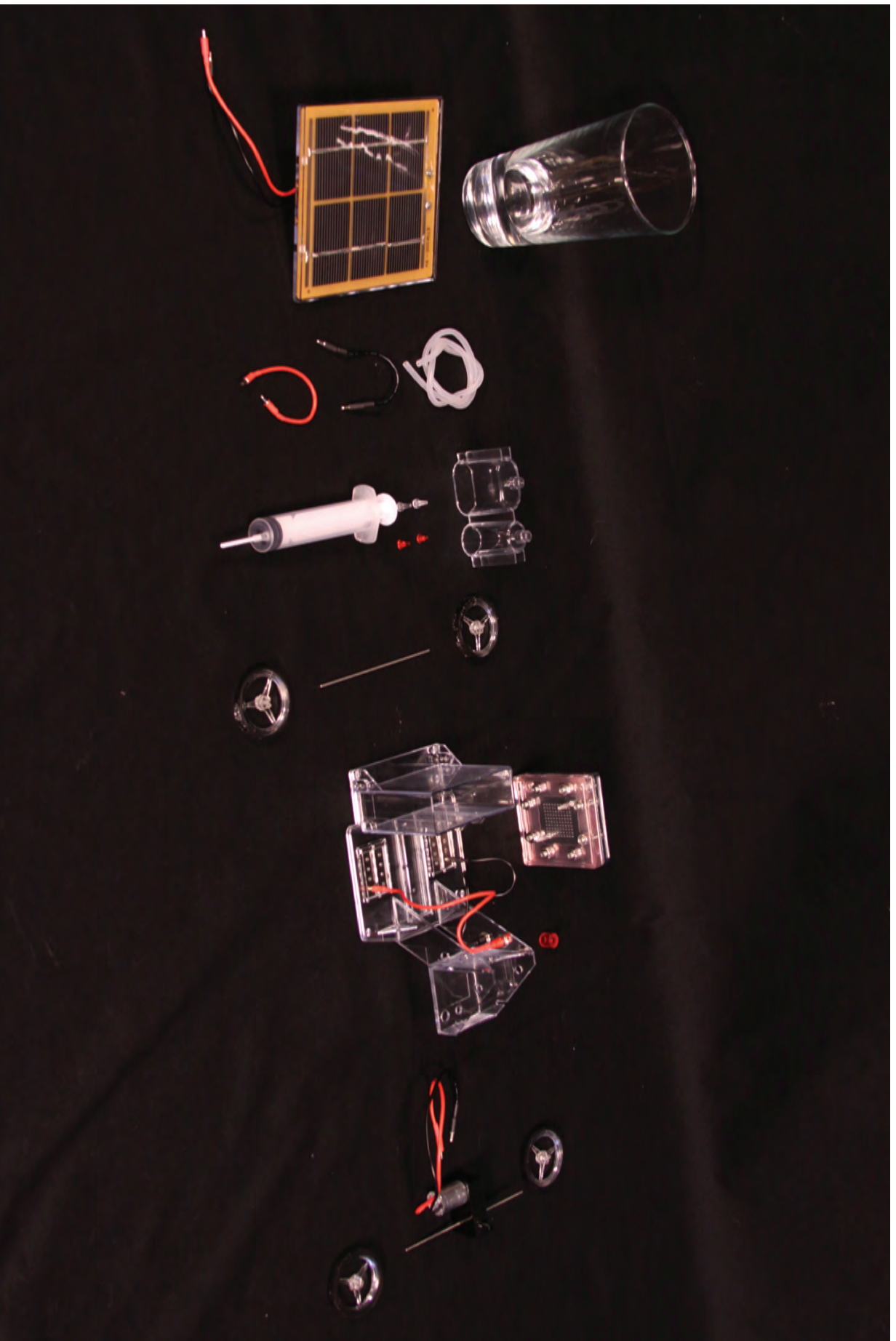
Power Grid:

A system of power lines, transformers and other equipment that distributes electricity to a large area



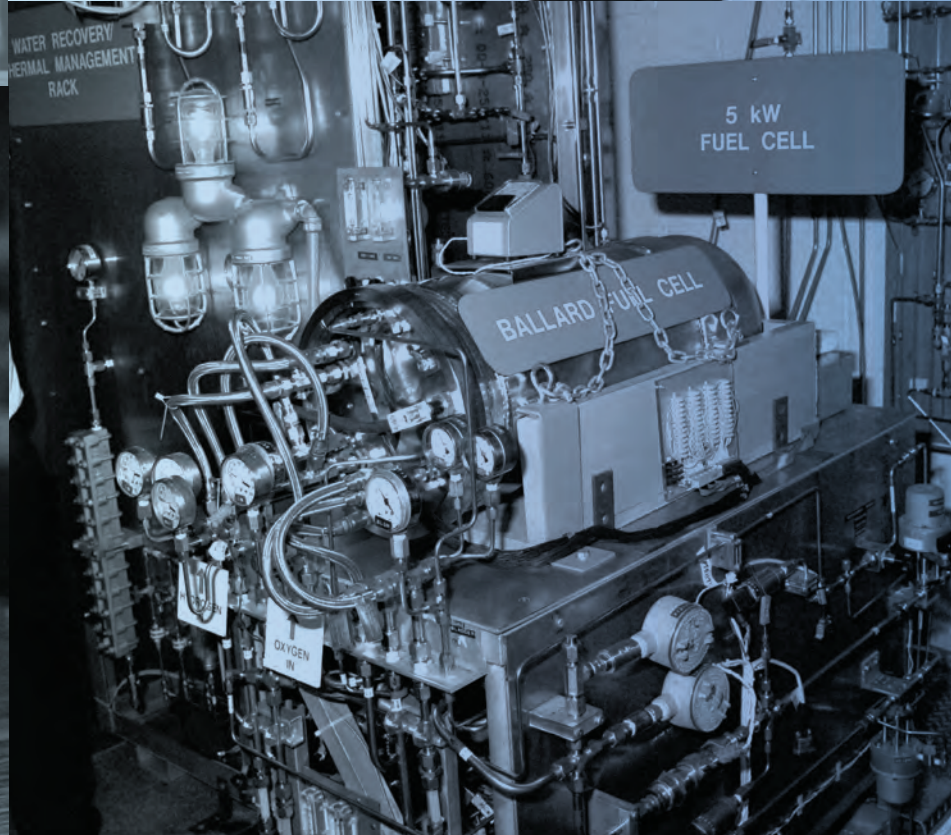
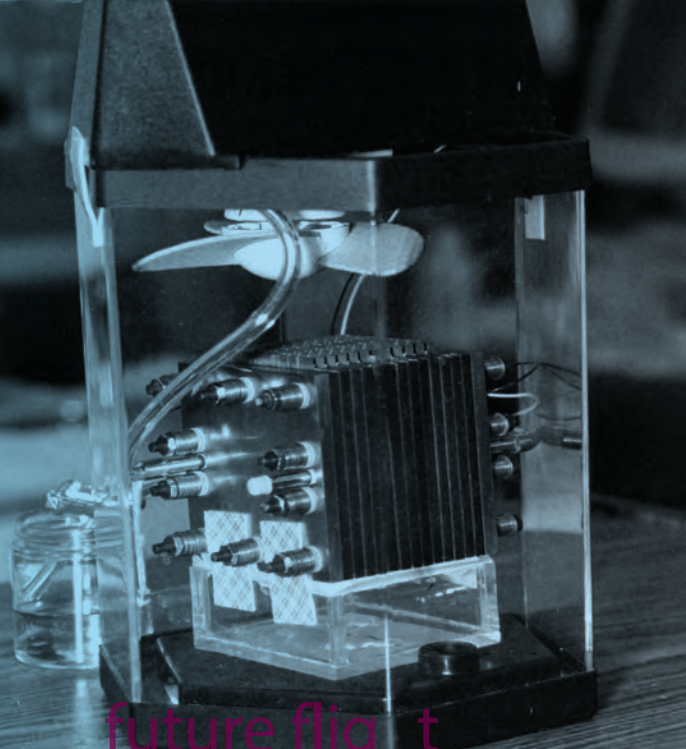
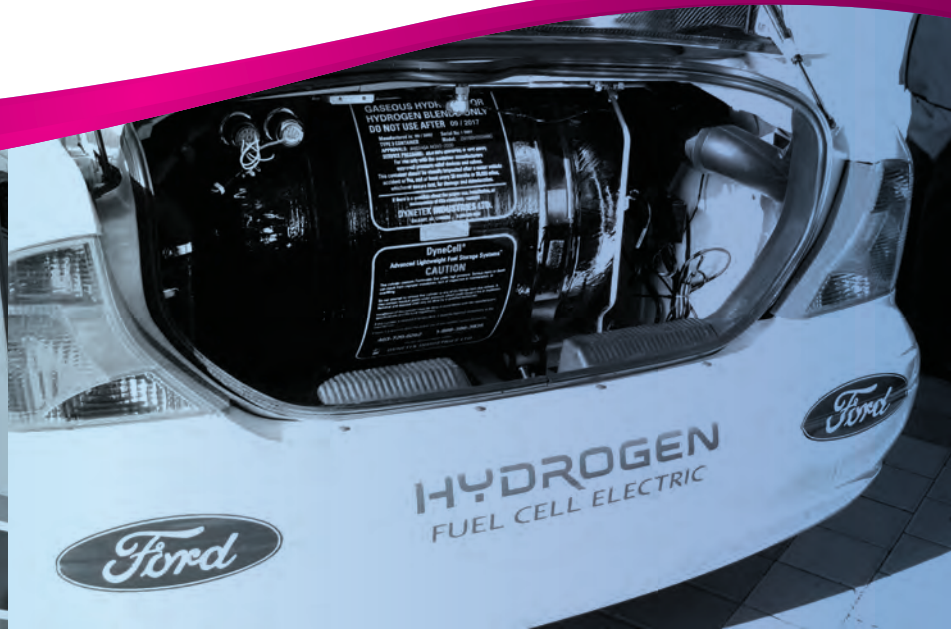
Images

Img. 1 Exploded view of Fuel Cell Car Kit

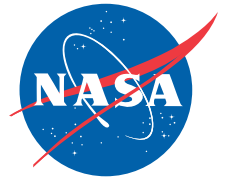


(photo courtesy of Lost Tribe Media, Inc.)

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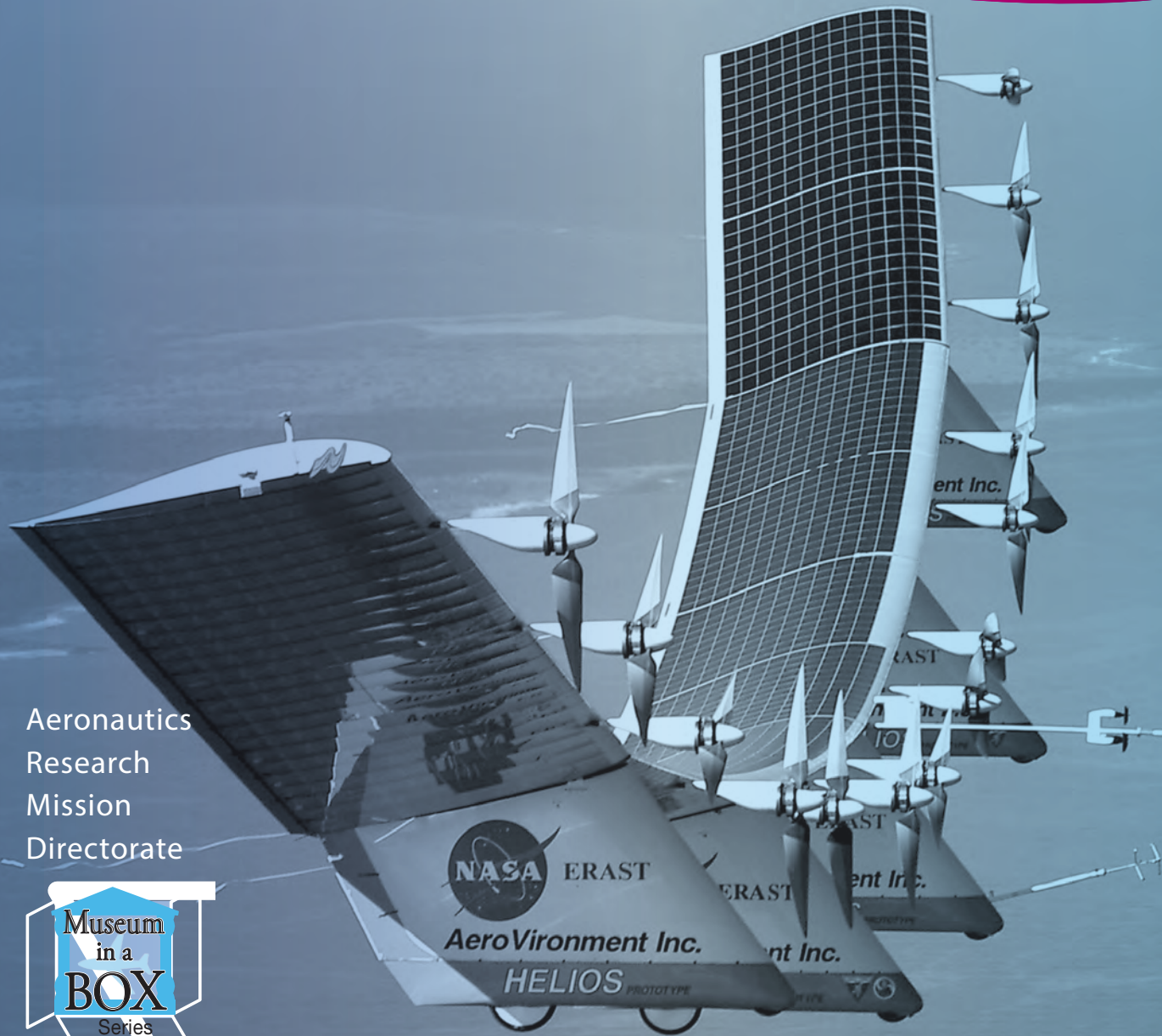
future flight



GRADES

5-12

Solar Power



future flight

Aeronautics
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(Photo courtesy of NASA - www.nasaimages.org)

Solar Power

Lesson Overview

By observing this demonstration, students will learn about energy and matter when light is converted into electricity using a solar panel. They will then see this electricity in use, powering a small car.

Objectives

Students will:

1. Convert solar energy (potential energy) into kinetic energy to power a small car.

Materials:

In the Box

Thames & Kosmos™ Fuel Cell Car & Experiment Kit
Phillips head screwdriver

Provided by User

Sunlight / lamp

GRADES **5-12**

Time Requirements: 30 minutes

Background

Solar Power

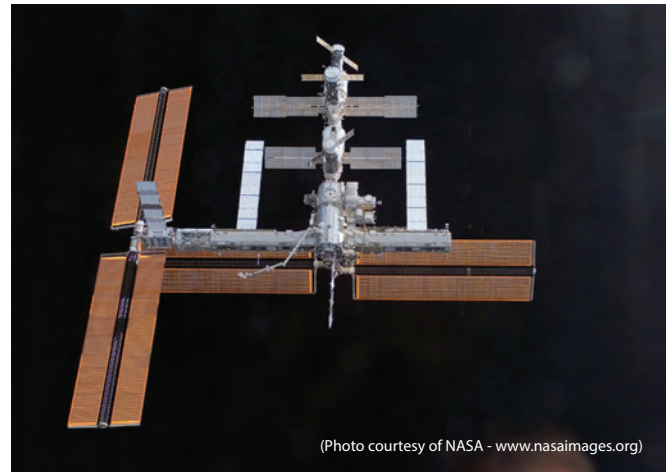
The ability to produce power without damaging the environment is a continuing challenge. Fossil fuels like gasoline, natural gas and coal, all come from non-renewable sources and when burned, increase the levels of air pollution and may harm the environment. Batteries, such as those found in flashlights and MP3 players, have limited lifetimes and often end up being disposed of in landfill. There are many environmentally friendly alternatives available today, such as wind power, geothermal and hydroelectric power, but in this lesson, we shall look at solar power.

The Sun emits a tremendous amount of energy every second of every day. The exact amount is unknown but scientists have estimated it to be 4×10^{26} , or

400,000,000,000,000,000,000,000,000 watts. Another way to quantify it is in comparison to a large power station. The sun emits as much energy in a second as 2 BILLION power stations would generate in an entire year!



Img. 2 The solar array of the Hubble telescope



Img. 1 The International Space Station

Now of course, only a very small fraction of the Sun's energy ever makes it to the Earth, but it's still an incredibly large amount. A lot of that energy is already used in the form of heat, or by plants needing the light for photosynthesis, converting carbon dioxide into sugars and eventually releasing breathable oxygen, but it still leaves a large portion un-used and ready for capture.

The photo-voltaic cell (or solar cell) is simply a thin slice of chemically treated material such as silicon or gallium arsenide. Sunlight is absorbed by the material which causes it to release electrons. These "free electrons" as they are known are present in any conductive material and are what allows an item to be conductive. The electrons "float" to the top of the cell and are collected on metal plates. Finally, by attaching wires to the top and bottom of these plates we can harness this electricity and put it to use.

A single solar cell isn't sufficient to provide much power, so they are typically joined together to create a solar panel. The panel in the kit, for example is comprised of 6 cells, each generating 0.5 volts, for a total of 3 volts.

For further information on the design, physics and operation of photo-voltaic cells, please refer to pages 32 – 48 in the Thames & Kosmos® Fuel Cell Lab Manual included in the Museum in a Box.

NASA's Solar Aircraft

NASA has developed four solar powered aircraft: the Pathfinder, Pathfinder Plus, Centurion and lastly, the Helios.

The Pathfinder (img. 3) is a lightweight, remotely piloted aircraft based on a flying wing design, meaning that it has no body or fuselage, just wings. Its purpose is to demonstrate solar power technology as used in long-duration, high-altitude flight. It is NASA's hope that this concept vehicle will lead to a fleet of solar-powered aircraft that could stay airborne for months at a time on scientific sampling and imaging missions.

Solar arrays cover most of the upper wing surface and provide power for the aircraft's electric motors, avionics, communications and other electronic systems. It also has a backup battery system that can provide power for up to five hours, which gives it a limited amount of flight time after dark.

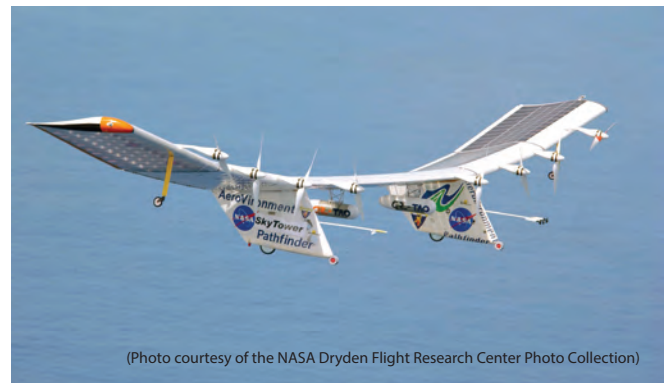
Pathfinder is slow in terms of modern aircraft, flying at an airspeed of only 15 to 25 mph. Pitch, or the up/down motion of the aircraft, is controlled by the use of tiny elevons on the rear, or trailing edge of the wing while turns are accomplished by slowing down or speeding up the motors on the outboard sections of the wing.

In 1997, the Pathfinder set an altitude record of 71,530 feet over Kauai, Hawaii.

The Pathfinder Plus (img. 4) and Centurion (img. 5) were based on the original Pathfinder but were designed to carry more weight or fly higher or longer. The Pathfinder Plus reached 80,201 feet while the Centurion was designed to fly up to 100,000 feet!



Img. 3 The Pathfinder over runway in Kauai, Hawaii



Img. 4 The Pathfinder Plus in flight



Img. 5 The Centurion during takeoff

The Helios (Img. 6) became NASA's fourth design after seeing the performance gains achieved in the Centurion. It has the largest wingspan of any of NASA's solar aircraft at 75 meters (247 feet), which provided more room for additional solar panels as well as space underneath for electronics.

On August 13th, 2001, the Helios reached an altitude of 96,863 feet, a world record for a winged aircraft. Not only did it break the previous record by 11,000 feet, it also spent more than 40 minutes at that altitude. In addition, it was the first to use a hydrogen fuel cell to provide additional electrical power to the motors.



(Photo courtesy of the NASA Dryden Flight Research Center Photo Collection)

Img. 6 The Helios Prototype in flight

Unfortunately in June of 2003 the Helios suffered a catastrophic failure over the Pacific Ocean about 10 miles west of Kauai, when excessive turbulence caused the aircraft to exceed its designed speed limits and literally break apart.

As NASA scientists and engineers work to improve solar power technology, the practical applications can help to develop a fleet of solar-powered, high altitude aircraft, improve the efficiency of solar-powered cars, and lead to new developments in solar-powered technologies.

Activity 1

Solar Powered Car Demonstration

GRADES 5-12**Time Requirements:** 30 minutes**Materials:**In the Box

Thames & Kosmos™ Fuel Cell Car & Experiment Kit
Philips head screwdriver

Provided by User

Sunlight / lamp

Worksheets

None

Reference Materials

None

Key Terms:

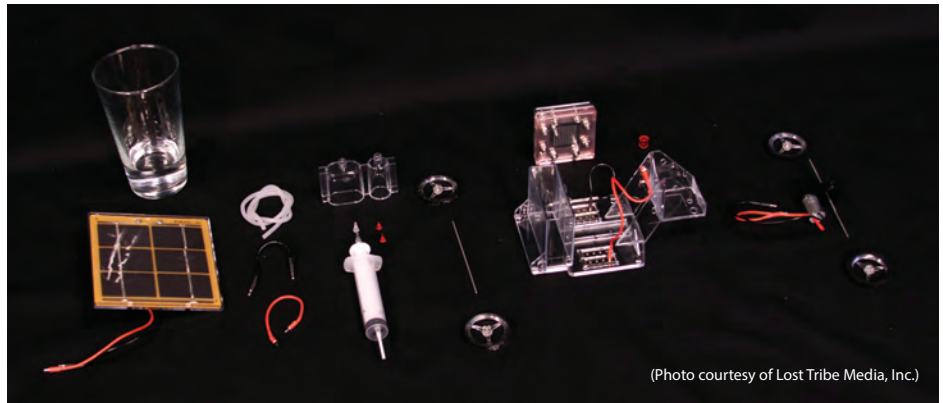
Gallium arsenide
Geothermal energy
Hydroelectric energy
Photo-voltaic cell
Photosynthesis
Silicon
Solar cell

Objective:

Students will convert solar energy (potential energy) into kinetic energy to power a small car.

Activity Overview:

By observing this demonstration, students will learn how light is converted into electricity using a solar panel. They will then see this electricity in use, powering a small car.

**Activity:**

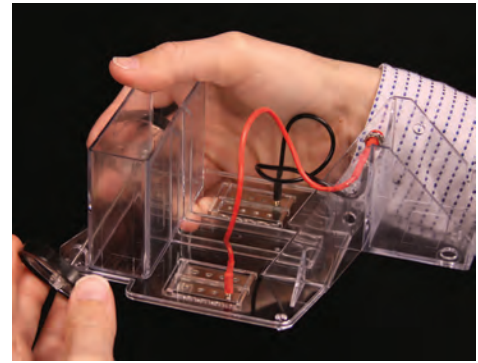
The kit may require time to build prior to the demonstration. It takes approximately 20 minutes to assemble the vehicle itself (if not previously used), with an additional 10 minutes required to complete the demonstration.

Caution: *The kit contains many small, easily breakable parts. It is important to exercise caution during both the setup and the demonstration.*

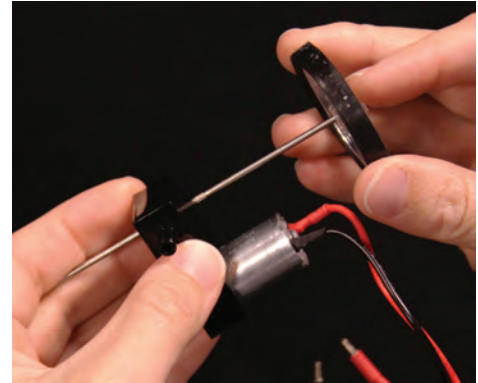
1. To begin, review the **Background** information with your students.

2. Next, assemble the car as follows:

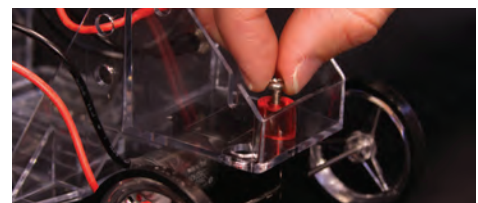
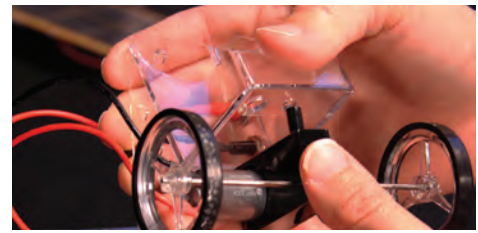
- a. Pass a metal axle through the holes in the rear of the body and attach a wheel to each end.



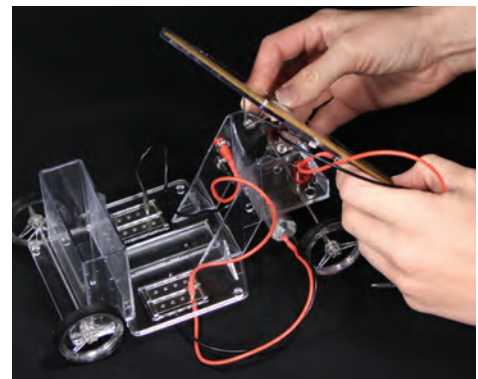
- b. Attach a wheel to each end of the axle on the motor assembly.



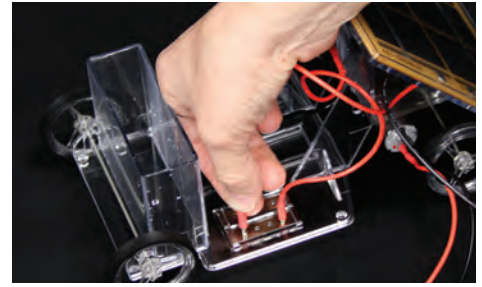
- c. Attach the motor assembly to the body of the car using the Phillips screw and spacer.



- d. Attach the solar cell to the car's body by inserting the plastic tabs into the holes in the front of the car.

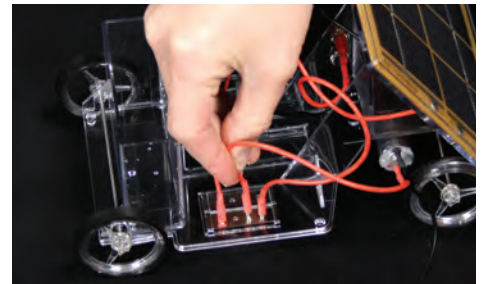


- e. Connect the wires of the solar cell to the car, ensuring that the red wire connects to the right side of the car and the black wire to the left side.



- f. Attach the wires from the motor to the plugs in the body. Connect the red wire to the right side of the car, the black wire to the left.

At this point there may already be sufficient light to power the motor. You may wish to raise the wheels of the car while connecting the motor.



- g. Take the car outside, or to a brightly lit area. Place the car on the ground and let it go!

Discussion Points:

1. **What just happened?**

The solar panel, or more accurately, the silicon in the photo-voltaic cell, absorbed the photons in the light. This allowed electrons already within the silicon to break free and move throughout the cell, creating electricity. This electricity was used to power the motor, whose energy was transferred to the wheels, causing the car to move.

2. **What is the difference between a solar cell and a solar panel?**

A solar cell is the smallest unit of a solar panel. A single cell cannot produce much electricity, but when combined in a large quantity (solar panel) it is quite effective. While we could use many individual solar cells to power the car, it is much quicker to connect a single panel.

3. **What is the difference between a solar cell and a photo-voltaic cell?**

A solar cell was designed specifically to work with sunlight, while a photo-voltaic cell can work with any form of light, including infra-red. In practical use however, a group of cells is nearly always referred to generically as a solar panel.

4. **How do living organisms currently use the Sun's energy?**

Answers will vary but may include (1) plants using sunlight for photosynthesis, (2) cold-blooded animals using the Sun's heat to warm their bodies, and (3) migrating animals or plants using diminishing light levels and dropping temperatures as a cue to begin their annual journey or to shed their leaves.

5. **Name some ways we can put the Sun's energy to use.**

Answers will vary but should include using sunlight to power electrical devices, heating water, powering cars, etc.

This demonstration is just one of many experiments that can be performed using this kit. The other activities available with this Solar Power kit are listed below. Detailed instructions can be found in the Thames & Kosmos® Fuel Cell Lab Manual.

1. **Page 17 / Experiment 2: The Brighter the Faster**
In this experiment, students will compare the performance of the solar panel in a variety of lighting conditions.
2. **Page 20 / Experiment 3: Measurement of Short Circuit Current and No-load Voltage**
This experiment expands on Experiment 2 above, quantifying the results using a multimeter.
3. **Page 24 / Experiment 4: Calibration of a Radiation Meter**
Students completing this experiment will calibrate their solar panel and graph the relationship between light input and voltage output.
4. **Page 26 / Experiment 5: Direct and Diffuse Radiation**
In this experiment, students will compare the effects of direct light with those of reflected and refracted light.
5. **Page 28 / Experiment 6: Daily Cycle of Solar Radiation**
Students will compare the power available from the Sun at various times of the day.
6. **Page 38 / Experiment 7: Characteristic Curve of a Solar Panel**
By adding varying amounts of resistance (or load) to a circuit, students will graph the performance of the solar panel.
7. **Page 47 / Experiment 8: Determining the Efficiency of a Solar Cell**
Students will evaluate the efficiency of a solar cell by comparing the amount of radiation entering the cell with the amount of electricity generated.

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Properties and changes of properties in matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
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PHYSICAL SCIENCE

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Reference Materials

Glossary

Flying wing:

A style of aircraft that is constructed of just a single large wing; it has no fuselage (body), or tail sections

Gallium arsenide:

A compound (mixture) of Gallium and Arsenic and was designed to have better electrical properties than Silicon; is also identified by the letters GaAs

Geothermal energy:

Thermal energy that was created when the planet was formed and stored within the Earth

Hydroelectric energy:

The generation of electricity using the kinetic energy of water

Photo-voltaic cell / Solar cell:

A solid-state electrical device designed to convert light energy into electricity

Photosynthesis:

From the Greek word meaning "putting together", is the process by which plant matter converts carbon dioxide into sugars, which are then ingested by the plant, releasing oxygen in the process

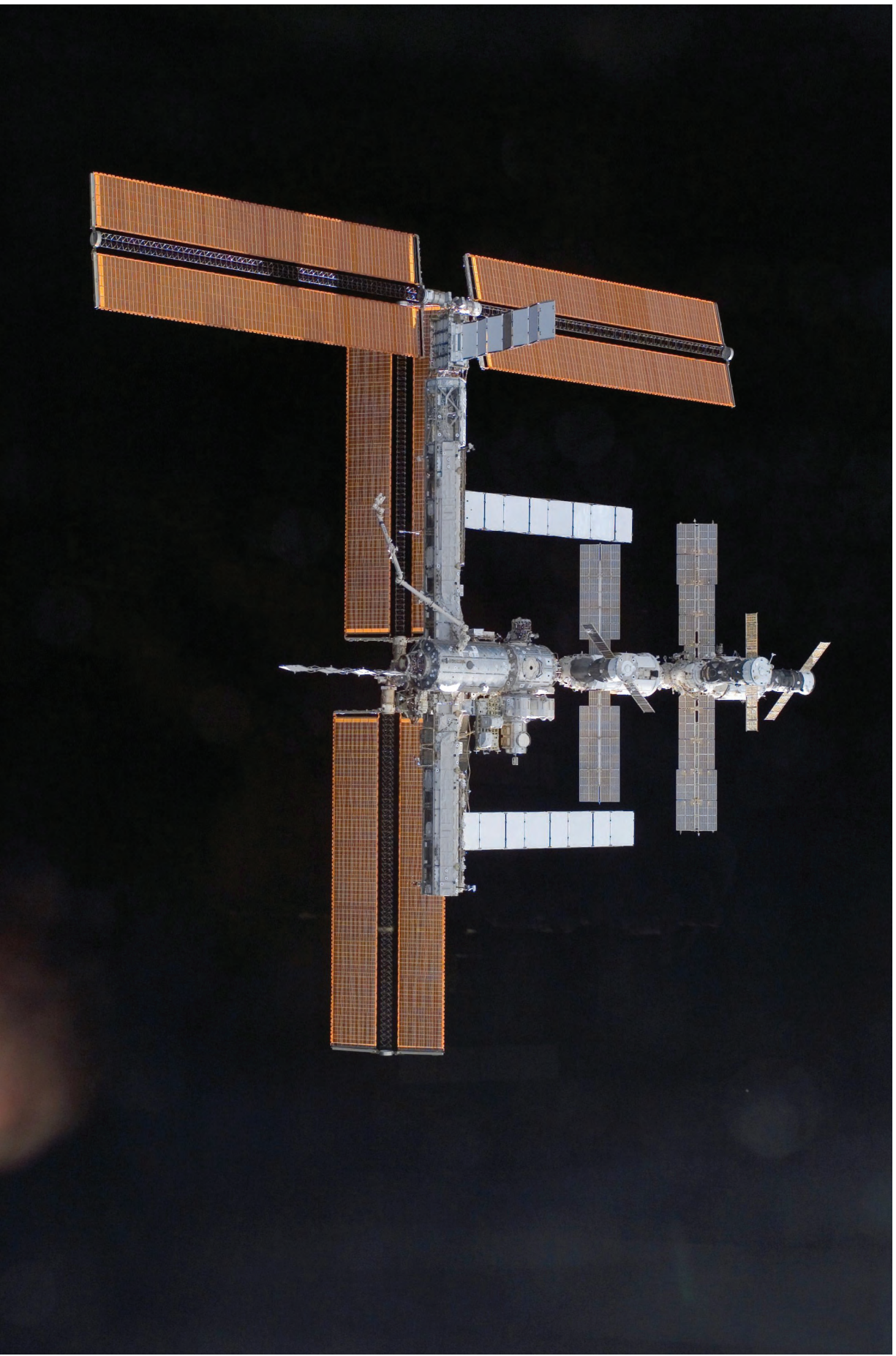
Silicon:

A chemical element with an atomic number of 14; is also identified by the letters Si



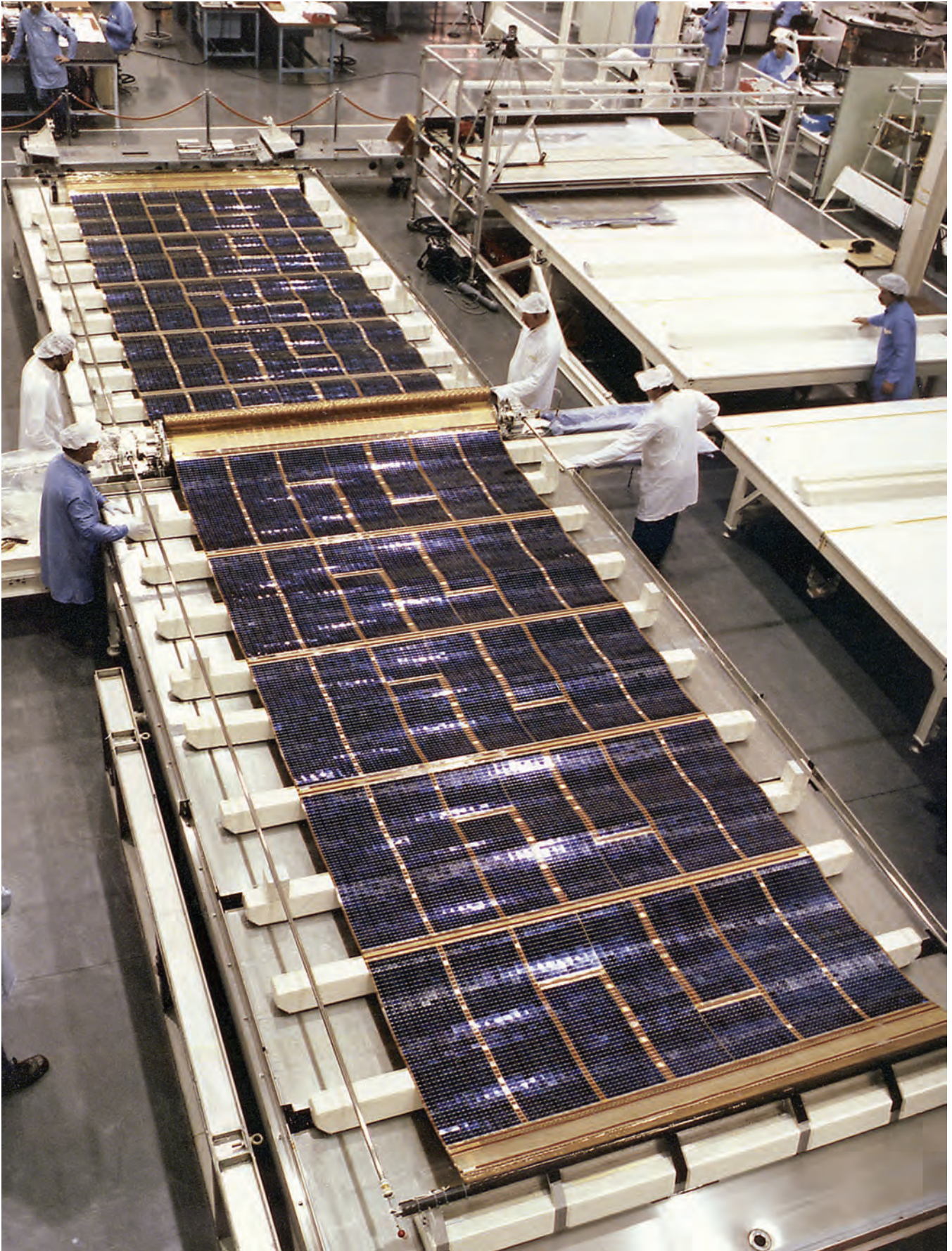
Images

Img. 1 The International Space Station



(Photo courtesy of NASA - www.nasaimages.org)

Img. 2 The solar array of the Hubble telescope



(Photo courtesy of NASA - www.nasaimages.org)

Img. 3 The Pathfinder ver runway in Kauai, Hawaii



(Photo courtesy of the NASA Dryden Flight Research Center Photo Collection)

Img. 4 The Pathfinder solar runway in Kauai, Hawaii



(Photo courtesy of the NASA Dryden Flight Research Center Photo Collection)

Img. 5 The Centurion during takeoff



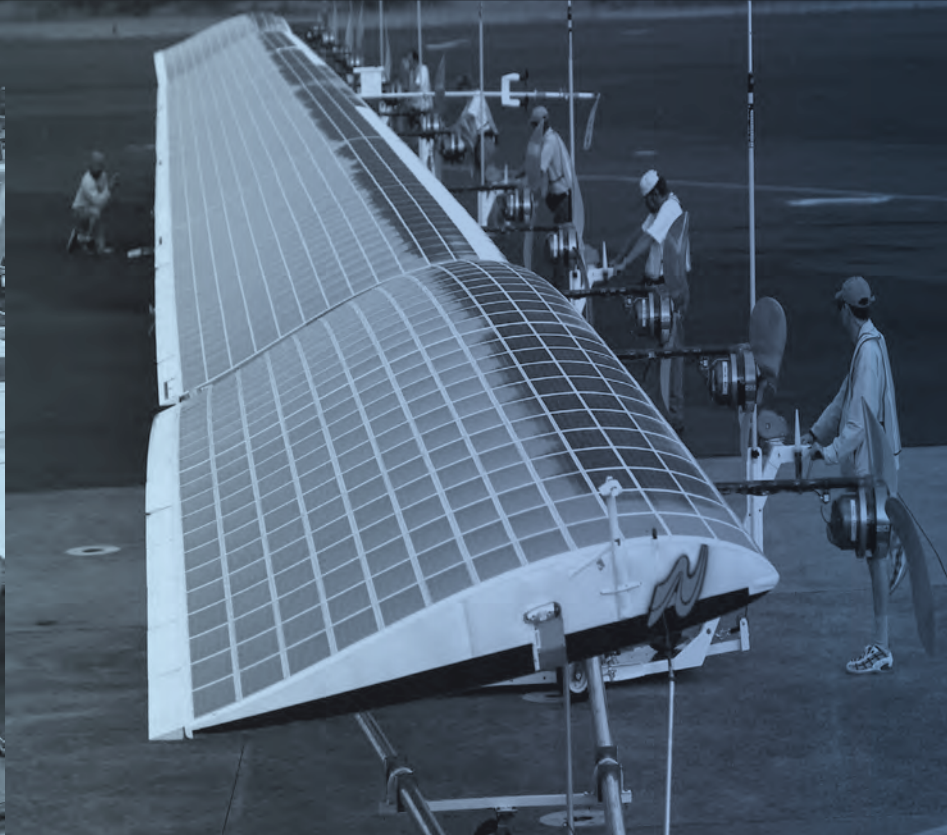
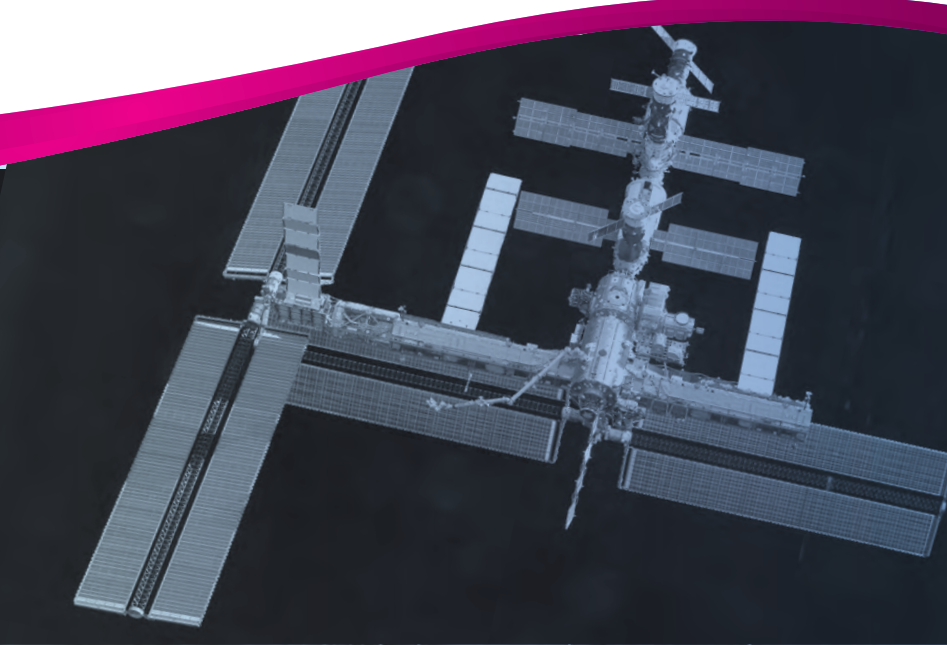
(Photo courtesy of the NASA Dryden Flight Research Center Photo Collection)

Img. 6 The Helios Prototype in flight

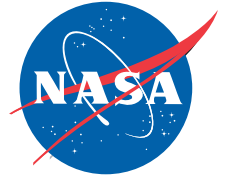


(Photo courtesy of the NASA Dryden Flight Research Center Photo Collection)

Aeronautics
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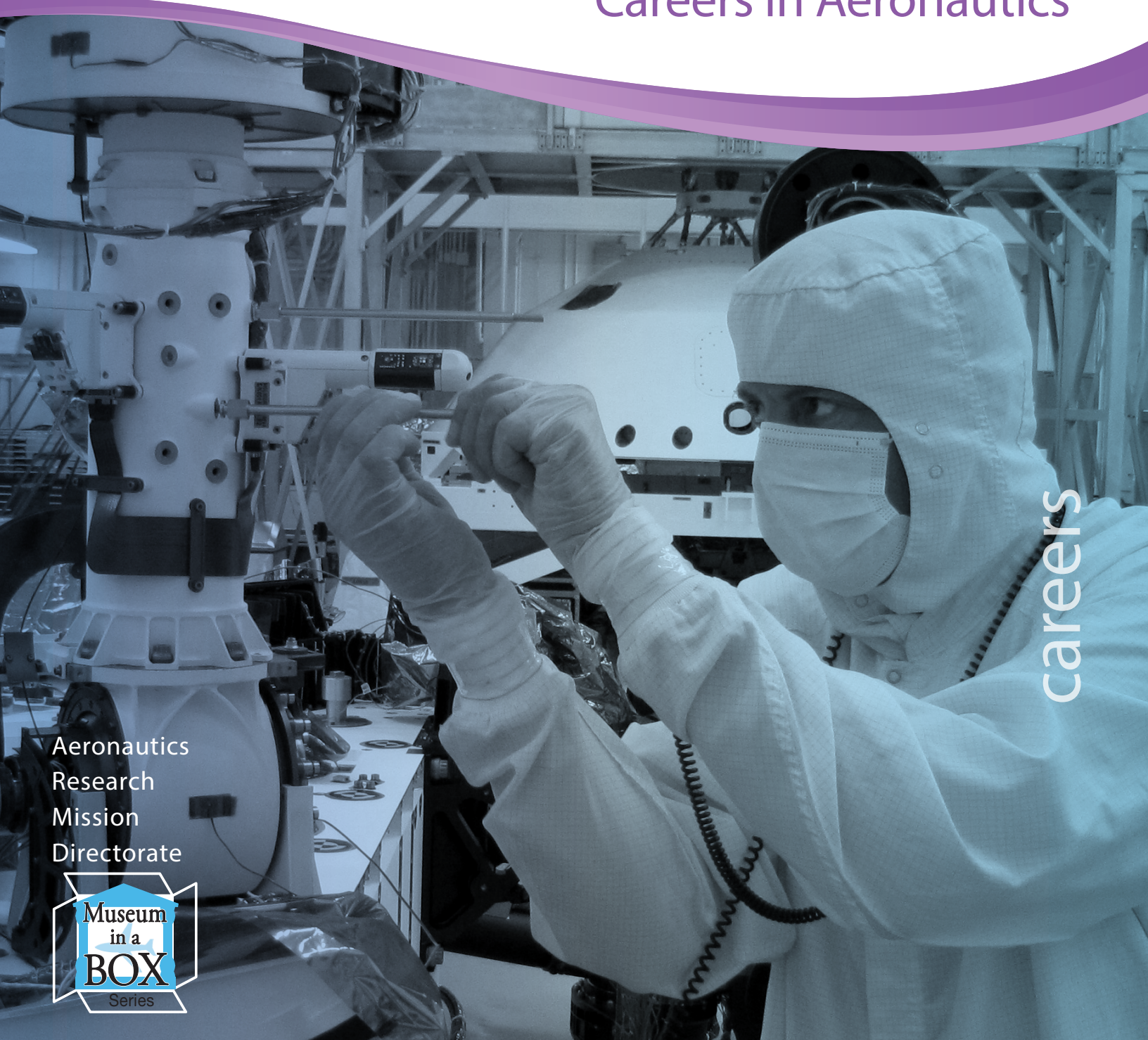
future flight



GRADES

5-12

Careers in Aeronautics



careers

Aeronautics
Research
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(Photo courtesy of NASA - www.nasaimages.org)

Careers in Aeronautics

Lesson Overview

This lesson is designed to increase a students' awareness of aeronautics-based career options by introducing them to several professions in this field. The students will explore their own strengths, weaknesses and interests and then determine what role may best suit them, should they decide to pursue a career in aviation.

Objectives

Students will:

1. Assess their talents and skills by performing a mock interview with a fellow class member.
2. Gain a better appreciation for the aeronautical career fields available to them.

GRADES

5-12

Time Requirements: 4 hours 40 Minutes

Background

Selecting a Career

As students explore career choices, they should be encouraged to complete high school with a well-rounded education that encompasses as many math and science-based courses as possible, in order to graduate with the most career path options. Students will also need to develop clear speaking and writing skills to be competitive in the work force. By strengthening these important work skills, students can go on to discover their interests in particular work tasks or professions uninhibited.

Deciding on an employment area, career or industry is a difficult task even for adults. Interest guide questionnaires, available at both school guidance offices and online, can be helpful in the career exploration process. These guides provide a series of questions that gauge the student's interest level for a particular task. Based on their responses, students are presented with the career areas that fit their interests, as well as the occupations associated with those career areas. This will help the students to find jobs and careers that are best suited to those preferences.



(Photo courtesy of the U.S. Department of Defense)



(Photo courtesy of NASA www.nasaimages.org)

Because keeping a flexible outlook is critical to one's survival in the workforce, most adults choose career paths that can adjust with the changing economy. The variety of different career paths that an individual can follow in the aeronautics field provides that flexibility.

Several careers in the field of aeronautics require high educational levels, such as a doctorate in engineering, physics, or another physical science. For these careers, students should anticipate a minimum of seven years of college, with two or three degrees earned on their path to success. Other aeronautics careers require specialized training and, while rare, sometimes even result in greater earnings than careers requiring a college degree. The choice between advanced college education and training depends on the student's interests and career goals.

Activity 1

Student Skills and Interest Matching

GRADES**5-12****Time Requirement:** 40 Minutes**Materials:**In the Box

None

Provided by User

None

WorksheetsSkills Assessment
(Worksheet 1)Reference Materials

None

Key Terms:

Aeronautics

Objective:

Students will assess their talents and skills by performing a mock interview with a fellow class member.

Activity Overview:

Students will conduct simulated job interviews to identify their strengths, weaknesses and interests, and then determine if there are any aeronautical careers that would be a good match for them.

**Activity:**

1. **As a group, ask students the following question: What is aeronautics?**
Through discussion, it should be ascertained that aeronautics is an all-encompassing term that describes the design and production, operation, support and servicing of all types of aircraft. It includes everything from the mechanic who repairs them, the pilots who fly them and the controller keeping them apart.
2. **Again as a group, ask the students to raise their hand in response to the following questions:**
How many of you are really good at:
 - a. Math?
 - b. Science?
 - c. Using a computer?
 - d. Building things?
 - e. History?

*Using the **Background** information as necessary, explain to the students that understanding their own personal strengths and weaknesses is vital in determining what career path they should follow.*

3. **Distribute one copy of the Skills Assessment Worksheet to each student.** Next, ask the students to sit with a partner or arrange them in pairs. While students will always partner based on familiarity, encourage them to partner with someone they do not know well. *As well as increasing productivity, pairing students with unfamiliar people will give them experience in talking to strangers about themselves; something they will experience in a real job interview.*
4. **Have the students write their name and the date at the top of the worksheet and then exchange them with their partners.**
5. **Using the questions on the worksheet, have the students take turns interviewing each other, writing the interviewee's answers on the worksheet.**
6. **When both students in the pair are finished, have them exchange papers and review the answers written.** This will ensure that not only did the interviewer correctly interpret the answers, but that the interviewee answered them clearly.
7. **Once the students have determined their interests and personal strengths are accurate, have them brainstorm to determine potential aeronautical careers that match.**
This can be done individually or in pairs.
8. **As a group, review and compare some of the students' answers and discuss which careers might be well-suited for various skillsets.**



NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Properties and changes of properties in matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 9-12

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Activity 2

Aeronautics Career Fair

GRADES**5-12****Time Requirement:** 4 hours**Materials:**In the Box

None

Provided by User

None

WorksheetsSkills Assessment
(Worksheet 1)Reference Materials

Educational Topics

Key Terms:

Aeronautics

Objective:

In this activity, students will gain a better understanding of the aeronautical careers available to them.

Activity Overview:

Students will explore several careers available to them using the research materials provided. If possible, students should also meet adults currently working in those careers to answer their questions. This will assist each student in selecting the most appropriate career to pursue

**Activity:**

Prior to beginning the lesson, print all of the Educational Topics in the Reference Materials section and display them as appropriate in the classroom.

1. **If the students haven't already done so, begin by performing [Activity 1 - Student Skills and Interest Matching](#).** This activity will assist the students in understanding their strengths and weaknesses.
2. **Hold up one of the Educational Topics and explain to the students how to correctly use the sheet.**
 - a. Start by looking at the "Interests / Abilities" column on the left and answering the questions it poses.
 - b. If the students answer Yes to those questions, move to the "Suggested School Subjects / Courses" column and ask yourself "Am I good at these classes?"

- c. If the students answer Yes to that question, read the rest of the sheet and determine if that job might be a good fit.
 - d. If the students answer No to any of the questions, that may indicate that this is not the best topic for their career.
3. **Optional: If possible, have adults who currently work in the aeronautics industry available to answer questions the students may have.** Students' parents, friends and other educators make great resources to help students set their career goals.
 4. **Optional: If available, have the students research their selected career further on the Internet.**
 5. **Finally, have the students record their chosen career path on their worksheet from [Activity 1](#) for future reference.**

NATIONAL SCIENCE STANDARDS 5-8

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Reference Materials

Glossary

Aeronautics:

From the Greek words meaning "Navigation of the Air", it is the term given to describe the science of flight. This includes the study, design and manufacture of any machine with flight capability, or anything associated to its flight.



Educational Topic

Aerospace Engineer

Related Job Titles:

Fluid Dynamicist, Mechanical Engineer

Job Description:

Aerospace engineers design, develop, test and oversee the building of aircraft, spacecraft, propulsion systems and space flight mission paths. When designing a new product, engineers first figure out what it needs to do. Then they design and test the parts, fit the parts together and test to see how successful it is. They also write reports on the product. Most engineers work in office buildings or laboratories. Some work outdoors at construction sites. Some must travel to different work sites.

Interests / Abilities:

- Are you good at math?
- Is your work detailed?
- Do you like to solve problems?
- Are you interested in how things work?
- Do you like working with computers?
- Do you like to take things apart and put them back together?

Suggested School Subjects / Courses:

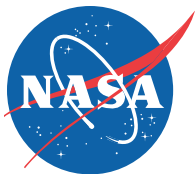
- Mathematics (trigonometry, calculus)
- Science (physics, chemistry)
- Computer programming
- Engineering (fluid dynamics, aerodynamics, thermodynamics, propulsion dynamics, mechanical)

Education / Training Needed:

The minimum education required for this position is a bachelor's degree in aerospace engineering or a related subject from an accredited college or university. To do research, a Ph.D. is highly desired for this position.

Areas of expertise:

- *Aerodynamics*: design aerospace craft with the best air flow
- *Structures*: design and build new constructions such as a space station
- *Propulsion*: design and develop systems that drive or propel an aerospace craft
- *Astroynamics*: design spacecraft that can move and function in a space environment



Educational Topic

Atmospheric Chemist

Related Job Titles:

Atmospheric Scientist, Environmental Scientist, Air Quality Analyst, Meteorologist, Atmospheric Physicist

Job Description:

Atmospheric chemistry is a multi-disciplinary field that is a sub-set in the broader field of atmospheric science. Atmospheric Chemists are interested in the chemical composition of the atmosphere and how the chemical constituents of the atmosphere interact with each other. Atmospheric Chemists make observations and collect data to understand how the atmosphere reacts and changes to sunlight and many parts of the Earth's surface including soils, vegetation, oceans, ice and snow. Some Atmospheric Chemists analyze the composition of our current atmosphere to compare with past data to understand the local, regional, and global impacts of our industrial practices. Atmospheric Chemists can also help gain an understanding of a distant planet's composition because they can analyze the chemistry of a planet's atmosphere remotely.

Interests / Abilities:

- Are you interested in the world around you and the processes that effect our planet?
- Can you perform calculations quickly with great accuracy?
- Are you patient when it comes to completing forms requiring detailed information?
- Do you like to solve logic puzzles?
- Are you a good problem solver?

Suggested School Subjects / Courses:

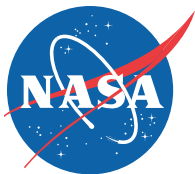
- Chemistry
- Math (algebra, trigonometry)
- Physics
- Meteorology
- Statistics
- Computer modeling
- Environmental studies
- Electronics

Education / Training Needed:

The minimum education required for this position is a bachelor's degree in Atmospheric Sciences or Chemistry from an accredited college or university. Experience in hands-on laboratory techniques is extremely helpful for this job. To do research, at minimum a master's degree is required, and a Ph.D. is highly desired for this position.

Areas of expertise:

- *Synoptic*: analyze data from satellites, radar, and surface-observing instruments
- *Research*: study atmospheric chemistry, refine theories and improve mathematical/computer models of atmospheric composition and its impacts on the planet
- *Environmental*: monitor pollution from traffic and industry and its effects on the planet



Educational Topic

Biologist

Related Job Titles:

Life Scientist, Medical Scientist, Biomedical Engineer, Biological Scientist, Psychologist

Job Description:

Biologists study living things and their relationship to their environment. Most biologists work in research and development. Some work on basic research to learn more about living things such as bacteria and viruses. Some work on applied research, which uses research to come up with new medicines, ways to make plants grow better or ways to protect the environment. At NASA, Biologists often research how space environments affect living things, how to support life in space and how life began and changed over time. Some Biologists spend time writing proposals to ask for funding for their research. They usually work regular hours in laboratories and use microscopes, computers and other equipment. Some use plants and animals for experiments. Many do research outside, and many work with a team.

Interests / Abilities:

- Do you enjoy science?
- Do you enjoy doing experiments?
- Are you interested in how animals and plants function?
- Do you work well on your own?
- Do you work well with a team?
- Do you enjoy solving mysteries or problems?

Suggested School Subjects / Courses:

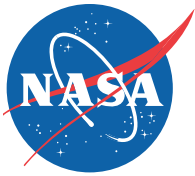
- Biology
- Chemistry
- Physics
- Biochemistry with laboratory research and fieldwork
- Math

Education / Training Needed:

The minimum education required for this position is a bachelor's degree in Biology or other appropriate field of Life Science from an accredited college or university. This course of study must include at least 20 semester hours of Physical Science, Engineering or experience that leads to the understanding of the equipment used for manned aerospace flights. To do research, a Ph.D. is highly desired for this position.

Areas of expertise:

- *Chemical and biological evolution*: study what life is, where it's located and how it began and changed over time
- *Life support*: research, develop and test life support equipment for aerospace flight
- *Microbiology*: study animals or plants so small, they can only be seen through a microscope
- *Biochemistry*: study the chemicals that living things are made of
- *Physiology*: study how plants and animals function including growth, reproduction, photosynthesis, respiration, movement and how these are affected by space environments
- *Neurobiology*: study the nervous system of living things and how it is affected by space environments



Educational Topic

Botanist

Related Job Titles:

Biologist, Life Scientist, Biochemist, Ecologist, Agricultural Scientist, Environmental Scientist, Paleontologist

Job Description:

Botanists study plants and their environment. Some study all aspects of plant life, others specialize in areas such as identification and classification of plants, the structure and function of plant parts, the biochemistry of plant processes, the causes and cures of plant diseases and the geological record of plants. Botanists work in a variety of environments both indoors and out. Good physical condition may be required to reach some remote areas where botanists collect plant samples to bring back to the laboratory for further testing. Others work solely in traditional, indoor environments such as laboratories, offices, museums, botanical gardens, or universities where they conduct research and a variety of experiments, write and publish papers, or teach. Many botanists strike a balance between indoor and outdoor environments.

Interests / Abilities:

- Do you like to examine things under a microscope?
- Are you good at observing and then reporting what you see?
- Do you like hiking or being out in nature?
- Can you clearly communicate your ideas to others?
- Are you good at organizing and classifying things?
- Are you curious about how living things function?

Suggested School Subjects / Courses:

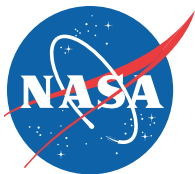
- Biology
- Chemistry
- Mathematics
- Environmental studies
- Laboratory research and fieldwork
- Writing and Speech

Education / Training Needed:

The minimum education required for this position is a bachelor's degree in Biology, Biochemistry, Agriculture, Horticulture or related field from an accredited college or university. A bachelor's degree in Botany will generally qualify you for a laboratory technician or technical assistant. A master's degree is required for applied research and managerial positions. A Ph.D. degree is usually necessary for independent research.

Areas of expertise:

- *Taxonomy*: identify and classify plants according to their presumed natural relationship
- *Agriculture*: manipulate genetics to breed crops or prevent disease
- *Pharmaceutical*: study of molecular structure and chemistry of plants and plant extracts to design new medicines
- *Paleobotany*: identify plant fossils or relics in rocks to help identify a geologic age or history of an area
- *Physiology*: study how plants function, including growth, reproduction, photosynthesis, respiration, and movement



Educational Topic

Chemical Engineer

Related Job Titles:

Organic Chemist, Polymer Chemist, Thermodynamicist, Fluid Dynamicist, Materials Engineer

Job Description:

Chemical Engineers use chemistry, engineering and physics to develop chemical products such as propulsion gases. When designing a new product, engineers first figure out what it needs to do. They then design and test the product. They also write reports on the product. Most Chemical Engineers work in office buildings or laboratories. Some must travel to different work sites.

Interests / Abilities:

- Are you good at math?
- Are you creative?
- Is your work detailed?
- Do you like to solve problems?
- Are you interested in how things work?
- Do you like working with computers?
- Are you good at working with a team?

Suggested School Subjects / Courses:

- Mathematics (algebra, geometry, trigonometry, pre-calculus, calculus)
- Science (physics, biology, chemistry)
- Engineering (thermodynamics, fluid mechanics)
- Computer programming
- English (writing)

Education / Training Needed:

The minimum education required for this position is a bachelor's degree in Chemical Engineering or a related subject from an accredited college or university. To do research, a Ph.D. is highly desired for this position.

Areas of expertise:

- *Manufacturing*: design and update machines such as airplanes, robots, cars, etc.
- *Fluids*: design and build fluid flow systems or processes such as pipes
- *Biomedical*: design and develop instruments, such as a heart pump, for medical use
- *Systems*: design and analyze mechanical or heating systems



Educational Topic

Computer Engineer

Related Job Titles:

Computer Hardware Engineer, Electronics Engineer, Computer Scientist

Job Description:

Computer Engineers design and develop computers or robots. When designing a new product, engineers first figure out what it needs to do. They then design and test the parts, fit the parts together, and test to see how successful it is. They also write reports on the product. Most engineers work in office buildings or laboratories. Some must travel to different work sites.

Interests / Abilities:

- Are you good at math?
- Are you creative?
- Is your work detailed?
- Do you like to solve problems?
- Are you interested in how things work?
- Do you like working with computers?
- Are you good at working with a team?

Suggested School Subjects / Courses:

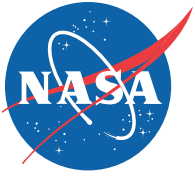
- Mathematics
- Science (physics)
- Engineering (computer electronics, electrical, mechanical, systems engineering)
- Computers programming
- Social studies (history)
- English (writing)

Education / Training Needed:

The minimum education required for this position is a bachelor's degree in Computer Engineering or a related subject from an accredited college or university. To do research, a Ph.D. is highly desired for this position.

Areas of expertise:

- *Computer hardware:* design and develop computer equipment
- *Robotics:* design and develop robots



Educational Topic

Computer Scientist

Related Job Titles:

Systems Analyst, Computer Engineer, Software Engineer, Software Developer, Database Administrator, Computer Support Specialist, Network Engineer, Hardware Engineer, Network Administrator, Systems Administrator, Database Specialist, Communications Specialist

Job Description:

Computer Scientists design and develop new computer hardware and software. They research and form new computer rules. They also invent new products such as robots that use virtual reality, new computer languages, programming tools or even computer games. They normally work in offices or laboratories and spend most of their time on the computer.

Interests / Abilities:

- Do you enjoy working with math and technology?
- Are you good at math?
- Are you good at reasoning and logic?
- Do you like to solve problems?
- Do you work well with a team?
- Do you pay close attention to details?
- Do you express yourself well when speaking to others?

Suggested School Subjects / Courses:

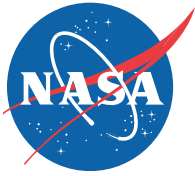
- Math
- Science (physics)
- Computer programming
- Electronics

Education / Training Needed:

The minimum education required for this position is a bachelor's degree in Computer Science, Computer Engineering, Electrical Engineering, Information Science, Computer Information Systems, Data Processing or a similar subject from an accredited college or university. This study must include 30 semester hours of Differential and Integral Calculus, Statistical Techniques and Computer Science Theory and Practical Applications. To do research, a Ph.D. is highly desired for this position.

Areas of expertise:

- *Computer engineering:* use math and science to design hardware, software, networks and processes to solve technical problems such as analyzing flight systems and aerospace data
- *Applications programming:* design and develop software that controls and automates processes such as flight software
- *Communications:* install, test and solve problems for hardware and software on a network
- *Systems analysis:* use computer technology to solve specific business, scientific or engineering problems
- *Database administration:* design, change, test and manage the security of computer databases
- *Computer Support:* assist and advise computer users with hardware, software and system problems



Educational Topic

Computer Specialist

Related Job Titles:

Systems Programmer, Applications Programmer, Computer Programmer, Systems Administrator

Job Description:

Computer Specialists write, test and manage computer programs (detailed instructions for computers). They break down each computer task into a series of steps the computer can follow. They then use a computer language to write these instructions. After writing the program, they test it to make sure the computer follows the steps correctly and they fix any problems they find. Computer programmers work in offices and spend most of their time on the computer.

Interests / Abilities:

- Do you enjoy working with math and technology?
- Are you good at reasoning and logic?
- Do you pay close attention to details?
- Do you keep working at a problem until you find a solution?
- Do you work well under pressure?
- Are you imaginative and creative?
- Do you express yourself well when speaking to others?

Suggested School Subjects / Courses:

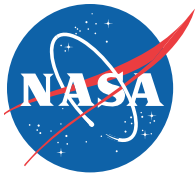
- Math
- Science (physics)
- Computer programming

Education / Training Needed:

The minimum education required for this position is a bachelor's degree in Computer Science, Information Science, Mathematics, Engineering, Physical Science or a similar subject from an accredited college or university. It is helpful to have experience with computers from internships or summer jobs. Since Computer Science changes quickly, all Computer Programmers must keep their skills up-to-date by seeking training throughout their career.

Areas of expertise:

- *Applications programming:* write software to handle specific jobs in an organization or business
- *Systems programming:* manage the use of computer systems software so that communication on a network works smoothly



Educational Topic

Electronics Engineer

Related Job Titles:

Electrical Engineer, Computer Engineer, Computer Scientist

Job Description:

Electronics Engineers design, develop, test and lead the production of electrical and electronic equipment including scientific instruments, motors, wiring in buildings, aircraft, radar, computers, robots and video equipment. Most Engineers work in office buildings or laboratories. Some work outdoors at construction sites. Some must travel to different work sites.

Interests / Abilities:

- Are you good at math?
- Is your work detailed?
- Do you like to solve problems?
- Are you interested in how things work?
- Do you like working with computers?
- Do you like to take things apart and put them back together?

Education / Training Needed:

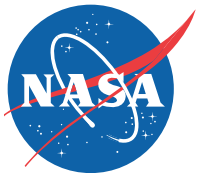
The minimum education required for this position is a bachelor's degree in Electrical or Electronics Engineering from an accredited college or university. To do research, a Ph.D. is highly desired for this position.

Suggested School Subjects / Courses:

- Mathematics (algebra, geometry, trigonometry, calculus)
- Science (physics, biology, chemistry)
- Computers
- Engineering (thermodynamics, fluid dynamics, mechanical, electronics)

Areas of expertise:

- *Sensors and transducers:* research and develop sensing devices such as lasers that are needed in aerospace research
- *Electronic instrumentation:* research and develop equipment that can detect, record and measure data for aerospace research
- *Guidance and navigation systems:* research and develop systems used to guide and navigate aerospace vehicles and spacecraft
- *Electromagnetic systems:* research and develop instruments, such as antenna systems, that measure electromagnetics
- *Tracking and telemetry systems:* research and develop systems and devices that track the flight of aerospace vehicles or that transmit and receive data and commands between space vehicles and the ground
- *Computer design:* design and develop computers or robots



Educational Topic

Engineer

Related Job Titles:

Electrical Engineer, Electronics Engineer, Mechanical Engineer, Aerospace Engineer, Chemical Engineer, Materials Engineer, Computer Engineer

Job Description:

Engineers design, develop and test products, machinery, factories and systems such as buildings, robots, instruments, spacecraft, airplanes, motors and other equipment. When designing a new product, Engineers first figure out what it needs to do. They then design and test the parts, fit the parts together and test to see how successful it is. They also write reports on the product. Most Engineers work in office buildings or laboratories. Some work outdoors at construction sites. Some must travel to different work sites.

Interests / Abilities:

- Are you good at math?
- Is your work detailed?
- Do you like to solve problems?
- Are you interested in how things work?
- Do you like working with computers?
- Do you like to take things apart and put them back together?

Suggested School Subjects / Courses:

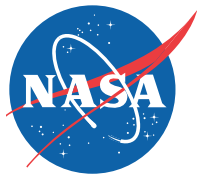
- Mathematics (algebra, geometry, trigonometry, calculus)
- Science (physics, biology, chemistry,)
- English (writing)
- Social studies (history)
- Computer programming
- Engineering

Education / Training Needed:

The minimum education required for this position is a bachelor's degree in Engineering from an accredited college or university. Engineering degrees are generally offered in Electrical, Mechanical, Aerospace or Civil Engineering. To do research, a Ph.D. is highly desired for this position.

Areas of expertise:

- *Electronics:* design and lead the production of electrical and electronic equipment such as motors, wiring, aircraft, radar and computers
- *Aerospace:* design, test and lead the building of missile, spacecraft and aircraft
- *Chemistry:* use chemistry and engineering to solve problems in producing or using chemicals and to design equipment for producing chemicals
- *Mechanics:* plan and design tools, engines, machines and other equipment such as jet and rocket engines and robots
- *Computers:* design and develop computers or robots
- *Materials:* develop and test new types of materials for aerospace systems and vehicles



Educational Topic

Engineering Technician

Related Job Titles:

Physical Science Technician, Data Technician, Engineering Aid, Aerospace Engineering Technician, Architecture Technician, Biomedical Technician, Chemical Engineering Technician, Civil Engineering Technician, Electrical Engineering Technician, Materials Engineering Technician

Job Description:

Engineering Technicians use science, math and engineering to solve technical problems. Most assist engineers and scientists by setting up or installing equipment, testing, maintaining and repairing equipment, conducting experiments, recording results, writing design plans and running tests. Engineering Technicians also gather data from various sources such as field notes, design books and lab reports. They look at the data and report any errors or data that do not fit with the rest. Engineering Technicians usually work in a laboratory, office or construction site. They spend a lot of time on the computer recording data, writing reports and writing design plans.

Interests / Abilities:

- Do you enjoy math and science?
- Are you good at math?
- Do you like to solve problems?
- Are you interested in how things work?
- Do you like working with computers?
- Are you good at working with a team?
- Do you express yourself well when writing?

Suggested School Subjects / Courses:

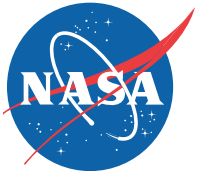
- Mathematics (algebra, trigonometry)
- Science
- Computers
- Technical drawing/drafting

Education / Training Needed:

At least two years of specialized training in Computer Hardware or Engineering Technology is required. This training may be earned at an institute, vocational school, community or junior college, or from work experience. It is helpful to have some experience from internships or summer jobs in laboratories.

Areas of expertise:

- *Electronics*: help design and lead the production of electrical and electronic equipment such as radar, sonar, navigation equipment and other instruments
- *Engineering drafting*: use graphics to show designs of products before they are built
- *Construction*: oversee the construction or repair of structures or facilities
- *Cartography*: create and edit maps and charts
- *Equipment*: test and maintain equipment



Educational Topic

Executive Manager

Related Job Titles:

Director, Administrator, Deputy, Chief

Job Description:

Executive Managers are the top leaders of a business or organization. At NASA, an Executive Manager is the leader of a NASA center or a program office who sets the center or program goals and makes an action plan to lead activities, research, programs and missions. Most work long hours and are required to travel often to other NASA centers and conferences. They may speak or appear at public events.

Interests / Abilities:

- Are you confident?
- Are you good at making decisions?
- Do you have a lot of energy?
- Are you good at leading and persuading people?
- Do you express yourself clearly when speaking?
- Do you work well under pressure?
- Do you work at your goals until you succeed?
- Are you good at solving conflicts in a positive way?

Suggested School Subjects / Courses:

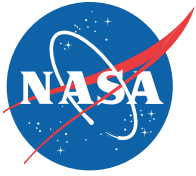
- Science
- Engineering
- Management
- Public speaking

Education / Training Needed:

The minimum education required for this position is a bachelor's degree from an accredited college or university. The qualifications sought in an Executive Manager include leadership skills in leading change, leading people, producing results, managing resources, communicating and building cooperation with others. Most Managers begin as a scientist or engineer and are promoted to a management position because of their leadership skills and their broad understanding of science.

Areas of expertise:

- *Center direction:* lead one of NASA's twelve centers.
- *Program office direction:* lead a large program such as Space Science.



Educational Topic

Human Factors Researcher

Related Job Titles:

Research Psychologist, Research Associate, Human Performance Researcher, Human Physiology Researcher

Job Description:

This type of work within aviation ranges from studying pilots in the cockpit as they relate to the cockpit controls all the way to studying sleep physiology in order to improve safety for pilots during flight operations of long duration. A Human Factors Researcher uses the scientific method to develop a hypothesis and set up an experiment to test the theory. After lengthy and repeated trials, the results would be presented and enacted in a trial of the new methodology being suggested by the study. The researcher would have to be able to develop and perform scientifically-based experiments and document the results. Such studies might occur over a long period of time, other studies might cover a few weeks or days with others lasting no more than an hour. The researcher must be a keen observer with excellent note taking skills as well as fine writing skills with which to develop detailed reports.

Interests / Abilities:

- Do you like to take things apart and see how they work?
- Are you fascinated with the human body and how it works? Would you be interested to see how it operates especially in extreme or unusual situations?
- Would finding a better way to make a machine or assembly line work more efficiently be a fun challenge?
- Do you enjoy studying people and how they interact with machines?

Education / Training Needed:

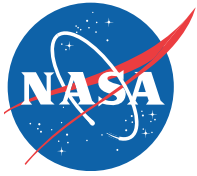
To perform the lab work would require a bachelor's degree from an accredited college or university in the field(s) of Biology, Psychology or Physiology. To oversee some research projects would require a master's degree in a complimentary subject. To manage a research program would require a Ph. D. Depending upon what specialty you go into, a license might be required which would mean you have to take a licensing exam.

Suggested School Subjects / Courses:

- Mathematics: Algebra and Statistics
- Psychology
- Sociology (the study of human relationships)
- Physiology (the study of body systems and their interactions)
- Kinesiology (the study of human movement and mechanics)
- Biology

Areas of expertise:

- *Behavioral Sciences, Psychology, Clinical Psychology, Physiological Psychology*
- *Biology, Biophysics, Physiology, Kinesiology*
- *Human/system integration technology*



Educational Topic

Materials Engineer

Related Job Titles:

Metallurgical Engineer, Ceramics Engineer

Job Description:

A Materials Engineer develops and tests new types of metallic and non-metallic materials (ceramics, plastics, and composites) for use in aerospace systems and vehicles. When making a new material, Materials Engineers select materials with the structure and features needed for a given purpose. For example, they might develop lightweight, strong, heat-resistant materials for use in space. Most Materials Engineers work in laboratories. Some must travel to different work sites.

Interests / Abilities:

- Are you good at math?
- Are you creative?
- Is your work detailed?
- Do you like to solve problems?
- Are you interested in how things work?
- Do you like working with computers?
- Are you good at working with a team?
- Do you express yourself well when speaking and writing?

Suggested School Subjects / Courses:

- Mathematics
- Physics
- Chemistry
- Engineering (materials)

Education / Training Needed:

The minimum education required for this position is a bachelor's degree in Materials Engineering or a related subject from an accredited college or university. To do research, a Ph.D. is highly desired for this position.

Areas of expertise:

- *Ceramics*: develop new ceramic materials
- *Metallurgy*: study and develop new metals by combining different metals



Educational Topic

Mathematician

Related Job Titles:

Computer Scientist, Computer Programmer

Job Description:

There are two types of Mathematicians: theoretical and applied. Theoretical Mathematicians come up with new mathematical rules and processes using the latest technology. Applied Mathematicians use math rules and processes to solve scientific, engineering and business problems. These problems might include studying and designing computer models that help to create faster and higher aerospace vehicles and systems. Mathematicians usually work in an office and spend a lot of time on the computer.

Interests / Abilities:

- Do you enjoy working with math and technology?
- Are you good at math?
- Are you good at reasoning and logic?
- Do you like to solve problems?
- Do you work well with a team?
- Do you keep working at a problem until you find a solution?

Suggested School Subjects / Courses:

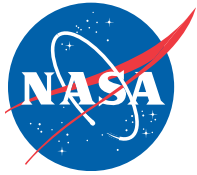
- Math (algebra, geometry, statistics, calculus)
- Computer science (programming)
- Engineering
- Science

Education / Training Needed:

The minimum education required for this position is a bachelor's degree in Mathematics from an accredited college or university. To do research, a Ph.D. is highly desired for this position.

Areas of expertise:

- *Modeling*: make simulations to study and improve aerospace craft and systems
- *Data analysis*: study aerospace problems and come up with the quickest, easiest method of modeling and solving them
- *Statistician*: design experiments, gather data, decide what the data means, and make predictions



Educational Topic

Mechanical Engineer

Related Job Titles:

Mechanical systems engineer, aerospace engineer, materials engineer

Job Description:

Mechanical **engineers** plan and design engines, machines and other equipment. When designing a new product, **engineers** first figure out what it needs to do. They then design and test the parts, fit the parts together and test to see how successful it is. They also write reports on the product. Most **engineers** work in office buildings or laboratories. Some work outdoors at construction sites. Some must travel to different work sites.

Interests / Abilities:

- Are you good at math?
- Are you creative?
- Is your work detailed?
- Do you like to solve problems?
- Are you interested in how things work?
- Do you like working with computers?
- Are you good at working with a team?

Suggested School Subjects / Courses:

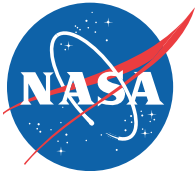
- Mathematics (algebra, geometry, trigonometry, pre-calculus, calculus)
- Science (physics, biology, chemistry)
- Engineering (thermodynamics, fluid mechanics)
- Computer programming
- Social studies (history)
- English (writing)

Education / Training Needed:

The minimum education required for this position is a **bachelor's degree in mechanical engineering** from an accredited **college** or **university**. To do research, a **Ph.D.** is highly desired for this position.

Areas of expertise:

- *Manufacturing*: design and update machines such as airplanes, robots, cars, etc.
- *Fluids*: design and build fluid flow systems or processes such as pipes
- *Biomedical*: design and develop instruments such as a heart pump for medical use
- *Systems*: design and analyze mechanical or **thermal** systems



Educational Topic

Microbiologist

Related Job Titles:

Biologist, Life Scientist, Medical Scientist, Molecular Biologist, Biochemist, Physiologist, Ecologist

Job Description:

Microbiologists study living things that are too small to be seen without a microscope, such as bacteria, algae or fungi. They are interested in the effects micro-organisms have on plants, animals and humans (for example, how micro-organisms assist in the breakdown and decomposition of living things). Microbiologists are also interested in the uses micro-organisms may have in the environment and people's daily lives, such as cures for human diseases. Microbiologists often work in traditional environments such as laboratories, offices, work stations or universities where they conduct research and a variety of experiments, write and publish papers, or teach.

Interests / Abilities:

- Do you like to examine things under a microscope?
- Are you good at observing and then reporting what you see?
- Can you clearly communicate your ideas to others?
- Do you like to help other people?
- Are you interested in what causes diseases and how they are spread?

Suggested School Subjects / Courses:

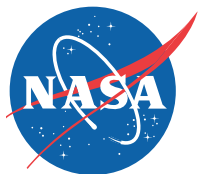
- Biology
- Chemistry
- Mathematics (algebra, trigonometry and calculus)
- Laboratory research and fieldwork
- Writing and speech

Education / Training Needed:

The minimum education required for this position is a bachelor's degree in Biology, Microbiology, or related field from an accredited college or university. This level generally does not involve research and generally involves assisting others in testing and observation. A master's degree is required for applied research and managerial positions. A Ph.D. degree is usually necessary for independent research.

Areas of expertise:

- *Bacteria*: study of bacteria and their relations to medicine, industry and agriculture
- *Mycology*: a branch of biology dealing with fungi
- *Viral*: a branch of science that deals with viruses
- *Food/Industrial*: micro-organisms to be used in yogurt, cheese, etc.
- *Environmental*: identify micro-organisms that may pollute food, water and the environment
- *Medical*: identify micro-organisms that can be used in medicines or help identify or treat disease



Educational Topic

Molecular Biologist

Related Job Titles:

Biologist, Life Scientist, Medical Scientist, Geneticist, Biochemist, Physiologist

Job Description:

Molecular Biologists study how genes in cells cause biological characteristics and function in organisms. They study the detailed genetic make-up of plants, animals, humans, bacteria, and fungi. They study nucleic acids (DNA and RNA) for medical testing for disease-causing organisms and to test for inherited human genetic disorders. Molecular biologists are also important in industry for developing new lines of plants, animals and micro-organisms, or aid in the development of new medicines. Molecular biologists often work long hours in traditional environments such as laboratories, offices, or universities where they conduct research and a variety of experiments, write and publish papers, or teach.

Interests / Abilities:

- Do you like to examine things under a microscope?
- Are you good at observing and then reporting what you see?
- Can you clearly communicate your ideas to others?
- Do you like to help other people?
- Do you pay attention to details and enjoy working accurately?
- Are you able to concentrate or work continuously for many hours?

Suggested School Subjects / Courses:

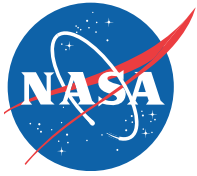
- Biology (biochemistry, genetics, microbiology, immunology)
- Chemistry (organic, physical, inorganic)
- Mathematics
- Laboratory research and fieldwork
- Writing and speech

Education / Training Needed:

The minimum education required for this position is a bachelor's degree in Biology, Microbiology, Biochemistry, or related field from an accredited college or university. This level general does not involve research and generally involves assisting others in testing and observation. A master's degree is required for applied research and managerial positions. A Ph.D. degree is usually necessary for independent research and several years of research and post-doctoral work are generally required.

Areas of expertise:

- *Genetics*: understand the inheritance of genetic diseases and provide counseling to families
- *Criminology*: provide law enforcement with evidence (such as DNA) to help solve crimes
- *Agriculture*: manipulate genetic makeup to breed new crop plants or livestock
- *Pharmaceutical*: study of molecular structure to design new medicines



Educational Topic

Physical Science Technician

Related Job Titles:

Biological Technician, Chemical Technician, Environmental Technician, Engineering Technician

Job Description:

Physical Science Technicians help scientists and engineers with their products and experiments. They set up and run laboratory instruments. When there are problems with the instruments, Physical Science Technicians fix them. They also check and track experiments, make observations of the experiments, record results, and often make conclusions. Physical Science Technicians gather data from various sources such as field notes, design books, and lab reports. They look at the data and report any errors or data that don't fit with the rest. Physical Science Technicians usually work regular hours and, depending on their area of study, may work in a laboratory or outdoors. They spend a lot of time on the computer.

Interests / Abilities:

- Are you good at solving problems?
- Do you like to use computers?
- Do you express yourself well when you speak and write?
- Do you work well with others?
- Do you like to do science experiments?

Suggested School Subjects / Courses:

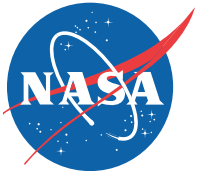
- Science (with laboratory activities)
- Math
- Computers

Education / Training Needed:

At least two years of specialized training in science or science-related technology is required to be a technician. This training may be earned at a technical institute, vocational school, from a community college or junior college, or from work experience. It is helpful to have some experience from internships or summer jobs in laboratories.

Areas of expertise:

- *Biology*: assist scientists in studying living things, such as viruses, microbes, and DNA
- *Chemistry*: assist scientists to develop, use, and study chemicals
- *Engineering*: assist scientists and engineers with instruments



Educational Topic

Project Manager

Related Job Titles:

Project Lead, Technical Lead, Principal Investigator

Job Description:

Project Managers plan, organize, and lead research, development, design, and computer activities. Project Managers lead other people by dividing tasks, making a schedule, reviewing, and assessing their work. They come up with a detailed plan of how to reach the goals of a project and estimate the cost of the project. They present ideas and projects to top management for approval or for funding. Project Managers spend most of their time in an office and in meetings. Sometimes they have pressure to meet deadlines.

Interests / Abilities:

- Do you manage your time well?
- Are you good at making decisions?
- Are you organized?
- Are you good at leading and persuading people?
- Do you get along well with others?
- Do you express yourself clearly when speaking?
- Are you good at inspiring or motivating others?

Suggested School Subjects / Courses:

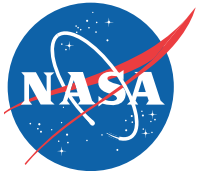
- Science, engineering or computer science
- Math
- Speech
- Leadership

Education / Training Needed:

To be a Program Manager, experience as an Engineer, Mathematician, Scientist, or Computer Professional is essential to understand and guide the type of work managed. The minimum education required for this position is a bachelor's degree from an accredited college or university. A Program Manager must know NASA's methods and rules of managing projects and gathering resources. Project Managers must also be able to organize many activities happening at one time. Most managers begin as a Scientist or Engineer and are promoted because of their management skills.

Areas of expertise:

- *Engineering*: lead people who design and develop equipment, products, and processes
- *Science*: lead research and development activities in chemistry, biology, geology, meteorology, or physics
- *Computer systems*: lead and plan programming and projects that use computers and coordinate development of computer equipment and software



Educational Topic

Psychologist

Related Job Titles:

Cognitive Psychologist, Research Psychologist

Job Description:

Psychologists study the human mind and behavior. They make predictions and collect data to test their predictions through lab experiments, tests, observations, interviews, or questionnaires. They may work at a counseling center, their own office, a hospital, a clinic, university, research center, business, non-profit or government organization. NASA Psychologists are usually Research Psychologists who do research and come up with explanations for how people behave or function in aerospace environments. These studies may include how well humans can use their senses and make decisions, how the environment affects a human's ability to think and work, and how well crew members work together and get along in aerospace conditions. Some travel is usually required to attend conferences or conduct research.

Interests / Abilities:

- Are you a good listener?
- Do you enjoy doing research?
- Do you pay close attention to details?
- Do you work well on your own?
- Do you work well with a team?
- Do you express yourself clearly when speaking and writing?

Suggested School Subjects / Courses:

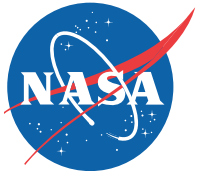
- Science (biology, psychology)
- Math (statistics)
- Research methods

Education / Training Needed:

The minimum education required for this position is a bachelor's degree in Behavioral Science or other appropriate subject from an accredited college or university. This course of study must include at least 20 semester hours of Physiology, Experimental Physiological Psychology or other appropriate life science or experience in biotechnology, hardware or other appropriate life science field. To do research, a Ph.D. is highly desired for this position.

Areas of expertise:

- *Human performance studies:* study how humans behave and function, how the crew works together, and how the senses work in aerospace environments
- *Manned systems:* design guidelines for hardware and software to best meet human needs in aerospace environments



Educational Topic

Software Engineer

Related Job Titles:

Computer Programmer, Computer Scientist, Systems Analyst, Programmer/Analyst, Quality Assurance Engineer, Technical Writer, Web Designer, Database Administrator

Job Description:

A software engineer writes the software that is used in automated systems. Automated systems help people do their jobs by providing them with information, giving them advice, performing repetitive tasks or in some cases, by controlling actual systems. The computer software contains the instructions that tell the system what to do. The first job of a Software Engineer is to understand the tasks that are going to be automated. Then, a Systems Analyst will decide how the automation system can assist or enhance the performing of those tasks. After that the Software Engineer, usually working in a team, will create programs to perform the functions desired by the users of the system. The Software Engineer will test the system to make sure it works the way it is supposed to work.

Interests / Abilities:

- Do you like logic puzzles and games?
- Can you patiently sit for hours while trying to figure something out?
- Do you enjoy working on a team?
- Is it easy for you to identify the steps it will take to do or make something?
- Do you enjoy building things and seeing them operate?
- Do you think it's fun to "play with numbers" while solving complicated equations?

Suggested School Subjects / Courses:

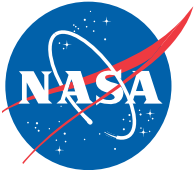
- Math
- Science
- Statistics
- English
- Computer Programming
- Electronics

Education / Training Needed:

For most programming jobs, a bachelor of arts or science degree is sufficient if in a technical field. For other jobs, a Masters or Doctorate in Computer Science or Electrical Engineering may be required. Some companies will hire people with little education or experience and train them in computer programming. Often times, the ability to learn and to think logically and creatively is more important than formal education or training. The abilities to communicate ideas and to understand others are also important when working as a member of a team, so English and public speaking are valuable skills.

Areas of expertise:

- *Computer programming languages*
- *Operating systems*
- *Application programming*
- *Distributed computing*
- *Networking*
- *Databases*
- *Graphical user interfaces*
- *Statistics*
- *Numerical computing*
- *Real-time computing*



Educational Topic

Weather Station Manager

Related Job Titles:

Meteorologist, Weather Officer, Weather Forecaster, Meteorology Researcher, Meteorological Modeling Specialist

Job Description:

As a manager, the primary work deals with supervising the employees (other meteorologists) working in your area. This means dealing with people-related issues and performance evaluation. The meteorologists collect weather data, survey weather indicators and make predictions regarding developing weather patterns. They advise air traffic controllers on weather hazards such as thunderstorms, developing storm cells and fronts, turbulence, icing and other such weather-related phenomena. They issue to controllers weather advisories for aircraft. They use sophisticated computer software programs that assist them in modeling the potential flow and intensity of storm cells and fronts. They are also available to participate in weather-related research projects that seek to improve air traffic management in adverse weather conditions.

Interests / Abilities:

- Do watching weather reports on television interest you?
- Do you notice the slightest change in the sky, the air temperature and the wind?
- Do you enjoy motivating people to work as a team?
- Do you like to motivate people toward self-improvement?
- When you take measurements, are you precise and double check your readings for accuracy?

Suggested School Subjects / Courses:

- Algebra
- Trigonometry
- Physics
- Meteorology
- Statistics
- Computer modeling
- Psychology (to help deal with people)
- Interpersonal communication (to help deal with people)

Education / Training Needed:

A Bachelors of Science and a Masters of Science degree in Meteorology from an accredited college or university is required. Experience in computer modeling techniques is helpful for this position. Management training courses are essential for competent and efficient job performance.

Areas of expertise:

- Meteorology
- Severe storms
- Icing
- turbulence
- Fronts
- Computer modeling software
- Human resources management



Student Worksheets

Worksheet 1 Skills Assessment

Name: _____ Date: _____

When you're not in school, name three things you like to do:

- 1. _____
- 2. _____
- 3. _____

What are your three favorite classes?

- 1. _____
- 2. _____
- 3. _____

What are your skills or personal strengths? What are your weaknesses?

What is your greatest accomplishment?

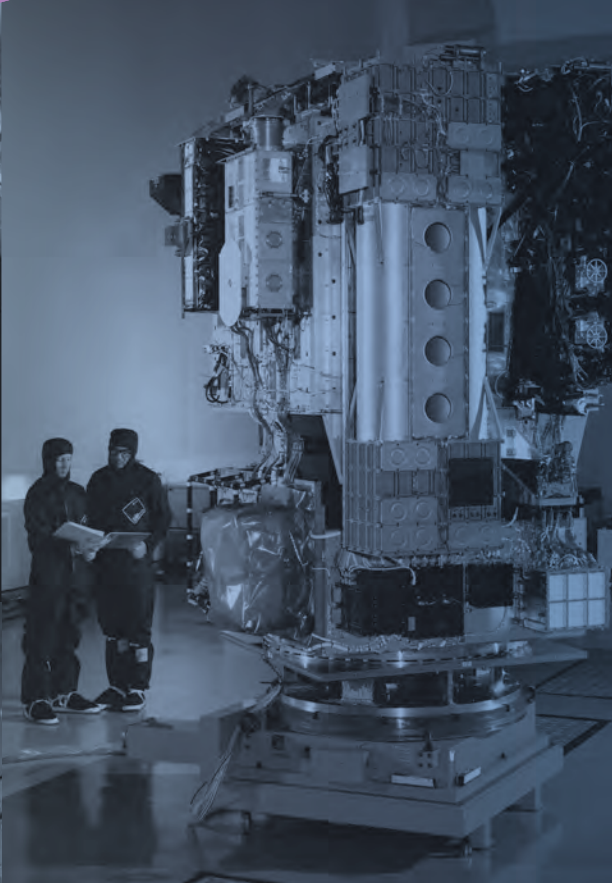
Worksheet 1 Continued

Do you know anyone who works in aeronautics? What do they do?

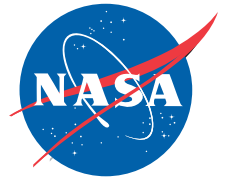
If so, does that job sound interesting? Why?

Have you considered a career in aeronautics? If so, what career have you considered and why?

Aeronautics
Research
Mission
Directorate



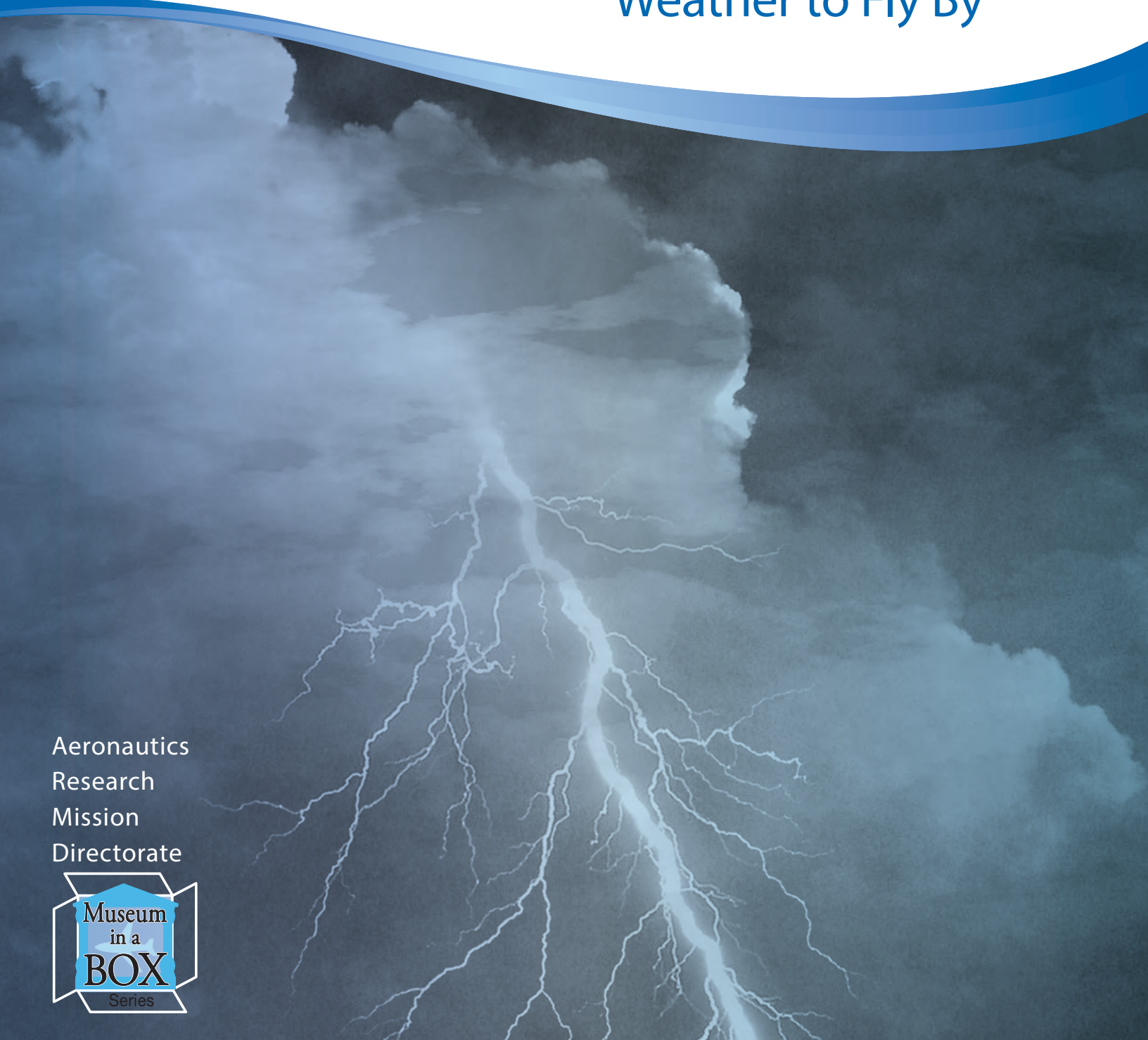
careers



GRADES

K-8

Weather to Fly By



Aeronautics
Research
Mission
Directorate



Weather to Fly By

Lesson Overview

This lesson includes various demonstrations to help students learn how density and other properties change weather conditions that can have an effect on flight, and why it's important for a pilot to be familiar with these conditions. Students will engage in activities to gain a better understanding of the terms air mass and density, how weather conditions are created, and the instrument meteorologists use to measure wind speed.

Objectives

Students will:

1. Discover that while invisible, air has mass and occupies space.
2. Determine that though two items look identical, they may not have the same density.
3. Simulate lightning through the creation of static electricity.
4. Observe the formation of a tornado by creating a fluid vortex.
5. Learn how to measure wind speed by building an anemometer.
6. Simulate how a satellite senses infrared energy to detect clouds.

Materials:

In the Box

Plastic fish tank
Stopwatch
Small piece of animal fur
Anemometer Kit

Provided by User

2 Unopened soda cans of the same size, one containing a diet soda, one containing a regular soda
2 Empty soda bottles, washed and with the labels removed, with a small hole (~7mm) drilled into one cap
4 Small paper cups (per group)
2 Straight plastic drinking straws (per group)
8 Styrofoam cups
Thumb tack (1 per group)
Stopwatch/Timer/Clock (1 per group; 1 included in MIB)
Permanent marker
Scissors (1 per group, or per class)
Stapler (1 per group, or per class)
Electric fan, air vent or other source of wind
Clear drinking glass
Paper towel
Strong tape, such as duct tape or electrical tape
Water
Styrofoam plate or tray
Pencil with eraser (1 per group)
Aluminum pie plate
Large metal cookie sheet
Small squares of paper in 4-5 different colors

GRADES

K-8

Time Requirements: 2 hours 5 minutes

Background

The Weather and its Effects on Flying

Weather is the state of the atmosphere with respect to wind speed and direction, temperature, moisture and pressure. A pilot needs to take all of these things into consideration while flying since it has a significant impact

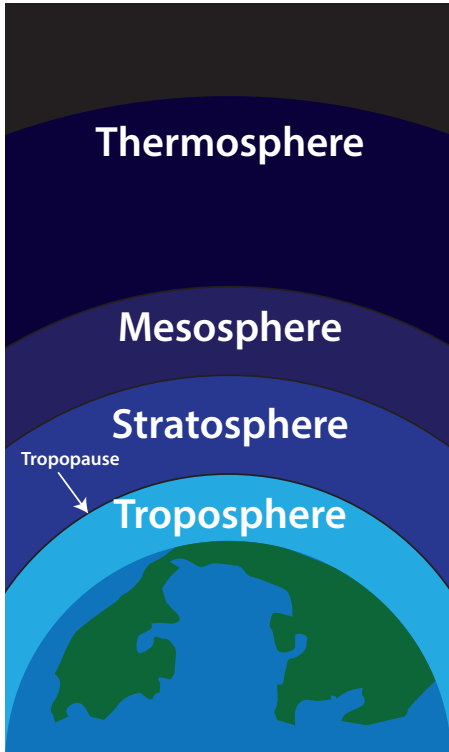


Fig. 1 The Earth's atmosphere

on the ability of both the airplane and the pilot to perform properly.

The atmosphere is made of up three different layers: The mesosphere, stratosphere and troposphere (Fig. 1). Weather occurs in the troposphere, which is the lowest layer. The tropopause, which is the upper edge of the troposphere, where weather typically ends, is anywhere from 5 miles above the Earth's surface at the poles, to as much as 11 miles above the surface at the equator. Weather is primarily driven by temperature and moisture differences between two places. The different temperatures affect the pressure of the air, which causes the warm air from the high pressure areas to move to areas of low pressure. This movement of the air is what we refer to as wind.

When flying long distances, it is quite common to take off and land in completely different weather conditions. However, since weather systems are often localized, landing conditions may be different even if you have only flown a few miles away. Before pilots take off it is important that they fully understand how the weather will affect their flight. Some of the items most commonly checked before a flight are wind, temperature and pressure, clouds (ceiling height and type) and dew point.

Wind: Wind direction and speed play an important role for an aircraft in flight as well as and during take-off and landing. Aviation weather reports include information for both surface winds and winds aloft, or the winds at altitude. When taking off or landing, a pilot ideally wants what is known as a headwind, where the air flows opposite to the direction of travel. This enables the aircraft to use less runway, or to carry more weight into the air. Having a headwind while in flight though will make the plane slower and burn more fuel; therefore during flight a tailwind is preferred. The opposite of a headwind, a tailwind is when air flows with the direction of travel.

One final term that pilots refer to is a crosswind. While having little effect in cruise flight, a strong crosswind, or wind blowing from the side of the aircraft, makes landing more difficult as it is harder to keep the aircraft aligned with the runway.

Temperature & Pressure: Since the sun heats the Earth unevenly, it creates air masses of varying density and pressure. Air reacts to these changes like a liquid, always trying to maintain a state of equilibrium. As such, these air masses move from the high pressure areas to the low pressure areas, creating what is more commonly known as wind. Strong winds occur when air masses of very different pressures are very close together.

Clouds: A cloud is nothing more than molecules of moisture in the atmosphere. Clouds vary in appearance due to differing atmospheric conditions, such as temperature, that cause them to form. When pilots understand the conditions in which a cloud is formed, they will have a better understanding of the weather they will encounter during a flight.

Stratus - A stratus cloud is a flat featureless cloud which usually covers a large portion of the sky. These clouds can either be high and transparent or low and gray. The air mass in which stratus clouds form is usually stable, as indicated by their smooth, flat appearance (Img. 1).

Cumulus - Cumulus clouds are the white puffy clouds which form when warm air rises (Img. 2). These clouds have a greater vertical development than the stratus cloud and because of the lifting action, may have unstable air associated with them.

Cumulonimbus - Cumulonimbus clouds are similar to cumulus clouds although they are usually associated with thunderstorms (Img. 3). Where possible, pilots avoid flying through these types of clouds as they generally equate to turbulent air and can contain hailstones, which can damage the aircraft. During the hot summer months, these clouds can reach as high as 60,000 feet (18,288 m).

Cirrus - Cirrus clouds are high altitude wispy clouds composed of ice crystals (Img. 4). These clouds are generally higher than most aircraft flight.

Dew Point: The dew point is the temperature to which the air must be cooled in order to reach saturation. Pilots will find that as the dew point gets closer to the current temperature, they will be more likely to encounter fog or clouds during their flight.



Img. 1 A stratus-covered sky over Key West, Florida



Img. 2 A collection of cumulus clouds over Southwest Florida, August 2009



Img. 3 An example of a cumulonimbus cloud seen over Pensacola, Florida



Img. 4 Cirrus clouds over Florida, August 2006

Activity 1

Air and the Space it Occupies

GRADES

K-8

Time Requirements: 15 minutes

Materials:In the Box

Plastic fish tank

Provided by User

Clear drinking glass

Paper towel

Tape (optional);
preferably double-sidedWorksheets

None

Reference Materials

None

Key Terms:Mass
Density**Objective:**

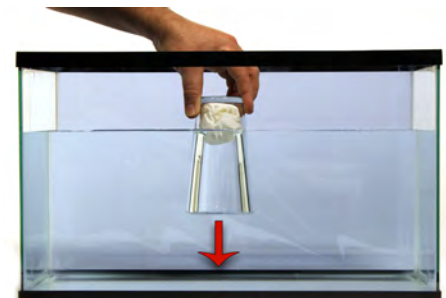
Students will observe that while invisible, air has mass and occupies space.

Activity Overview:

In this activity, students will take an air filled glass and attempt to displace that air with water. In doing so, they will discover that no two masses may occupy the same space simultaneously.

Activity:

1. **Fill the plastic fish tank with water.**
It is important that the vessel be filled sufficiently with water to submerge the entire glass.
2. **Crush a dry paper towel into a ball and place it securely at the bottom of the cup.** Depending on the size of the towel and the glass, you may want to use a small piece of double-sided tape to prevent the paper towel from falling when the glass is inverted.
3. **Ask the students to predict what they think will happen to the paper towel once the glass is submerged upside down in water.**
At this point do not correct the students' answers.
4. **Invert the glass and slowly lower it vertically into the water until it is completely submerged.**
5. **Hold the glass in the water for a few seconds and then remove it, taking care to ensure the glass remains vertical.**

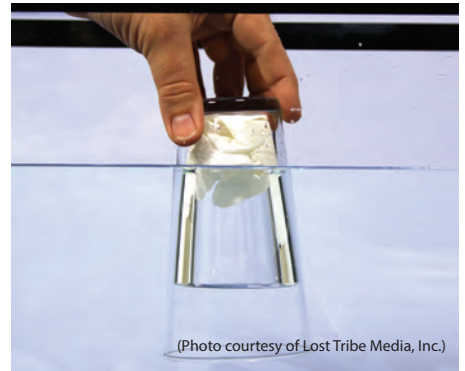


6. **Remove the paper towel from the glass, straighten it and hold it up for the students to see.**
It is important to demonstrate that the towel is still dry.
7. **Ask the students to predict why the towel is still dry.**
As the students answer, it may be necessary to guide them towards the correct solution, which is that the air in the glass is preventing the water from reaching the towel.
8. **Repeat the experiment, only this time tilt the glass slowly, allowing the air to gradually escape the glass.**
This will demonstrate that the air can now escape and is being replaced by the water (as indicated by the bubbles), which causes the paper towel to become wet.



Discussion Points:

1. **Why did the paper towel stay dry during the first part of the experiment?**
Before the glass was placed into the water, it was full of air. As the air could not escape the glass, it prevented the water from entering. The air prevented the water from entering the glass because no two masses can be in the same place at the same time.
2. **Why did the paper towel get wet when the glass was tilted to the side?**
As the air escaped from the glass, it allowed the water to take its place inside the glass.
3. **Why didn't the water pass through the air in the glass to wet the towel?**
Water has a greater density than air, which means that the air will always try to be above the water. In this demonstration however, the air was restricted by the glass so that it couldn't move upward. Instead, the water was forced to rise above the air (Img. 5).



Img. 5 Air in the glass prevents the water from entering

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Properties and changes of properties in matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

Activity 2

Which Object is More Dense?

GRADES**K-8****Time Requirements:** 15 minutes**Materials:**In the Box

Plastic fish tank

Provided by User

2 Unopened soda cans of the same size, one containing a diet soda, one containing a regular soda

Water

Worksheets

None

Reference Materials

None

Key Terms:

Density
Aspartame

Objective:

Students will learn that even though two objects may look, feel, and appear to be exactly the same, their densities may be different.

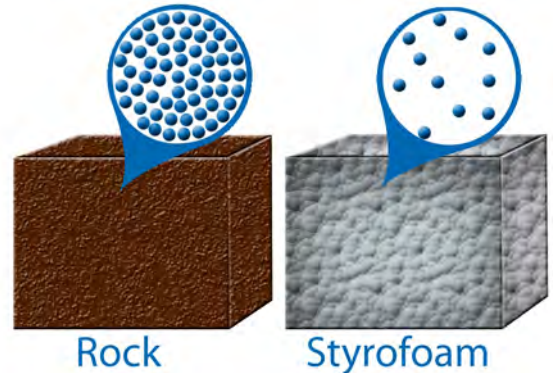
Activity Overview:

Students will compare the densities of two soda cans that look the same and contain the same amount of liquid by submerging them in a liquid of known density, water.

Before beginning this activity, fill the fish tank with water.

**Activity:**

1. Explain to the class that density is a measurement of the compactness of a material, as measured in terms of mass per unit of volume. Density is used to describe the compactness of the molecules within an object.



For example, a solid rock that

measures one cubic meter (1m x 1m x 1m) weighs more (and therefore has more mass) than one cubic meter of Styrofoam. This is because the rock is denser, or has more molecules per cubic meter, than the Styrofoam. We can calculate an object's density by using the formula $\text{Density} = \text{Mass} / \text{Volume}$.

2. Pass the two soda cans around the class. Ask the students to compare them for similarities and differences.

It should be discovered that the cans are the same size, appear to be the same weight and contain the same quantity (volume) of soda.

- Place the can of regular soda in the water.

Students should observe that it sinks to the bottom of the container.

- Ask the students to explain why the can of soda sank.

If necessary, guide the discussion in order to ascertain that the can of soda sank because the density of the can and its contents was greater than that of the water.



- Now, hold up the can of diet soda and ask the students to hypothesize as to what might happen when the can is placed in the water.

It is likely that the students will assume that this can will also sink. For now, do not correct this assumption.

- Place the diet soda can into the water. Instead of sinking, it should float. Ask the students why this can floated when an identical can sunk.

If necessary, guide the discussion so that the students discover that while the two cans are virtually identical, it is the density of the soda inside that is making the can float. The diet soda, while being in the same quantity as the regular soda, is significantly less dense than water, causing it to float.



Discussion Points:

- What is the difference between regular and diet soda that causes such a change in density?

The can of regular soda contains sugar instead of a much stronger chemical sweetener. Since the large quantity of sugar adds to the mass (and therefore the density) of the soda, it will make the can denser than water, causing it to sink. (You can note the grams of sugar in a regular can of soda from the Nutritional Information on the label of the can.) The diet soda, by comparison, uses aspartame, a chemical that requires just a very small amount to accomplish the same level of sweetness.

- If two cans of diet soda were glued together, would it still float? What if it was one REALLY big can?

Probably, yes. While there would be additional mass from the glue, the overall density of the cans of diet soda would not change due to an additional quantity. As such, regardless of how much diet soda there was present, it would always float. Changing the quantity of an item doesn't change its density.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Properties and changes of properties in matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

Activity 3

How to Make Lightning

GRADES

K-8

Time Requirements: 15 minutes

Materials:In the Box

Small piece of animal fur

Provided by User

Styrofoam plate

Thumb tack

Pencil with eraser

Aluminum pie plate

Worksheets

None

Reference Materials

None

Key Terms:

Electron
Charge
Conductor
Static electricity

Objective:

By creating static electricity, students will learn how lightning occurs naturally in the atmosphere.

Activity Overview:

Lightning is the discharge of electrical energy between positively and negatively charged areas in the atmosphere. It can occur within a cloud, between clouds or between a cloud and the ground. Lightning is simply static electricity on a very large scale. Using the apparatus below, students will make their own lightning on a smaller scale.

Before starting this activity, you may find it helpful to dim the lights in the room, or close the blinds if possible. A darker room will provide for a more dramatic presentation.

Activity:

1. **To begin, secure the eraser-end of the pencil to the center of the aluminum pie plate using the thumb tack.**

The goal is to provide a way of picking up the plate without touching it.

The pencil eraser insulates the plate from your hand.



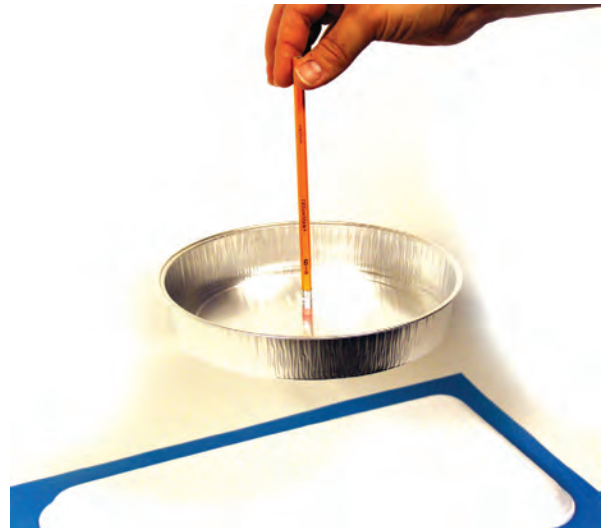
Note: You may need to make a hole in the Styrofoam plate to provide a recess for the thumbtack, as the Styrofoam and metal plates must come into contact with one another later in this activity.

2. **Next, rub the Styrofoam plate vigorously against the fur.** The goal is to build up a layer of static electricity on the Styrofoam plate. It will take about 15-20 seconds of rubbing to accomplish this.

- Now, place the Styrofoam plate on a non-metallic table.
- Using the pencil handle, pick up the aluminum pie pan and hold it approximately 6 inches above the Styrofoam plate, and drop the pie plate onto the Styrofoam.

Caution: Be careful not to touch either plate at this time!

Before completing the next step, have the students stand close to the plates as the spark is quite small and hard to see.



- Slowly bring your pointed finger towards the metal pie plate.

A spark will jump from the pie plate to your finger.



- Now, using the pencil, raise the pie plate approximately 3 inches above the Styrofoam plate.

Using your other hand, slowly bring your pointed finger closer to the pie plate. Another spark will jump from your finger to the pie plate.



- If desired, have the students repeat this demonstration.

Start with Step 2 and repeat as desired.

Discussion Points:

- What happened just before you touched the aluminum pie pan?

A spark was created.

- Why do you think this happened?

The spark was created because of a build-up in static electricity. Normally, the Styrofoam plate contains an equal number of electrons and protons, meaning that it is neutrally charged. When the Styrofoam plate was rubbed against the fur, it took electrons from the fur and added them to the plate. As the plate now has extra electrons, and because the electrons are negatively charged, this made the Styrofoam plate negatively charged. When you placed the pie plate on top of the Styrofoam, the electrons in the pie plate wanted to move as far away as possible from the large quantity of electrons in the Styrofoam plate. Just like with magnets, opposites attract, similar repels!

When you put your finger close to the pie plate, the electrons in the pie plate saw a way of getting even farther away from the extra electrons in the Styrofoam – by leaving the pie plate entirely and going to your finger. It is this transfer of electrons that caused the spark.

The electrons do this in an attempt to make the combined unit of pie plate and Styrofoam plate as close to neutral as possible. However when the plates are separated, this leaves the pie plate positively charged (due to its lack of electrons) while the Styrofoam plate retains its negative charge.

3. So, why did we get another spark when we lifted the pie plate and touched it again?

When you first touched the plate, the electrons belonging to the pie plate jumped to your finger, which made your finger (and you) negatively charged. This meant the pie plate had fewer electrons than it was supposed to have, which made it positively charged. After you lifted it away from the Styrofoam, the pie plate (being positively charged) wanted the electrons back, so as soon as you brought your finger near the plate, all the electrons that had previously jumped into your finger went back to the plate.

4. How does it work in the real world? How do clouds produce lightning?

In simple terms, when two clouds rub together it acts the same way as when you rubbed the fur onto the Styrofoam plate. Electrons from one cloud build up on the other cloud. Eventually there are simply too many electrons for one cloud to hold and they all decide to leave and head toward the first positively-charged (or neutrally-charged) body they can find, either another cloud or the Earth.

5. How does this experiment relate to the flight of an aircraft?

The majority of airplanes are made from aluminum, which is a great conductor of electricity. As they fly, the friction of the air rubbing past the plane causes static electricity to build up, which can affect the aircraft's communication and navigation systems. To prevent this, aircraft are designed to dissipate this static electricity by using small devices called 'Static Wicks'. As their name implies, these devices channel the static electricity away from the fuselage of the aircraft and out to the wings and tail, where it can be safely discharged back into the atmosphere.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Properties and changes of properties in matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

Activity 4

Tornado In A Bottle

GRADES**K-8****Time Requirements:** 20 minutes**Materials:**In the Box

Food coloring

Provided by User

2 Empty soda bottles, washed and with the labels removed, with a small hole (~7mm) drilled into one cap

Strong tape, such as duct tape or electrical tape

Water

Worksheets

None

Reference Materials

None

Key Terms:

Density

Mass

Vortex

Vacuum

Objective:

Students will observe how a vortex is created and discover basic fluid dynamic .

Activity Overview:

In this activity students will observe the creation of a water vortex by swirling water in a bottle. The swirling motion of the bottle creates a vacuum, as well as a pathway for the air as the water displaces the air mass below.

Before beginning this activity, drill a hole in the cap of one of the soda bottles, discarding the other cap. Using the duct or electrical tape, secure the cap upside-down onto the bottle so that the threads are exposed. This will allow for the bottles to be re-used/refilled as needed. Fill the other bottle 2/3 full of water, add a few drops of food coloring, and then screw the other bottle assembly to it. Until you are ready to start the demonstration, ensure that the bottle containing the water is on the bottom!

Note: For photographic purposes we added food coloring to the water. This is highly recommended to allow the students to better observe the demonstration.



Activity:

1. **Start this demonstration by showing the students a photo of a tornado from the Images section (Img. 6).**

Explain that, in very basic terms, a tornado is created when warm air tries to rise upwards through a mass of heavy, dense air. As it rises, it is replaced by the dense air and heavy rain from above. The wind causes this descending air mass to start rotating, which when the conditions are just right, causes a tornado.



(Photo courtesy of Sean Waugh –NOAA / NSSL)

Img. 6 A tornado in Kansas, May 23rd, 2008

2. **Show the students your prepared bottle assembly.**

Explain that the water will represent the dense air and rain and the empty bottle represents the warm air.

3. **Invert the bottles so that the bottle containing the water is on top.**
You will notice that just a thin, intermittent stream of water enters the lower bottle. If you have completed Activity 1, ask the students why the water is pouring so erratically. If not, explain as follows:

The water is a more dense mass than the air in the bottle below and a more dense mass always tries to sink below a less dense mass. However, it cannot do so in this case as the air in the lower bottle has no means of escape. The gulping noise is the sound of the air forcing itself past the water through a combination of vacuum and gravity.



4. **Start swirling the bottle assembly.**

Caution: Do NOT shake!

As the rotational speed increases, a water vortex will form in the upper bottle and water will start flowing smoothly into the lower bottle. Ask the students why the water is now flowing smoothly.

The swirling water is creating a water vortex. The vortex is a funnel shape with a hollow center, just like a tornado. As such, the air from the bottle below can now pass unrestricted through the center of the vortex and into the bottle above.



5. If desired, have the students perform the demonstration themselves by inverting the bottle again so that the water is back on top.

Discussion Points:

1. Can you name any other places where you have seen this effect before?

Answers may include bathtubs and sinks when they drain.

2. Why did the water sink quicker when we swirled the bottle faster?

As the water rotated, the hole in the center grew larger which allowed more air to pass through. Since the air can escape quicker, it allows the denser water to descend faster too.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Properties and changes of properties in matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

Activity 5

Making an Anemometer

GRADES**K-8****Time Requirements:** 30 minutes**Materials:**In the Box

Anemometer Kit

Provided by User4 small paper cups
(per group)2 straight plastic drinking
straws (per group)1 Thumb tack
(per group)1 Pencil with eraser
(per group)1 Timer / Clock / Watch
(per group)

1 Permanent marker

1 Pair of scissors
(per group, or per class)1 Stapler
(per group, or per class)

Tape

Electric fan, air vent, or
other source of windWorksheetsWind Speed Comparison
(Worksheet 1)Reference Materials

None

Key Terms:

Anemometer

Objective:

Students will discover how wind speed is measured.

Activity Overview:

As discussed in the **Background** information, it is vitally important for pilots to know the speed of the wind they will be flying in. In this activity, students will build an anemometer using straws and cups. By measuring the number of revolutions the device makes in a given time, students will be able to measure the speed of the wind.

Activity:

1. Review the **Background** information with the students.
2. Divide the students into groups of 3-4 students.
3. Demonstrate how to create the anemometer and have the students follow along as you complete each step.

If these items are not available, a single Anemometer kit is included in the MIB.

- a. Using tape to secure them, arrange the two plastic drinking straws to create a cross with four legs of equal length.

- b. Push the thumb tack through the center of the cross and into the eraser of the pencil. This will create the axle and provide something to hold the anemometer with.



- c. Staple a paper cup to each leg, ensuring they all point in the same direction.
- d. Using the marker, clearly mark one of the cups so it can be differentiated from the others while spinning.

4. **By blowing on the anemometer, demonstrate how the paper cups collect the wind energy and convert it into motion.**
5. **Have the students place their anemometers into a steady source of wind, such as a fan or air vent, or the wind outside.** Ask the students to count the number of revolutions their anemometer makes in one minute by counting how many times the marked cup passes.
6. **Have the groups compare their finding .** Did everyone's anemometer spin at the same speed?
Based on the assumption that everyone used the same length straws and same sized cups, the results should be very similar for the same wind source.
7. **Optional: If desired, have the students repeat this experiment outside each day for a week and record their findings on the Wind Speed Comparison Worksheet.**

Compare the number of rotations of their devices to the actual wind speed as reported in the local media, or by visiting www.weather.gov. Is there a correlation?

The goal is to determine that there is a direct correlation between the rotational speed of the anemometer and the reported wind speeds.



Discussion Points:

1. **Our devices don't tell us the actual wind speed, only the number of rotations the anemometer makes. How could we make these devices more useful and give us the actual wind speed?**
To record actual wind velocity, we would need to know the precise speed at which our anemometer rotates for a known wind speed. We could do this by using the device for a week and plotting the results on a graph, and then comparing the wind speed against the rotational speed. From there, we could calibrate our device and use it to measure unknown wind speeds.

2. **How could this machine be better designed? Are there any inherent problems with the design that might cause spurious readings?**

Paper Cups – despite being wax coated, will eventually fail from being exposed to the elements. Plastic cups would help with this.

Thumb Tack/Pencil axle – Could cause unwanted friction which could slow down the rotational speed. Mounting on a post with lubricated bearings would help reduce the friction.

Straws – These are fairly flexible and may absorb some of the wind energy, slowing the rotation. Using a stiffer material would help.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
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NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
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Activity 6

Detecting Clouds Using Infrared Energy

GRADES**K-8****Time Requirements:** 30 minutes**Materials:**In the Box

None

Provided by User

8 Styrofoam cups

Water

1 Pen or marker that can write on the cups

1 Large metal cookie sheet

Small squares of paper in 4-5 different colors (enough to cover the cookie sheet)

Worksheets

None

Reference Materials

None

Key Terms:

Infrared energy

Objective:

By using only their hands, students will demonstrate how a satellite's infrared detector can see weather by creating a thermal image map.

Activity Overview:

Cloud cover plays an important role in aviation. As well as reducing visibility for landing, clouds can also help pilots predict how turbulent the flight will be. In this activity, students will discover how satellites use infrared energy to locate clouds and track storms.

Some preparation is required prior to starting this activity:

Without the students seeing, fill the 8 styrofoam cups with water of various temperatures.

Use the pen to mark the temperature of the water (V. Hot, Hot, Warm, etc.) on the cups for later reference.

For the most effect, and if safe to do so, use a wide range of temperatures ranging from extremely hot tap water, to ice water. Then place the 8 cups in various locations on a table but so they can all be covered by the cookie sheet.

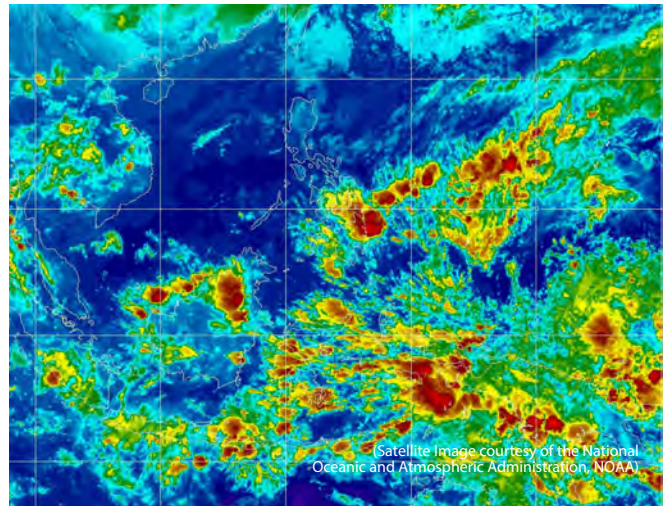
**Activity:**

1. **Before beginning this activity, ensure the above set-up instructions have been completed.**

The time spent explaining this activity to the students will give the cookie sheet a chance to heat/cool as necessary. For classes with many students, it may be beneficial to set up multiple sets of cups and trays.

2. **Show the students the false-color infrared satellite image (Img. 7).** Explain that by using satellites and adding color to enhance the image, meteorologists can use them to identify where the weather systems are located.

For advanced students who desire more detail, you can also explain that the temperature of a cloud is a good indicator of its altitude; the higher clouds are colder than the lower ones. Typically, warm clouds are a good indicator of poorer weather and usually associated with rain. The (relatively) very hot clouds are normally storm producing clouds associated with heavy rain and turbulence.



Img. 7 A false-color infrared satellite image of Southeast Asia

3. **Using just their hands, have the students gauge the temperature of the cookie sheet in various locations, using the colored paper to indicate areas of differing temperature.**

It may be easier to first establish the areas of extreme hot/cold using just two colors, then fill in the rest incrementally.



4. **Once the cookie sheet has been completely covered with paper, gently remove the sheet and compare the color coding to the markings on the cups underneath.**

The students will discover that without ever seeing the cups, or knowing the temperature of the water, they have correctly located the areas of hot and cold.



Discussion Points:

1. **How is this possible? How could we determine the areas of hot/cold water without ever touching the water?**

All objects, whether hot or cold, emit infrared energy. The cookie sheet absorbed that energy and converted it back into a temperature which could be detected by your hand.



2. **Where else have you seen infrared energy in use?**

Some answers may include: toy ovens; thermal imaging cameras (used by firefighters to detect trapped people); heat lamps or space heaters; TV remote controls.



Reference Materials

Glossary

Anemometer:

A device used to measure the speed of wind through a measurement of its rotational speed

Aspartame:

A chemically based artificial sweetener; often contained in products branded as "diet" where it is replacing the sugar of the "regular" variety

Charge:

The measure of the number of electrons in an object, or a measure of electricity

Conductor:

A material that provides little resistance to an electrical current or thermal energy

Crosswind:

Air moving perpendicular to the path of travel of an aircraft

Cumulus:

A type of cloud; associated with unstable air, these clouds are white and puffy in appearance

Cumulonimbus:

A type of cloud; similar in appearance to cumulus, cumulonimbus clouds are taller, more unstable and are associated with thunderstorms

Density:

The compactness of the molecules within a body of matter; a body that is more dense has more tightly packed molecules

Electron:

A negatively charged particle

Headwind:

Air moving opposite to the direction of travel of an aircraft

Infrared energy:

Light with a wavelength shorter than that which is visible to humans; infrared energy is outside of the range of visible light

Mass:

The measure of the amount of material contained in a body of matter

Stratus:

A type of cloud, usually a flat layer, grey in appearance; commonly referred to as an "overcast sky"

Static electricity:

A collection of excess surface electrons, usually generated through friction

Tailwind:

Air moving in the same direction as the path of travel of an aircraft

Vortex:

Commonly referred to as a whirlpool or a tornado, a vortex is a body of swirling or rotating mass that generates a vacuum at its center

Vacuum:

An area absolutely devoid of matter; often used with the term "suction" as a vacuum attempts to "suck" matter into it

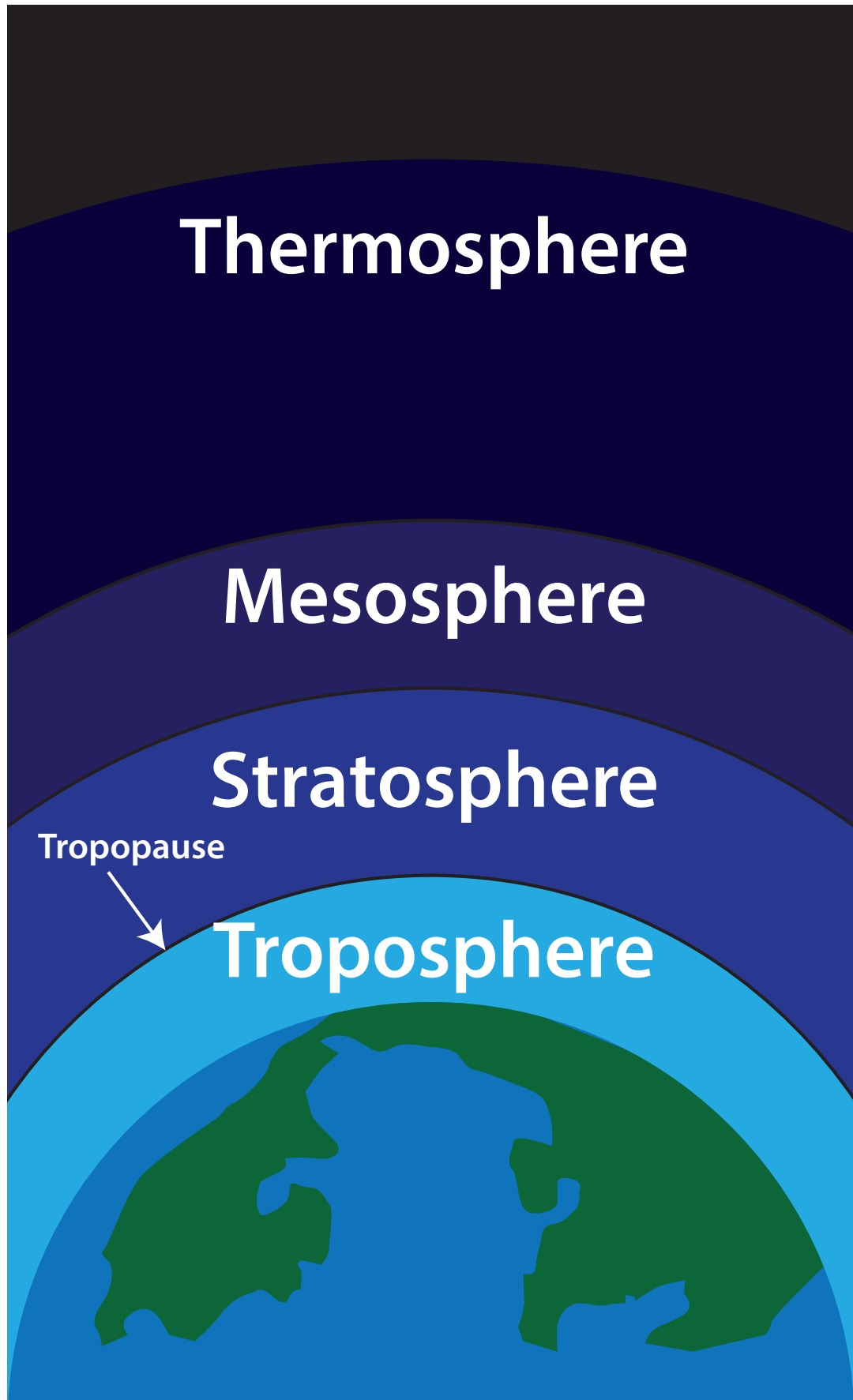
Wind:

The name given to the movement of an air mass

Winds aloft:

The name given to describe winds at the altitude of flight

Fig. 1 The Earth's atmosphere





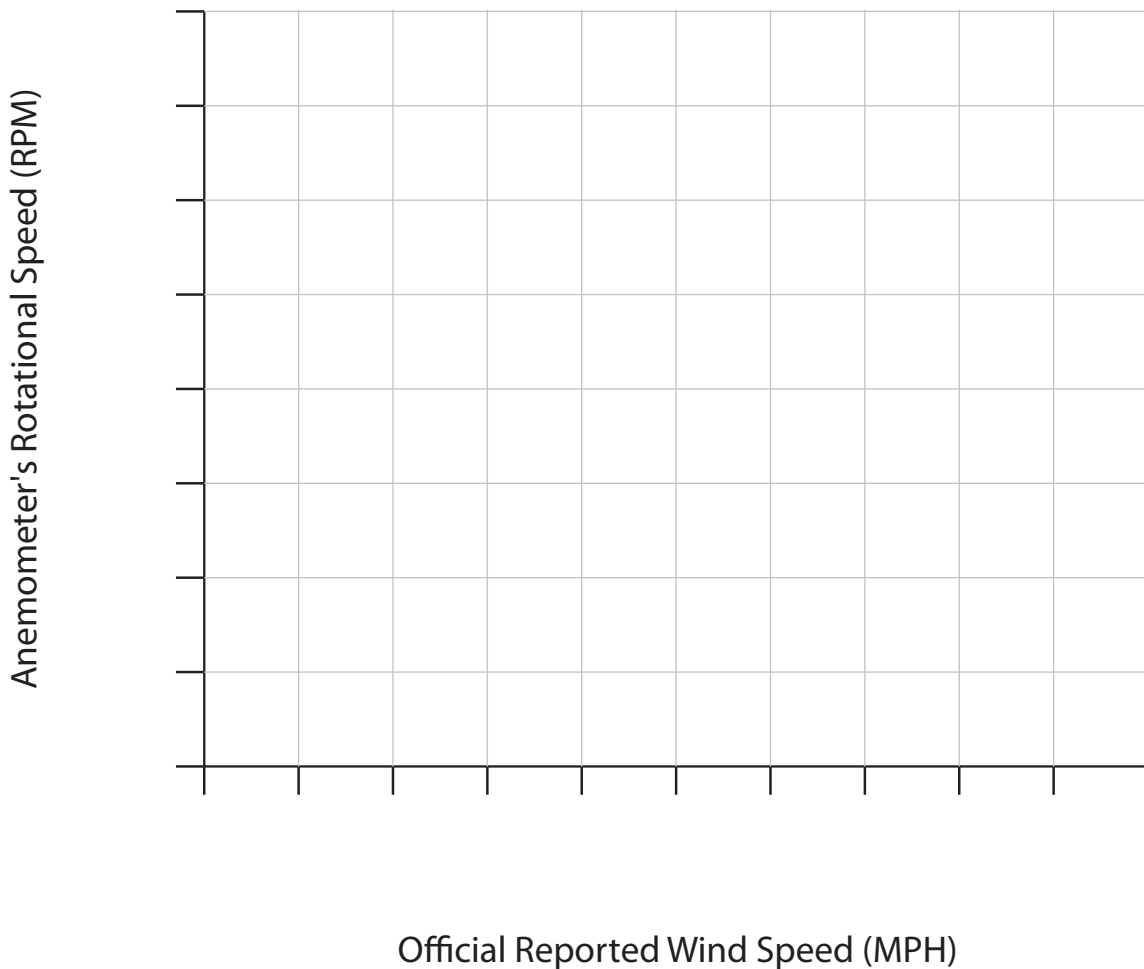
Worksheets

Worksheet 1

Wind Speed Comparison

Day	Anemometer's Rotational Speed (RPM)	Official Reported Wind Speed (MPH)

At the end of the week, plot your results on the graph below to visually determine the correlation between the number of rotations your anemometer made in one minute and the wind speed as reported by the National Weather Service. Label the tick marks on the X and Y axes to define a scale that best displays your results.





Images

Img. 1 A stratus-covered sky over Key West, Florida



(Photo courtesy of NOAA and The National Weather Service Weather Forecast Office, Key West, FL)

Img. 2 A collection of cumulus clouds over Southwest Florida, August 2009



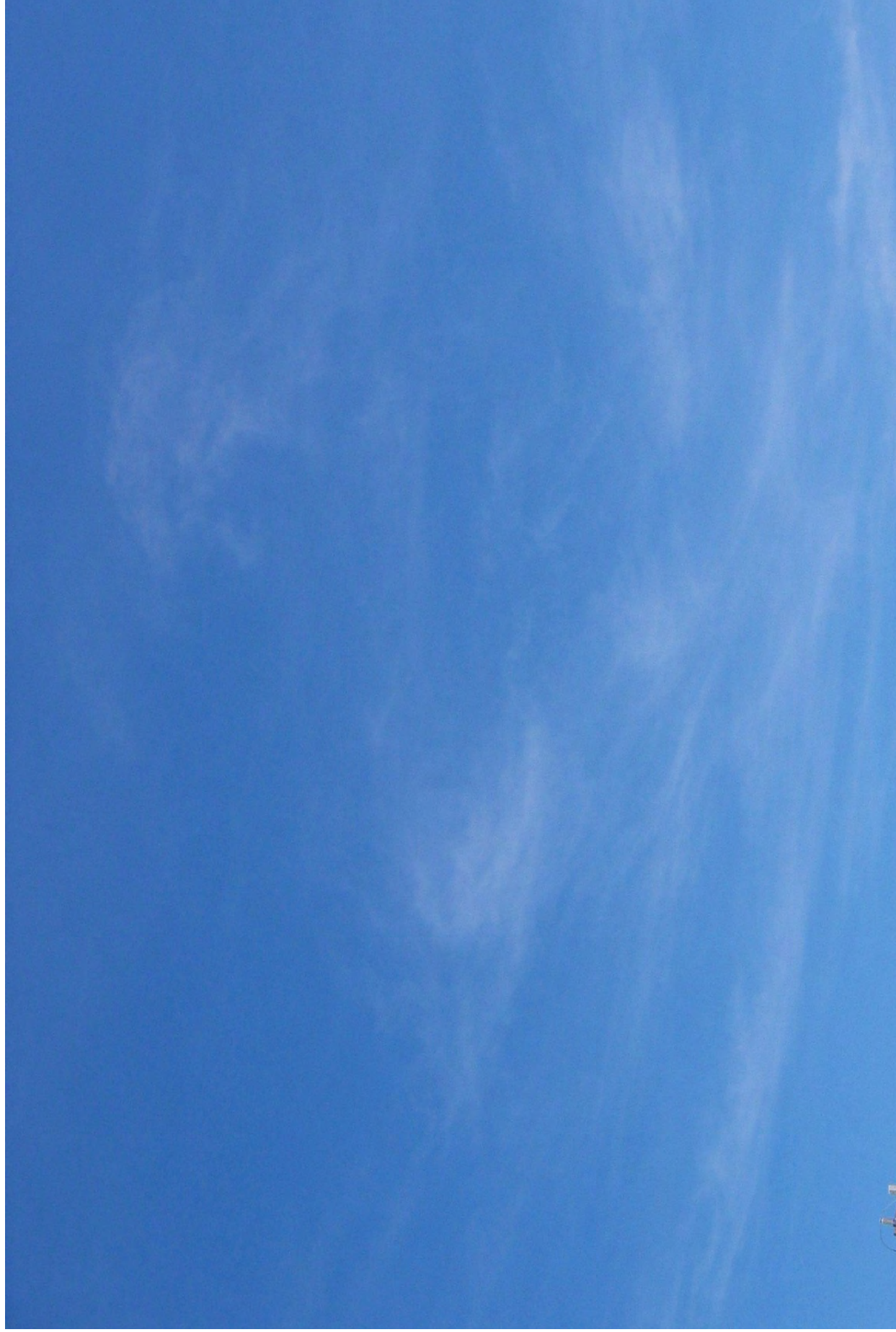
(Photo courtesy of NOAA and The National Weather Service Weather Forecast Office, Key West, FL)

Img. 3 An example of a cumulonimbus cloud seen over Pensacola, Florida



(Photo courtesy of NOAA and The National Weather Service Weather Forecast Office, Key West, FL)

Img. 4 Cirrus clouds over Florida, August 2006



(Photo courtesy of NOAA and The National Weather Service Weather Forecast Office, Key West, FL)

Img. 5 Air in the glass prevents the water from entering



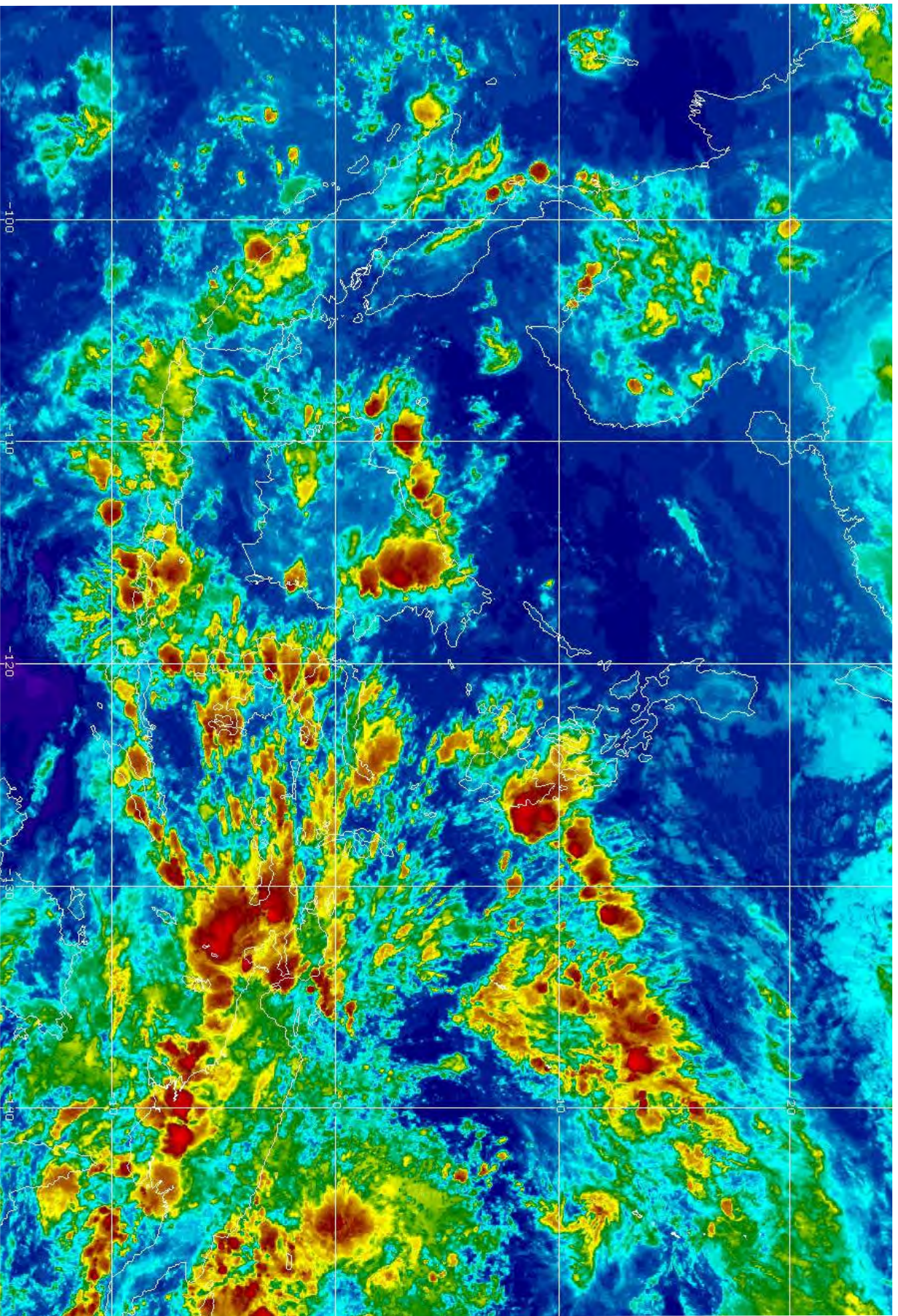
(photo courtesy of Lost Tribe Media, Inc.)

Img. 6 A tornado in Kansas, May 23rd, 2008



(Photo courtesy of Sean Waugh—NOAA / NSSL)

Img. 7 A false-color infrared satellite image of Southeast Asia

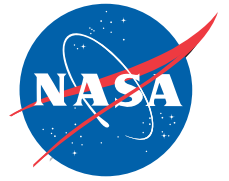


(satellite image courtesy of the National Oceanic and Atmospheric Administration, NOAA)

Aeronautics
Research
Mission
Directorate



airspace



GRADES

K-8

Good Vibrations



airspace

Aeronautics
Research
Mission
Directorate



Good Vibrations

Lesson Overview

Noise from aircraft is an increasing problem in our environment. Contributing factors include an increase in air traffic, demand for land in cities which has pushed developments closer to airports and larger aircraft which require more powerful engines. Science, Technology, Engineering, and Mathematics (STEM) will help solve this problem. Many groups are working to create solutions. The following three hands-on activities will help students better understand several basic principles of sound:

Tuning Forks: Students will engage in a series of demonstrations that illustrate the concept of vibrations, pitch, frequency, and beats.

Thunder Drum: Students will add a simple spring to the design of a thunder drum and hear very unusual sounds.

Resonator: Students will directly observe resonance in a pair of demonstrations using a series of wooden dowels to illustrate the concepts of natural frequency and resonance. Student worksheets are provided.

Objectives

Students will learn about transfer of energy, motions and forces, and interactions of energy and matter as they learn about the following concepts:

1. Several principles of sound.
2. Noise from aircraft is a growing problem that NASA along with many others are working to reduce the amount of
3. All sounds are caused by vibrations.
4. Vibrations can be sensed in several ways (hearing, seeing and touching).
5. Pitch is related to the speed or rate of vibration.
6. Resonance
7. Natural frequency of an object.

Materials:

In the Box

Tuning forks, set of 4
Tuning fork, C-256
Tuning fork activator
Tuning fork block (for holding the tuning forks)
Ping pong ball with attached string (1 ft.)
Large Thunder Drum
Safety glasses

Provided by User

Table
Container of water (plastic food storage container works well)
Several sheets of paper

GRADES**K-8****Time Requirements: 1 hour 5 minutes**

Background

As scientists and engineers work to reduce noise pollution from aircraft, a thorough understanding of the physics of sound is necessary. Sound is one of the most important ways we have of sensing our surroundings and communicating with others. Sound itself is a sensation created in the human brain in response to sensory inputs from the inner ear. However, not all sounds are desirable or beneficial.

All sounds are produced by vibrating objects. One of the reasons that there are so many different sounds is that there is an endless variety of materials that can vibrate and produce them. When you talk or sing, two ligaments that are hidden in your larynx vibrate. They are called your vocal cords or vocal folds. Each person has a unique set of vocal cords and a uniquely designed larynx which gives rise to the individual character of a person's voice.

Following are some properties of sound waves:

- Frequency and pitch depend on the length of an object that is vibrating; a short string will vibrate faster producing a higher frequency (or pitch) than a long string.
- Multiple sound waves can reinforce or interfere with each other.
- Sound insulation is designed to absorb sound waves. Many of the same materials used in temperature insulation can be used to reduce sound.
- Sound can be reflected (bounced off) or refracted (bent).
- Sound levels decrease rapidly as the distance from the point of origin to the receiver increases; if the distance from the source is doubled, then the intensity decreases approximately one-fourth.
- Some examples of sound intensities as measured by decibels:

Jet plane at takeoff	.....	110-140dB
Loud rock music	.....	110-130dB
Chain saw	.....	110-120dB
Thunderstorm	.....	40-110dB
Vacuum cleaner	.....	60-80dB
Normal voices	.....	50-70dB
Whisper	.....	20-50dB
Purring cat	.....	20-30dB
Falling leaves	.....	10dB
Silence	.....	0dB

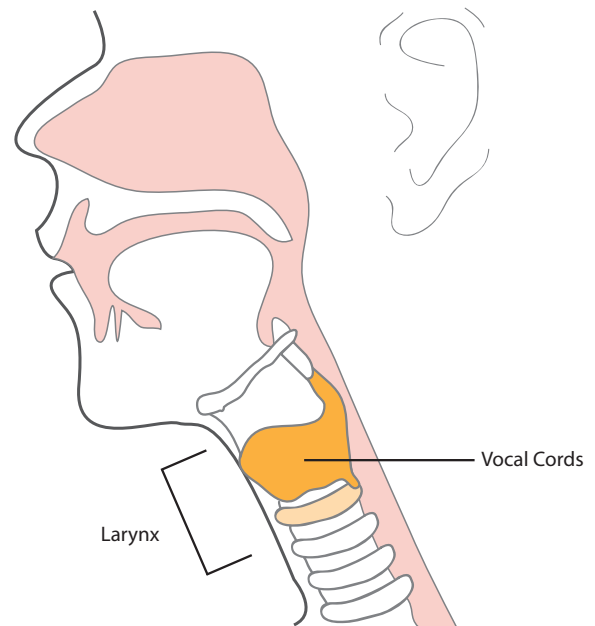


Fig. 1 Vocal cords and larynx

Objects have a frequency at which they prefer to vibrate. This frequency depends on its size and of the material of which it is made. This preferred frequency is called the **natural frequency**. The natural frequency is also called the **resonant frequency**. A guitar string is a good example: When plucked it will vibrate at its natural frequency.

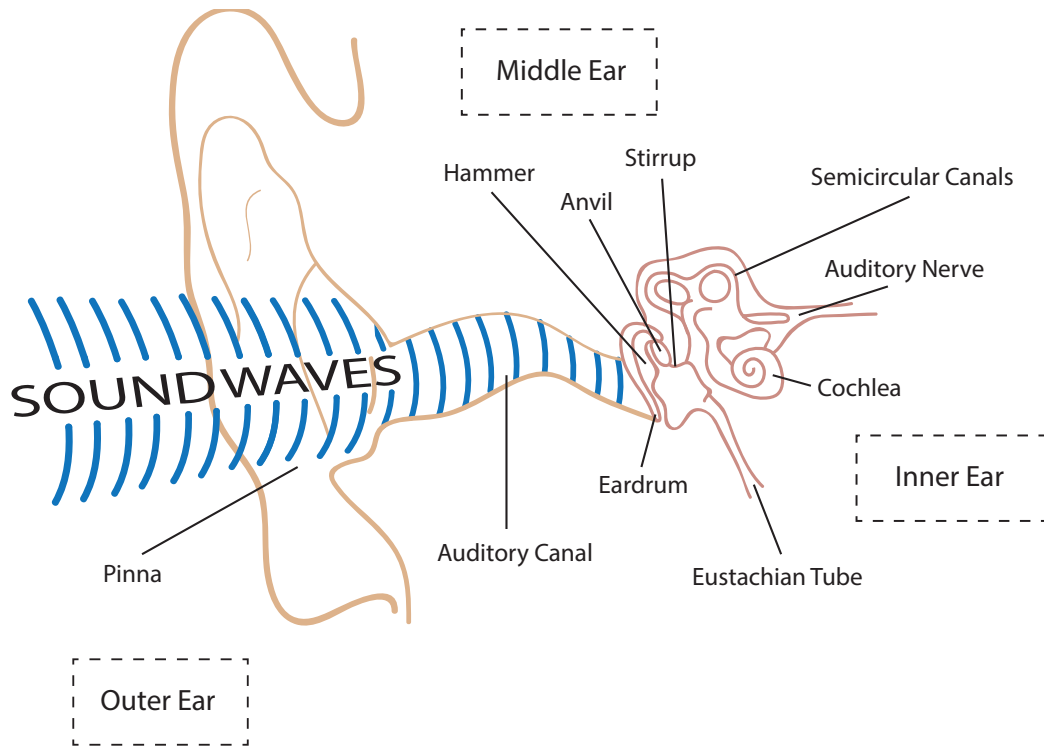


Fig. 2 The human ear

The Human Ear

- The outer ear collects sound waves.
- Sound waves travel down the ear canal and vibrate the eardrum.
- The three small bones (hammer, anvil, stirrup) vibrate behind the eardrum.
- The vibrations enter the cochlea which changes the mechanical energy of the vibrations into electrical nerve impulses that travel to the brain.
- The normal range of sound that a human can hear is about 40 – 18,000 Hertz (Hz).
- As we age, the frequency range tends to narrow; the higher range is most affected.
- Many animals can detect a wider range of sound frequencies than humans can. Dogs can hear higher frequencies than humans; elephants can hear lower frequencies.

For additional information on sound, please review the following Museum in a Box lessons:

Quieting the Popper

Speed of Sound

Seeing Sound

Activity 1

Tuning Forks

GRADES

K-8

Time Requirements: 45 minutes

Materials:In the Box

Tuning forks, set of 4
 Tuning fork, C-256
 Tuning fork activator
 Tuning fork block (for holding the tuning fork)
 Ping pong ball with attached string (1 ft.)

Provided by User

Table
 Container of water (plastic food storage container works well)
 Several sheets of paper

Worksheets

Tuning fork worksheet
 (Worksheet 1)

Reference Materials

None

Key Terms:

Frequency
 Pitch
 Vibrations
 Interference

Objective:

Students will learn about motions and forces, transfer of energy, and interactions of energy and matter as they study the following:

- Several principles of sound
- Sounds are caused by vibrations
- Vibrations can be sensed in several ways (hearing, seeing, touching)
- Pitch is related to the speed or rate of vibration

Activity Overview:

Students will engage in a series of demonstrations using tuning forks that illustrate the concept of vibrations, pitch, frequency, interference and beats.

**Activity:**

Note: Always use the "Tuning Fork Activator" (the rubber block) to initiate the tuning fork vibrations. Activating a tuning fork on the soft edge will make it ring at its fundamental resonant frequency – no distortion from higher harmonics. The tuning fork activator also eliminates dings and scratches typically caused when tuning forks are chimed against each other or on a tabletop.

1. **Activate each of the four tuning forks and listen to the sound by placing the tuning fork close to one ear.** Compare the pitch of each of the tuning forks: 256-C, 320-E, 385-G and 512-C. The number, e.g., 256, indicates the frequency in Hertz of the tuning fork. With a 256-C tuning fork the tines, or metal forks, will be moving back-and-forth 256 times in one second. Describe what you hear on Worksheet 1.

2. **Reactivate the tuning fork using the tuning fork activator.**
3. **Place the tips of your fingers lightly on the vibrating tines of a tuning fork and feel the vibrations.** Describe what happens on Worksheet 1.
4. **Hold a sheet of paper in one hand and use the other hand to activate the tuning fork with the activator.** Touch the paper to the vibrating tines of a tuning fork. What occurs? Describe what happens on Worksheet 1.
5. **Place the tines of a vibrating tuning fork into the water.** Describe what happens on Worksheet 1.
6. **Try placing the end of the handle of a vibrating tuning fork on the top of your head.** Press the handle against your skull bone fairly hard. You may be able to hear the vibrations from the tuning fork transmitted through your skull to the tiny bones in your inner ear. Describe what you hear on Worksheet 1.
7. **Instead of using the top of your skull, try placing the handle against the skull bone immediately behind one of your ears.** Describe what happens on Worksheet 1.
8. **Try placing the handle onto the top of a table or other objects.** Describe what happens on Worksheet 1.
9. **Suspend the Ping Pong Ball with the Attached String like a pendulum by holding the free end of the attached string.** Slowly, bring a vibrating tuning fork in contact with the motionless ping pong ball. Describe what happens on Worksheet 1.
10. **Activate the two "C" note tuning forks.** Hold both vibrating tuning forks next to your ear. You should hear a pulsing sound. The sound will not be constant or consistent. The intensity should vary. You are hearing the beat frequency, caused by alternating constructive/destructive interference. In order for beats to occur, the frequencies of the two tuning forks must be close, but do not have to be exactly the same. Even though the tuning forks indicate a frequency of 256 Hz, due to the manufacturing process normally you will not find two tuning forks with exactly the same frequency. Describe what you hear on Worksheet 1.
11. **As an experiment, using the two "C" note tuning forks, place a small piece of masking tape near the top of one of the tuning fork tines.** This should be enough to slightly change the frequency of vibrations. By adding weight, and sometimes this is intentionally done, what effect do you think it will have on the frequency? (Hint: Compare the size of a 256-C and a 320-E fork.) What is the effect on the sound due to different sizes? Describe it on Worksheet 1.

Worksheet 1 Questions/Answers

1. Circle the tuning fork that had the lowest pitch:

256-C

320-E

385-G

512-C

2. Circle the tuning fork that had the highest pitch:

256-C

320-E

385-G

512-C

3. Describe what happened when you placed the vibrating tines:
next to your fingers

the tines tickle your fingers

next to a sheet of paper:

you hear a buzzing sound made as the tines hit the paper

in the water:

the water splashes

in contact with the ping pong ball

the ping pong ball quickly bounces away

4. Describe what happened when you placed the handle:
on top of your skull:

you may begin to hear the vibrating tuning fork as the vibrations are transmitted through your skull to the tiny bones behind your ear drum

on the skull bone behind your ear:

same result as above

on top of a table:

the table may resonate and amplify the sound of the vibrating tuning fork

on other objects:

results vary depending on the object; some objects will resonate while others will not

Discussion Points:

- All sounds are produced by vibrations.** When something vibrates it moves back and forth and usually does so very quickly. If the vibrations are within the range of human hearing, we detect a sound. For example, when set in motion, the two forks (tines) of a tuning fork move back and forth, or vibrate.
- Ask students to correlate the frequency of a tuning fork to the pitch of the sound.** As the frequency of the sound increases, the pitch increases. *Note: it is important to activate the tuning fork properly by using the tuning fork activator. Otherwise, something called harmonics result which could cause confusion in trying to answer this question. When properly activated, very little sound from the tuning fork will be heard unless the tuning fork is placed close to the ear. Any sounds heard at a distance from the tuning fork are probably harmonics. Harmonics have a higher frequency than the fundamental natural frequency.*

The lowest frequency that an object can vibrate at is called the fundamental frequency. The fundamental frequency is the simplest way at which an object can vibrate. An object can also resonate at other frequencies and these are called harmonics. In most cases when an object vibrates, there are many harmonics produced which give musical sounds a quality known as timbre. For example, when a piano and a violin play the same note, there is a big difference in the way we perceive the sound quality. This is due to the different harmonics produced in the respective instruments. The number of harmonics produced depend on the object vibrating and the way the vibration is achieved. So, with the tuning fork, to achieve primarily the fundamental mode, it should be struck with the rubber activator.

- All music instruments produce sounds by something that vibrates.** Ask students to identify what vibrates in the following music instruments:

Instrument	Primary source of vibration
Guitar	Strings
Piano	Strings
Saxophone	Reed
Trumpet	Player's lips
Drum	Drumhead
Flute	Air inside the flute

- Since there is no engine in a glider to make noise, does a glider pilot experience any noise?**
Yes, the sound of air rushing over the wings and fuselage.
- When does an airplane make the most noise? Why?**
When taking off and climbing. There are many possible causes for this. Larger aircraft engines generate more noise than smaller aircraft. The sound intensity during take off and climbing are produced nearer the ground and do not have as far to travel to a person than when an aircraft is 4,000 meters in altitude. The intensity from a point source of sound obeys the inverse square law. A sound source 2 times farther away will produce only 1/4 the sound intensity.
- Ask students to describe their own experiences with noise from aircraft.** They might compare the noise produced by commercial jets, military jets, helicopters and propeller driven airplanes.
- What causes all sounds?**
Vibrations
- What are vibrations?**
For example, a guitar string that rapidly moves back and forth is a vibration.
- What is pitch?**
Highness or lowness of a sound
- Compare the pitch of the predominate sound made by a helicopter and a jet engine. Which do you think produces the higher pitch?**
Jet engine

11. What is frequency?

The periodic change in sound pressure

12. What units are used to measure frequency?

Cycles per second or in Hertz, Hz.

13. What is pitch?

The degree of height or depth of a tone or of sound, depending upon the relative rapidity of the vibrations by which it is produced.

14. How is pitch related to frequency?

When frequency increases, the pitch goes up.

15. Explain noise.

Noise is a random mixture of frequencies.

16. Do you think that aircraft can produce sounds that humans cannot hear but other animals can?

Yes; both above and below the normal range of human hearing.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Properties and changes of properties in matter
- Transfer of energy
- Motions and forces

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

Activity 2

Thunder Drum

GRADES**K-8****Time Requirements:** 20 minutes**Materials:**In the Box

Large Thunder Drum

Provided by User

None

Worksheets

None

Reference Materials

None

Key Terms:

Vibrations

Resonance

Objective:

Students will learn about motions and forces and transfer of energy as they:

- Understand that vibrations cause sound
- Are introduced to resonance

Activity Overview:

Students explore vibrations as the source of sound through the use of the Thunder Drum, which provides an introduction to the principle of resonance. A simple spring that has been added to the design produces some unusual sounds.

**Activity:**

The Thunder Drum is a musical instrument used in theaters to create thunderous rumbling with a twitch of the attached string. In order to play it:

1. Place your fingers through the handle slots and shake it with a twisting motion, thus allowing the spring to vibrate.
2. You can create a variety of sounds by placing the opposite hand over the top and scrape the spring or strike it while it is in motion to create a variety of sounds.

3. Lift the spring and let it go to demonstrate a greater resonance .
4. Gently place your finger tips on the drumhead that does not have the spring connected while the Thunder Drum vibrates and produces a sound. What do you feel?



Discussion Points:

1. **The Thunder Drum provides an excellent demonstration of resonance, which occurs when a vibrating object causes another similar object to vibrate.** Specifically, resonance occurs in the Thunder Drum when the drumhead with the spring begins to vibrate. The air inside the drum vibrates and transfers energy to the other end which also begins to move back and forth (vibrate).
2. **Can energy from the vibrating drumhead with the spring be transferred to the other drumhead through the drum cylinder?**
Yes. To answer this question, place your fingertips lightly on the drum cylinder to determine if it is also vibrating.
3. **Aeronautical engineers are very concerned about resonance in the design of engines and the airframe.** In most cases it is not ideal for vibrating parts of the engine or airframe to cause other parts to begin to vibrate. Unwanted vibrations can cause critical parts to break or fail to function.
4. **Compare resonance in musical instruments with resonance in aircraft.** (Musical instruments are designed to produce resonance in the instrument. For example, a guitar string without the guitar body and sound hole would not sound very loud. Aeronautical engineers work to reduce or eliminate resonance from the engines.)

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Properties and changes of properties in matter
- Transfer of energy
- Motions and forces

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology



Reference Materials

Glossary

Decibel:

Unit of sound intensity

Frequency:

The periodic change in sound pressure; frequency is measured in cycles per second or in Hertz (Hz)

Hertz (Hz):

The unit used when designating frequency; cycles per second

Intensity:

The average rate at which sound energy is transmitted through an area between a source and a receiver; sound energy is measured in watts/cm² or in decibels (dB)

Interference:

Regarding sound waves, when two waves of the same, or nearly the same, frequency pass through the same region of space, they interact with each other and cause interference; interference can be either constructive or destructive, depending on how the waves interact

Noise:

Sound with no set patterns in rhythm or frequency; a random mixture of frequencies

Pollution:

The contamination of soil, water, or air with substances, or sounds, that do not belong

Pitch:

The highness or lowness of a sound

Resonance:

The vibration of an object when exposed to sound at its own natural frequency, as in a window pane vibrating when a helicopter flies overhead

Vibrations:

The back-and-forth motion of an object, usually rapid; when referring to sound, many different "objects" can vibrate, such as a guitar string, a column of air, the reed in a clarinet, or your vocal chords

Fig. 1 Vocal cords and larynx

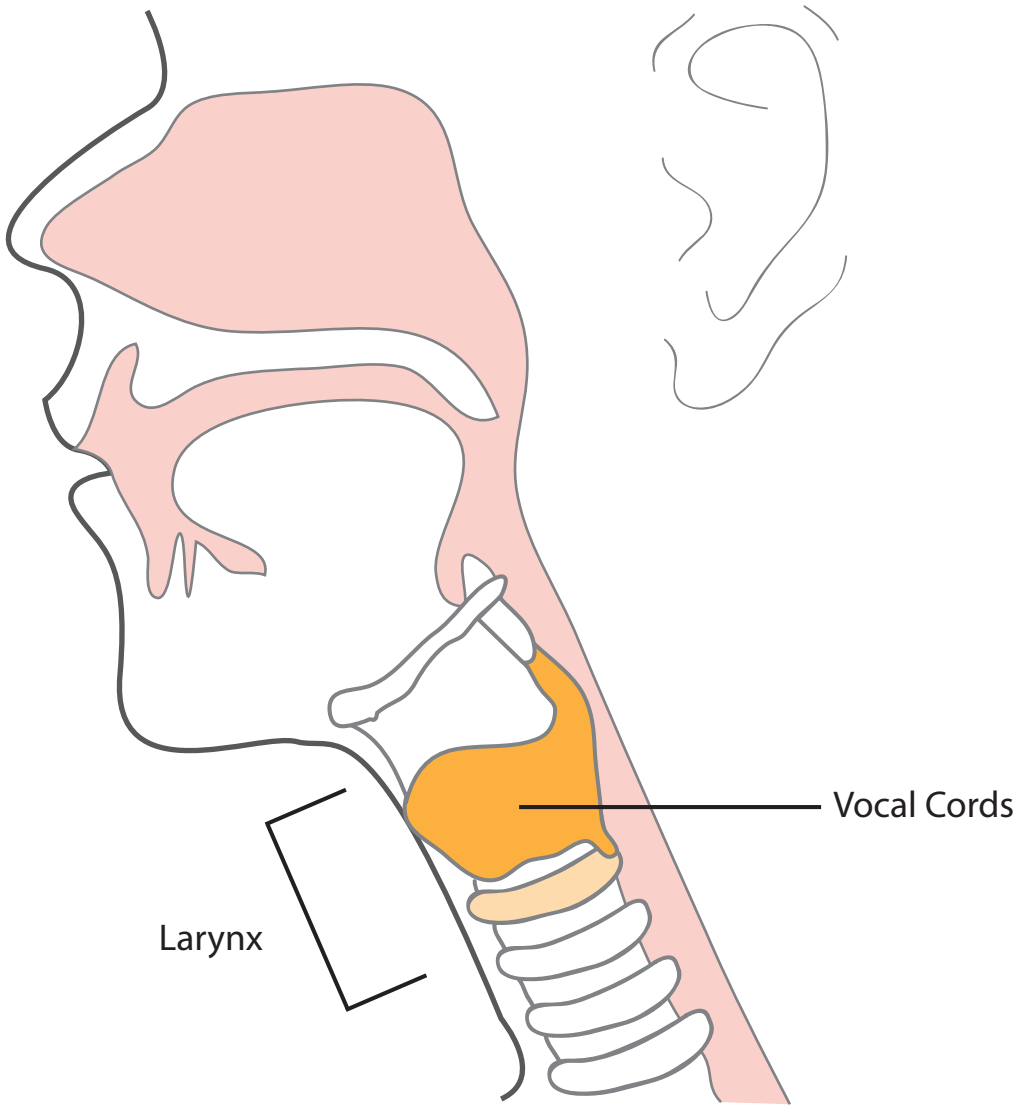
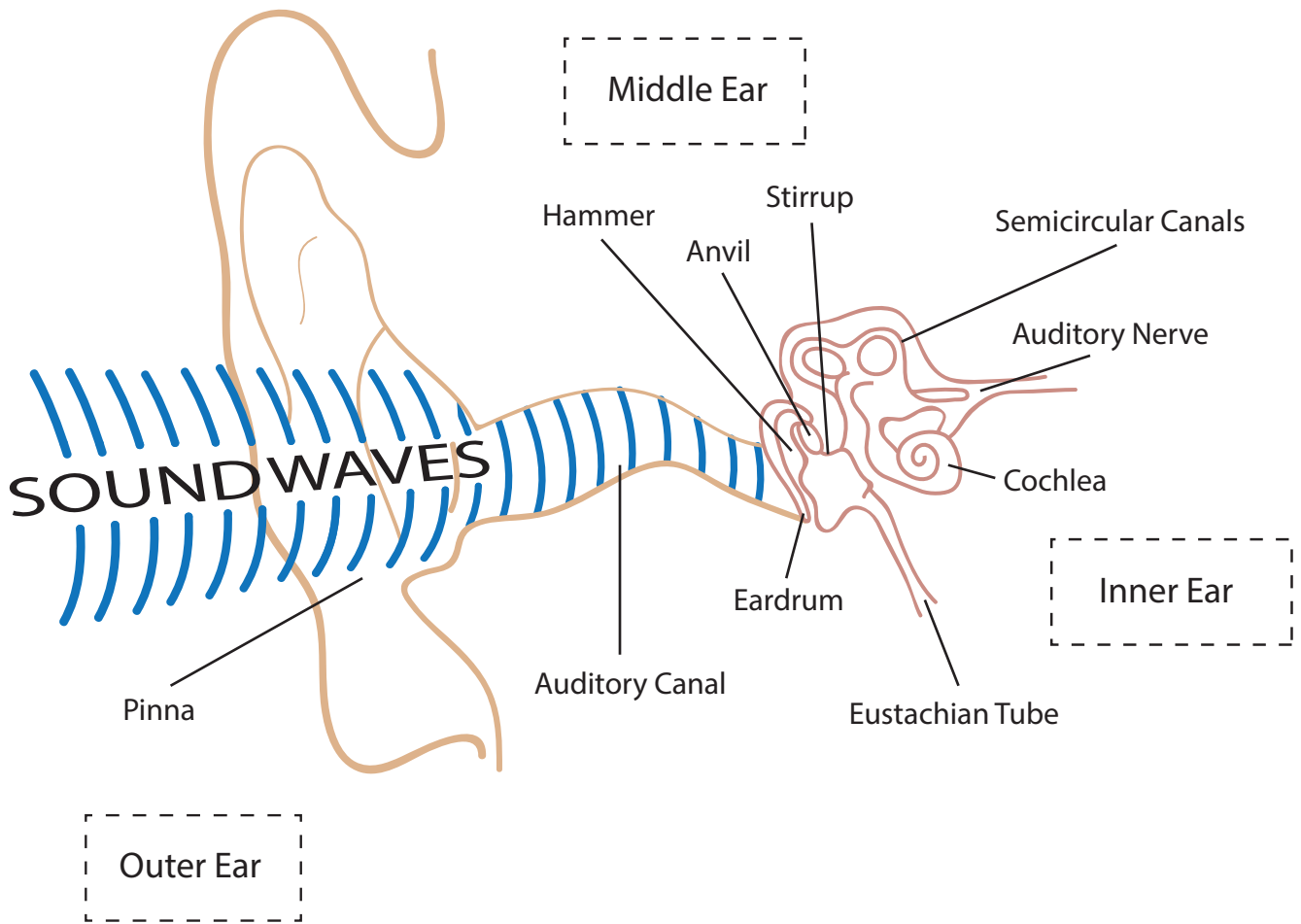


Fig. 2 The human ear





Worksheets

Worksheet 1

Tuning Forks

1. Circle the tuning fork that had the lowest pitch:

256-C 320-E 385-G 512-C

2. Circle the tuning fork that had the highest pitch:

256-C 320-E 385-G 512-C

3. Describe what happened when you placed the vibrating tines:
next to your fingers

next to a sheet of paper:

in the water:

in contact with the ping pong ball

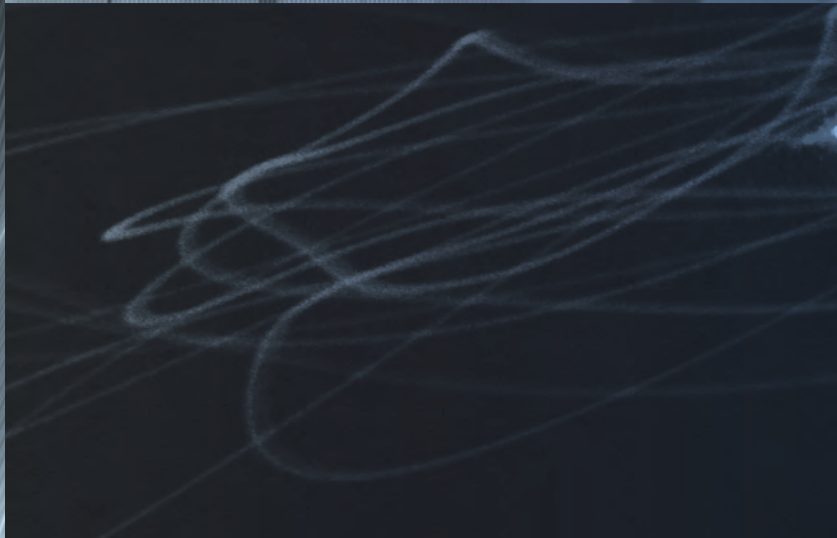
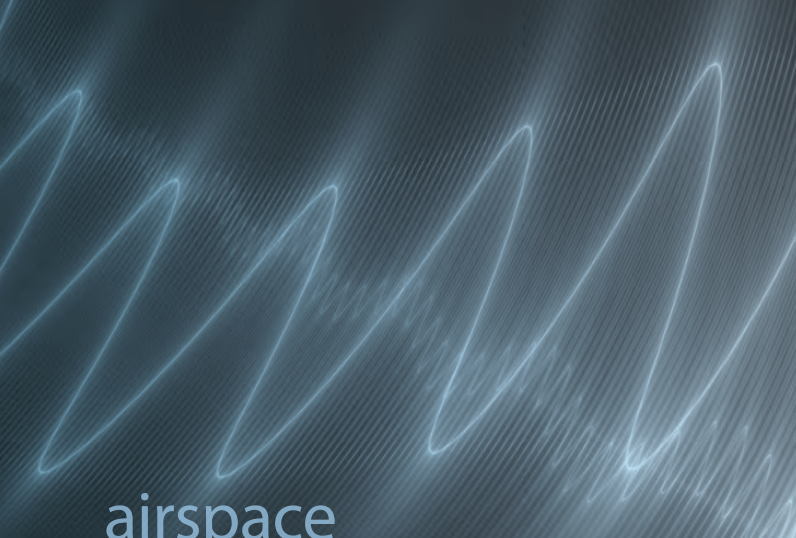
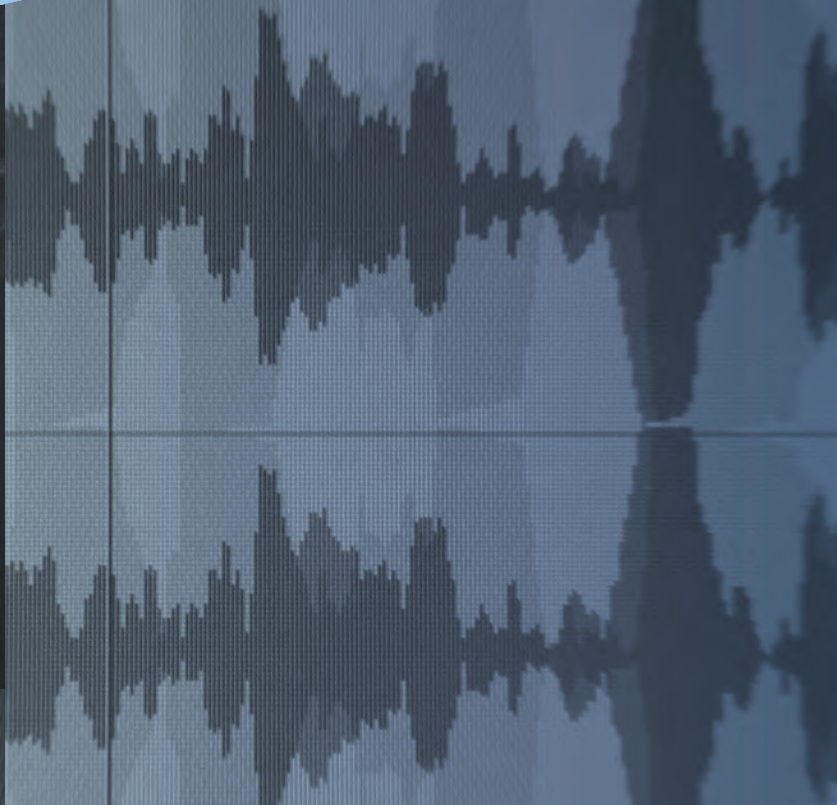
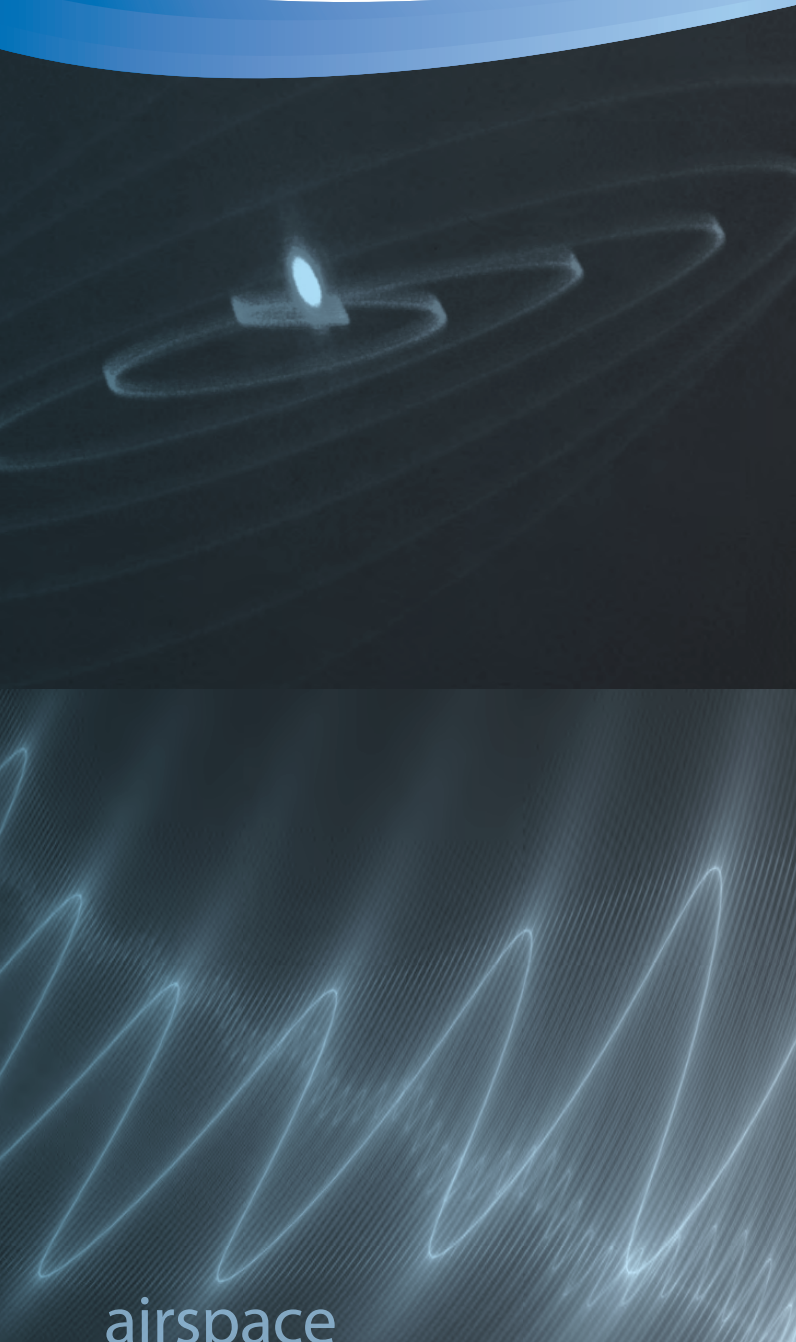
4. Describe what happened when you placed the handle:
on top of your skull:

on the skull bone behind your ear:

on top of a table:

on other objects:

Aeronautics
Research
Mission
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airspace



GRADES 9-12

Good Vibrations



Aeronautics
Research
Mission
Directorate



Good Vibrations

Lesson Overview

Noise from aircraft is an increasing problem in our environment. Contributing factors include an increase in air traffic, demand for land in cities which has pushed development close to airports and larger aircraft which require more powerful engines. Science, Technology, Engineering, and Mathematics (STEM) will help solve this problem. Many groups are working to create solutions. The following three hands-on activities will help students better understand several basic principles of sound:

Tuning Forks: Students will engage in a series of demonstrations that illustrate the concept of vibrations, pitch, frequency, and beats.

Thunder Drum: Students will add a simple spring to the design of a thunder drum and hear very unusual sounds.

Resonator: Students will directly observe resonance in a pair of demonstrations using a series of wooden dowels to illustrate the concepts of natural frequency and resonance. Student worksheets are provided.

Objectives

Students will learn about transfer of energy, motions and forces, and interactions of energy and matter as they learn about the following concepts:

1. Several principles of sound.
2. Noise from aircraft is a growing problem that NASA along with many others are working to reduce the amount of.
3. All sounds are caused by vibrations.
4. Vibrations can be sensed in several ways (hearing, seeing and touching).
5. Pitch is related to the speed or rate of vibration.
6. Resonance.
7. Natural frequency of an object.

Materials:

In the Box

- 1 stick of modeling clay
- 2 wood dowel rods, 1/8" diameter, 18" long
- 1 wood dowel rod, 3/16" diameter, 36" long
- 1 wood dowel rod, 3/16" diameter, 24" long
- 1 wood dowel rod, 3/16" diameter, 30" long
- 2 wood dowel rods, 3/16" diameter, 18" long
- Sandpaper
- 7 Sponge balls
- Wood base, predrilled
- Safety glasses

Provided by User

- Table
- Phillips-head screwdriver or nail

GRADES 9-12

Time Requirements: 45 minutes

Background

As scientists and engineers work to reduce noise pollution from aircraft, a thorough understanding of the physics of sound is necessary. Sound is one of the most important ways we have of sensing our surroundings and of communicating with others. Sound itself is a sensation created in the human brain in response to sensory inputs from the inner ear. However, not all sounds are desirable or beneficial.

All sounds are produced by vibrating objects. One of the reasons that there are so many different sounds is that there is an endless variety of materials that can vibrate and produce them. When you talk or sing, two ligaments that are hidden in your larynx vibrate. They are called your vocal cords, or vocal folds. Each person has a unique set of vocal cords and a uniquely designed larynx which gives rise to the individual character of a person's voice.

Following are some properties of sound waves:

- Frequency and pitch depend on the length of an object that is vibrating; a short string will vibrate faster producing a higher frequency (or pitch) than a long string.
- Multiple sound waves can reinforce or interfere with each other.
- Sound insulation is designed to absorb sound waves. Many of the same materials used in temperature insulation can be used to reduce sound.
- Sound can be reflected (bounced off) or refracted (bent).
- Sound levels decrease rapidly as the distance from the point of origin to the receiver increases; if the distance from the source is doubled, then the intensity decreases approximately one-fourth.
- Some examples of sound intensities as measured by decibels:

Jet plane at takeoff	.....	110-140dB
Loud rock music	.....	110-130dB
Chain saw	.....	110-120dB
Thunderstorm	.....	40-110dB
Vacuum cleaner	.....	60-80dB
Normal voices	.....	50-70dB
Whisper	.....	20-50dB
Purring cat	.....	20-30dB
Falling leaves	.....	10dB
Silence	.....	0dB

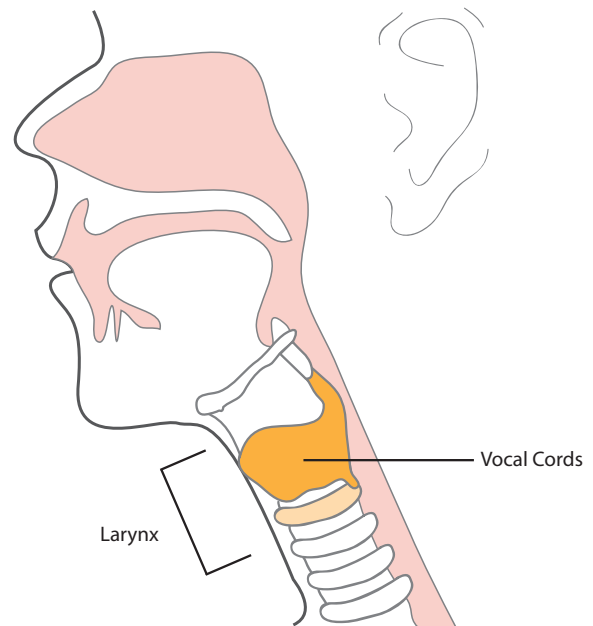


Fig. 1 Vocal cords and larynx

Objects have a frequency at which they prefer to vibrate. This frequency depends on its size and of the material of which it is made. This preferred frequency is called the **natural frequency**. The natural frequency is also called the **resonant frequency**. A guitar string is a good example: When plucked it will vibrate at its natural frequency.

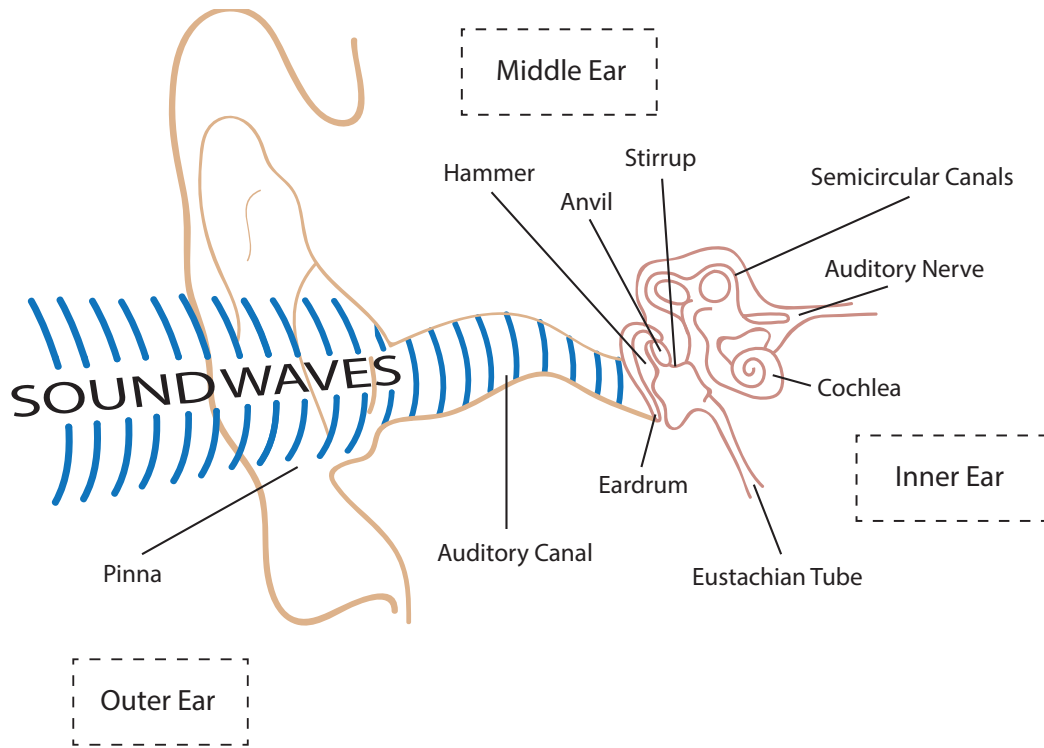


Fig. 2 The human ear

The Human Ear

- The outer ear collects sound waves.
- Sound waves travel down the ear canal and vibrate the eardrum.
- The three small bones (hammer, anvil, stirrup) vibrate behind the eardrum.
- The vibrations enter the cochlea which changes the mechanical energy of the vibrations into electrical nerve impulses that travel to the brain.
- The normal range of sound that a human can hear is about 40 – 18,000 Hertz (Hz).
- As we age, the frequency range tends to narrow; the higher range is most affected.
- Many animals can detect a wider range of sound frequencies than humans can. Dogs can hear higher frequencies than humans; elephants can hear lower frequencies.

For additional information on sound, please review the following Museum in a Box lessons:

Quieting the Popper

Speed of Sound

Seeing Sound

Activity 1

Resonator

GRADES 9-12

Time Requirements: 45 minutes

Materials:

In the Box

- 1 stick of modeling clay
- 2 wood dowel rods, 1/8" diameter, 18" long
- 1 wood dowel rod, 3/16" diameter, 36" long
- 1 wood dowel rod, 3/16" diameter, 24" long
- 1 wood dowel rod, 3/16" diameter, 30" long
- 2 wood dowel rods, 3/16" diameter, 18" long
- Wood base
- Safety glasses
- 7 Sponge balls

Provided by User

- Phillips-head screwdriver, or nail
- Ruler or measuring tape

Worksheets

- Resonator Worksheet: Demonstration 1 (Worksheet 2)
- Resonator Worksheet: Demonstration 1 (Worksheet 3)
- Post-Lab Analysis (Worksheet 4)

Objective:

Students will learn about motions and forces, and interactions of energy and matter as they gain an understanding of resonance, natural frequency and vibration.

Activity Overview:

Students will understand the concepts of natural frequency and resonance by observing a series of wooden dowel demonstrations. First, four wooden dowels of various lengths are placed in a wooden base, which is then rocked back and forth. The different-size wooden dowels resonate at different times as the frequency of the back-and-forth motion of the base is varied. In the second experiment dowels of different diameters are used and the length is kept constant.

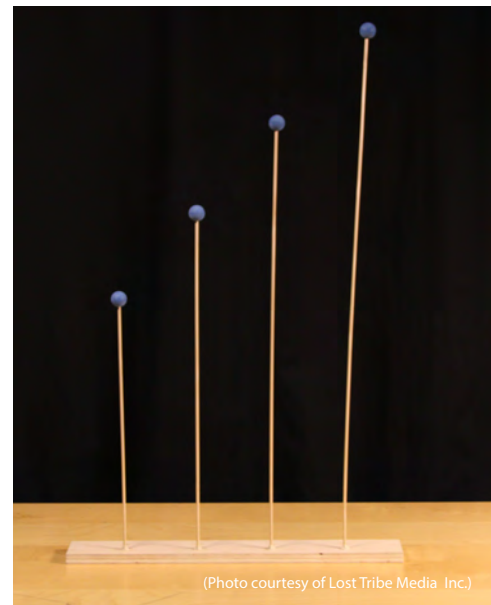
The Flinn Scientific Resonator Demonstration Kit includes a pre-drilled wooden base, pre-cut wooden dowels, 7 sponge balls, sandpaper, and modeling clay. Detailed teacher instructions and student worksheets are provided both in this lesson and in the Flinn instruction sheet.

Wear safety glasses when performing this demonstration. Students sitting or standing near the demonstration also should wear safety glasses. Be cautious when doing the demonstration – the wooden dowels may break if the base is shaken harshly. Follow all laboratory safety guidelines.

Activity:

Demonstration #1 illustrates how the length of a material affects its natural frequency.

1. Obtain four 3/16" diameter wooden dowels of different lengths (36", 30", 24", and 18").



(Photo courtesy of Lost Tribe Media, Inc.)

Img. 1 Demonstration #1 setup

Reference Materials

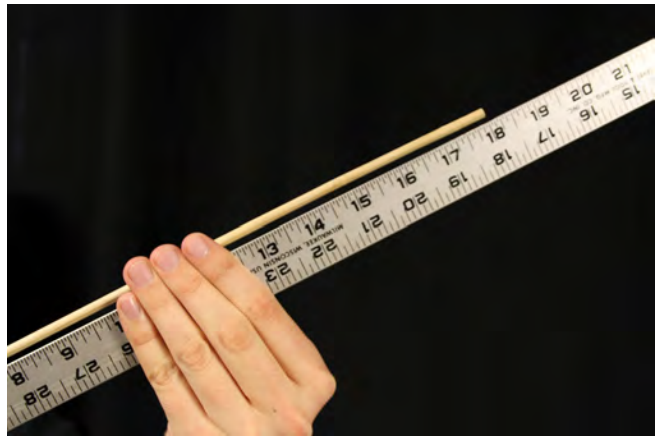
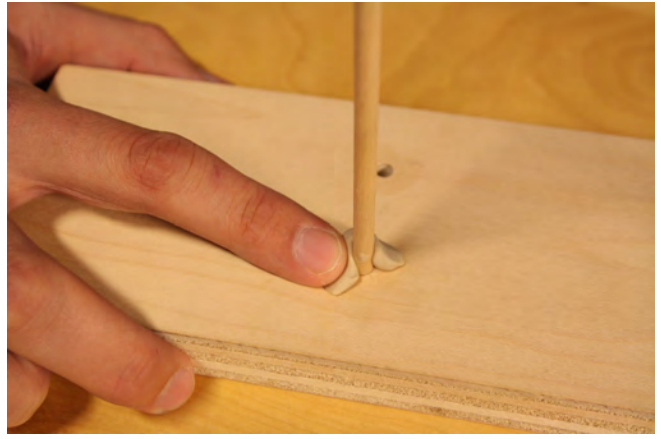
Image 1

Image 2

Key Terms:

Vibrations
Resonance
Frequency

2. **Place the dowel rods into the four aligned 3/16" holes in the wooden base as show in Image 1.** If a wooden dowel does not fit i to its proper hole, the wood may have swelled. Use the sand paper provided to wear down the circumference of the dowel until it will fit i to the proper pre-drilled hole.
3. **Secure the end of each wooden dowel into the hole in the base by placing modeling clay around the dowel and on top of the base.** Then place the sponge balls on top of the dowels.
4. **Measure the length of each wooden dowel and have students record this information on the proper section of Worksheet 2 Resonator Worksheet: Demonstration 1.**



- Place the wooden base on a flat surface and slide the base back and forth (away and toward you) as shown in Image 2. Start with a low frequency and gradually increase the frequency until only the 36" dowel rod begins to resonate (move back and forth). It will take some practice in order to find the correct timing. When the 36" dowel rod is vibrating vigorously, keep this frequency constant for 10-15 seconds and allow the students to observe. Have students record their observations on the Worksheet 2 Resonator Worksheet: Demonstration 1.

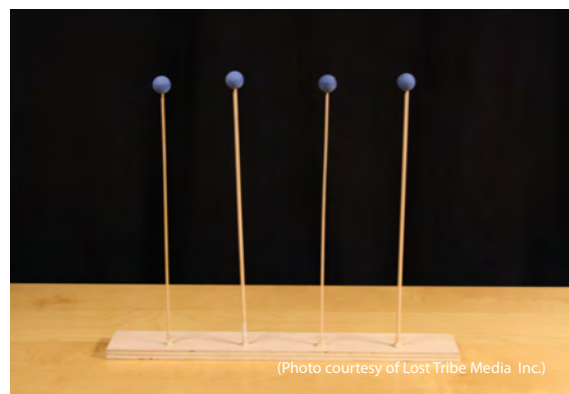


Img. 2 Back-and-forth motion

- Gradually increase the frequency of the back-and-forth motions of the base until the 30" dowel rod begins to resonate. (The 36" dowel will stop resonating.) When this occurs, keep the frequency constant for 10-15 seconds and allow the students to observe and record their observations Worksheet 2 Resonator Worksheet: Demonstration 1.
- Again, gradually increase the frequency of the back-and-forth motion of the base until the 24" dowel rod begins to resonate. Keep the frequency constant for 10-15 seconds and allow the students to observe and record their observations on Worksheet 2 Resonator Worksheet: Demonstration 1.
- Gradually increase the frequency of the back-and-forth motion of the base until the 18" dowel rod begins to resonate. Keep the frequency constant for 10-15 seconds and allow the students to observe and record their observations on Worksheet 2 Resonator Worksheet: Demonstration 1.
- Remove the wooden dowels and clay from the base.

Demonstration #2 illustrates how the diameter of a material affects its natural frequency.

- Obtain two 18" long wooden dowels that are $\frac{3}{16}$ " in diameter, and two 18" long wooden dowels that are $\frac{1}{8}$ " in diameter.
- Place the dowel rods into the proper holes in the wooden base as shown in Image 3. Place a sponge ball on each of the dowels.



Img. 3 Demonstration #2 setup

3. **Secure the end of each wooden dowel into the hole in the base with some modeling clay.**
4. **Measure the diameter of each wooden dowel and have students record this information on Worksheet 3 Resonator Worksheet: Demonstration 2.**
5. **Place the wooden base on a flat surface and slide the base back and forth as shown in Image 4.** Start with a low frequency and gradually increase the frequency until the 1/8" diameter dowel rods begin to resonate. This will take some practice in order to find the correct timing. When the 1/8" diameter dowel rods are vibrating vigorously, keep the frequency of the base constant for 10-15 seconds. Allow the students to observe and record their observations on Worksheet 3 Resonator Worksheet: Demonstration 2.
6. **Gradually increase the frequency of the back-and-forth motions of the base until the 3/16" diameter dowel rods begin to resonate.** When the 3/16" rods are vibrating vigorously, keep the frequency of the base constant for 10-15 seconds. Allow the students to observe and record their observations on Worksheet 3 Resonator Worksheet: Demonstration 2.



Img. 4 Back-and-forth motion

Upon the completion of demonstration 1 and 2 answer the questions in Worksheet 4 Post-Lab Analysis Worksheet.

Discussion Points:

1. **Choose one of the dowels with an attached ball.** Set it in motion and determine its frequency by counting the number of swings that it makes during a minute. One swing is defined as the ball moving from one side to the other and back again. This can also be referred to as a cycle. The frequency will then be that number of cycles per minute. You can write the frequency using the following notation: for example, if the ball went back and forth 30 times in a minute, you would write the frequency as 30 cycles/min. You could also give this frequency as .5 cycles/sec. For sound, that is a very low frequency – way too low for a human to hear. The threshold for human hearing begins at about 18/sec. Other ways to write the frequency are: 18 cycles per second or 18 Hertz, or 18 Hz.
2. **Ask students if they ever have had something in their car rattle.** Anything that can vibrate has what is called a natural frequency of vibration. If the vibrations produced by the engine or motion of the car matches that natural frequency, then a rattle can occur. NASA engineers must know about resonance in order to design aircraft that do not make a lot of noise.
3. **Relate this activity with the Tuning Fork activity.** The tuning forks have a natural frequency at which they vibrate. Is the length of the tuning fork and the frequency at which it vibrates consistent with the results of the Resonator experiment?

Worksheet 1 Resonator Worksheet: Demonstration 1 Questions/Answers

1. **Record the length of each wooden dowel used in Demonstration 1.**

36" 30" 24" 18"

2. **Which dowel resonated first (t the lowest frequency)?**

36", longest

3. **Which dowel resonated last (at the highest frequency)?**

18", shortest

4. **As a wooden dowel achieved resonance, what did you notice about the other dowels?**

As a wooden dowel achieved resonance, the other wooden dowels were either vibrating slightly or not moving at all.

5. **At any point during the demonstration, did two or more dowels resonate at the same time?**

No, two or more dowels did not resonate at the same time. As one dowel resonated, the others were motionless or vibrating slightly.

6. **Other than the length of the dowel, what variable affects the resonance of each dowel?**

The frequency of the back-and-forth motion determines which dowel will resonate.

Worksheet 2 Resonator Worksheet: Demonstration 2 Questions/Answers

1. **Record the diameter and length of the wooden dowels used in Demonstration #2.**

All dowels in this demonstration are 18" long. The diameters of the thin dowels are 1/8", and the diameters of the thick dowels are 3/16".

2. **Which dowel(s) resonated first (at the lowest frequency)?**

The 1/8" thin dowels resonated first when the instructor started moving the base.

3. **Which dowel(s) resonated last (at the highest frequency)?**

The 3/16" dowels resonated last.

4. **At any point during this demonstration did two or more dowels resonate at the same time? Explain your observation.**

Yes, the wooden dowels that have the same diameter resonate together. Therefore, they have the same natural frequency.

5. **What caused the different dowels to resonate at different times?**

The instructor changed the frequency of the back-and-forth motion of the base in order to resonate different dowels.

Worksheet 3 Post-Lab Analysis Worksheet Questions/Answers

1. **Based on your observations in Demonstration #1, do any of the dowels share the same natural frequency? Explain your answer.**

No, the dowels do not share the same natural frequency. They all resonate at different frequencies.

2. **Based on your observations in Demonstration #2, do any of the dowels share the same natural frequency? Explain your answer.**

Yes, wooden dowels that have the same diameter and length resonate together. Therefore, they have the same natural frequency.

3. **What characteristics are necessary in order for two dowel rods to resonate at the same time?**

Wooden dowels must have the same length and diameter in order to resonate together.

4. **Using the same dowels provided in this demonstration kit, describe how an experiment could be set up to test if dowels of different lengths and different diameters share the same natural frequency.**

Individually test each of the 3/16" diameter wooden dowels next to the 18" long 1/8" diameter dowel. Observe if any of the 3/16" dowels resonate at the same time as the 1/8" dowel when the base is moved back-and-forth. If resonance occurs, the two dowels share the same natural frequency.

5. **Describe the relationship between the length of an object and the frequency causing the object to resonate.**

The longer an object, the lower the frequency needed to cause resonance.

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Structure and properties of matter
- Interactions of energy and matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology



Reference Materials

Glossary

Decibel:

Unit of sound intensity

Frequency:

The periodic change in sound pressure; frequency is measured in cycles per second or in Hertz (Hz)

Hertz (Hz):

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Interference:

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Pollution:

The contamination of soil, water, or air with substances, or sounds, that do not belong

Pitch:

The highness or lowness of a sound

Resonance:

The vibration of an object when exposed to sound at its own natural frequency, as in a window pane vibrating when a helicopter flies overhead

Vibrations:

The back-and-forth motion of an object, usually rapid; when referring to sound, many different "objects" can vibrate, such as a guitar string, a column of air, the reed in a clarinet, or your vocal chords



Worksheets

1. Record the length of each wooden dowel used in Demonstration 1.
2. Which dowel resonated first (at the lowest frequency)?
3. Which dowel resonated last (at the highest frequency)?
4. As a wooden dowel achieved resonance, what did you notice about the other dowels?
5. At any point during the demonstration, did two or more dowels resonate at the same time?
6. Other than the length of the dowel, what variable affects the resonance of each dowel?

1. Record the diameter and length of the wooden dowels used in Demonstration #2.
2. Which dowel(s) resonated first (at the lowest frequency)?
3. Which dowel(s) resonated last (at the highest frequency)?
4. At any point during this demonstration did two or more dowels resonate at the same time? Explain your observation.
5. What caused the different dowels to resonate at different times?

Worksheet 3

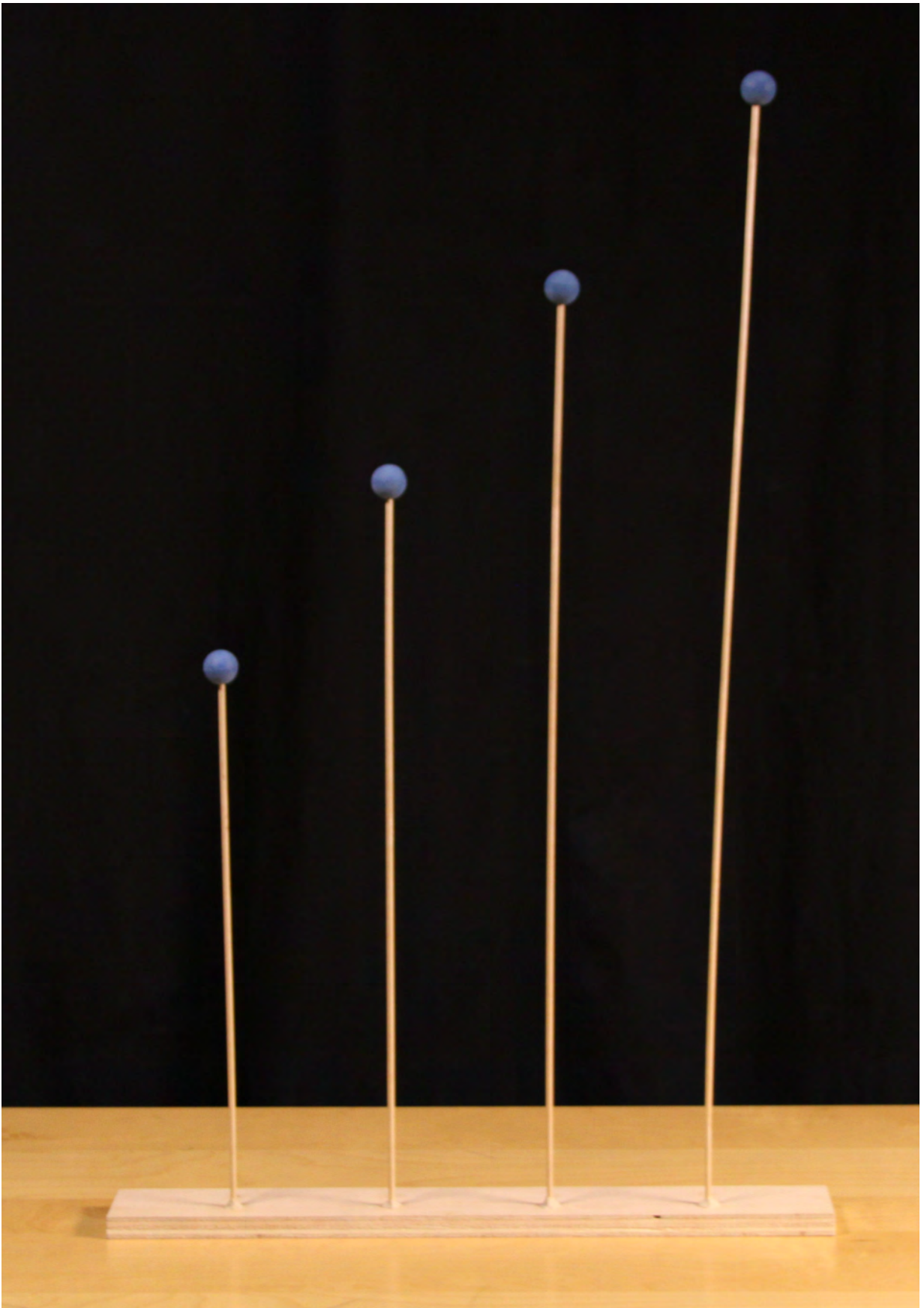
Post-Lab Analysis

1. Based on your observations in Demonstration #1, do any of the dowels share the same natural frequency? Explain your answer.
2. Based on your observations in Demonstration #2, do any of the dowels share the same natural frequency? Explain your answer.
3. What characteristics are necessary in order for two dowel rods to resonate at the same time?
4. Using the same dowels provided in this demonstration kit, describe how an experiment could be set up to test if dowels of different lengths and different diameters share the same natural frequency.
5. Describe the relationship between the length of an object and the frequency causing the object to resonate.



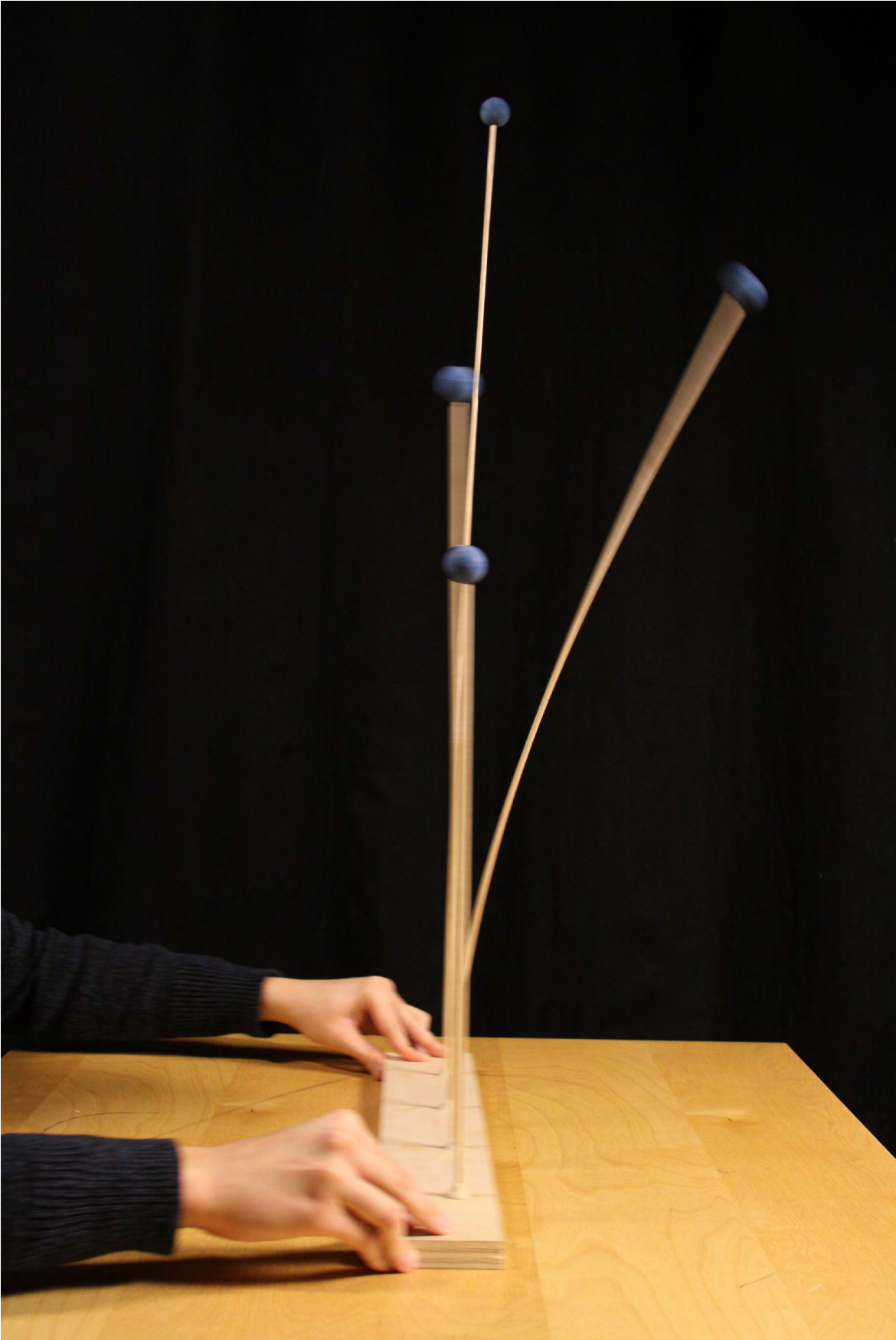
Images

Img. 1 Demonstration #1 setup



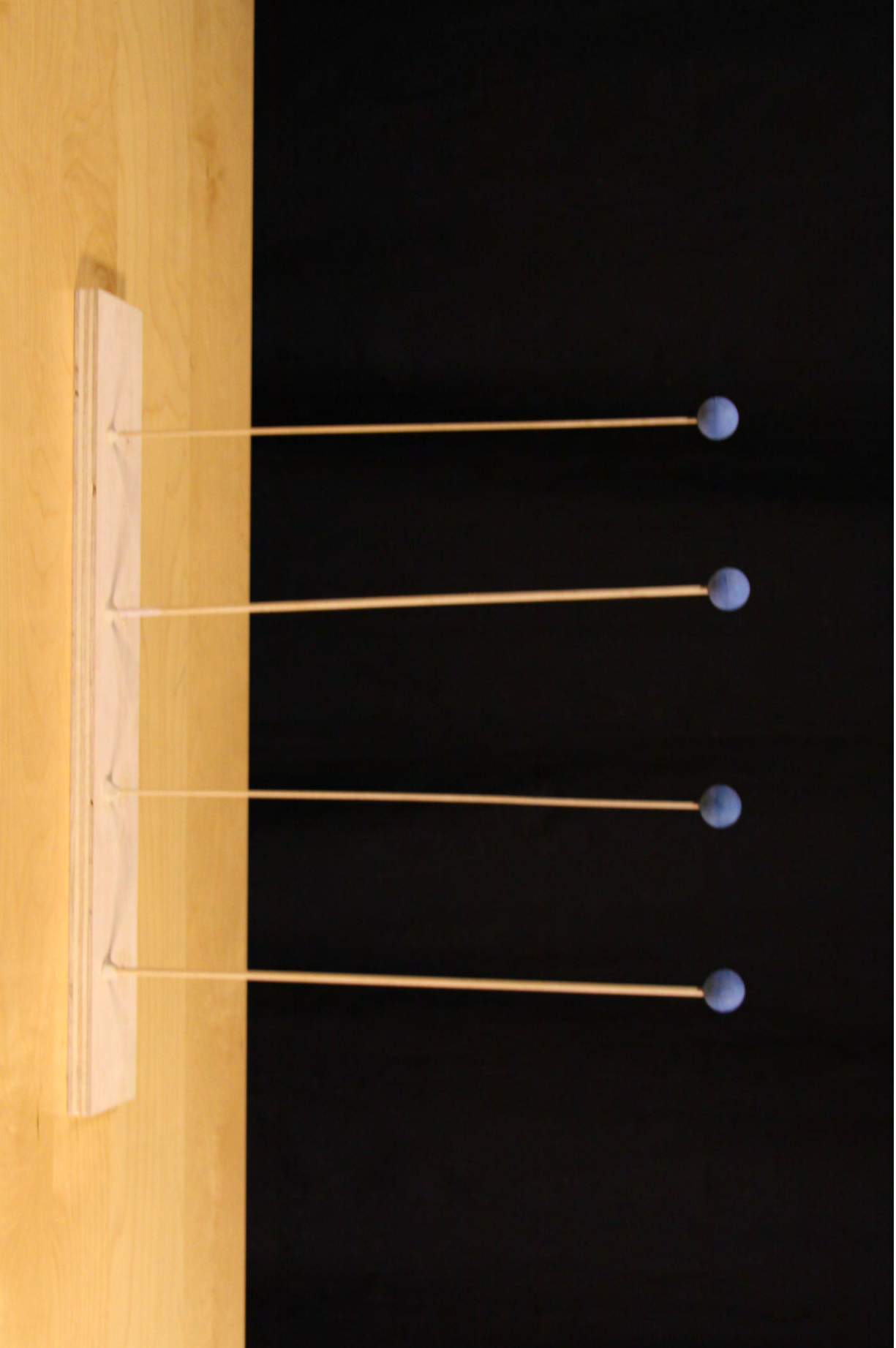
(Photo courtesy of Lost Tribe Media, Inc.)

Img. 2 Back-and-forth motion



(Photo courtesy of Lost Tribe Media, Inc.)

Img. 3 Demonstration #2 setup



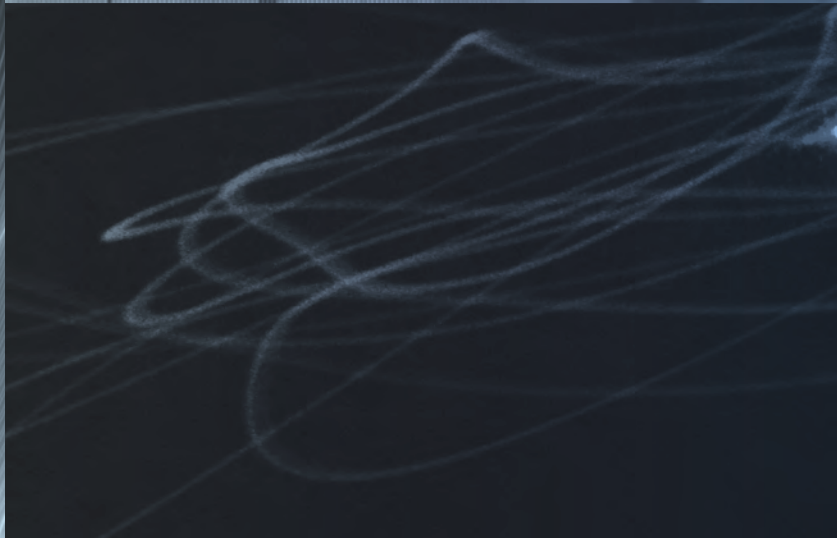
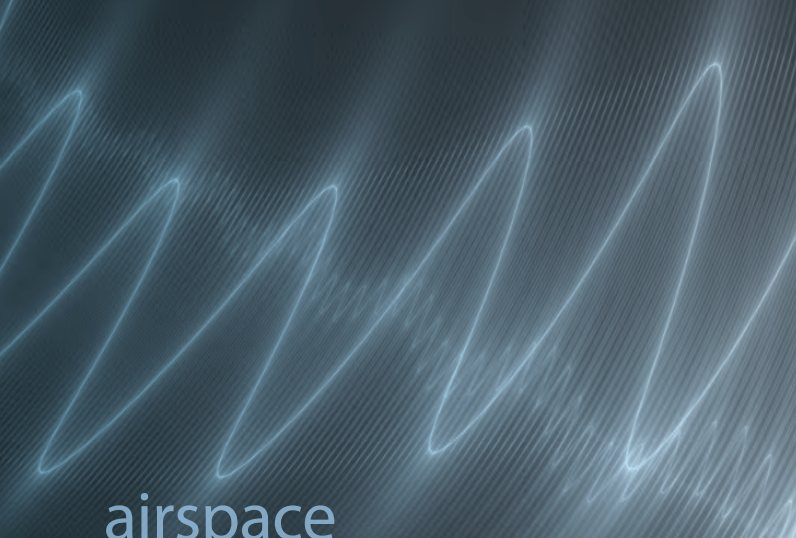
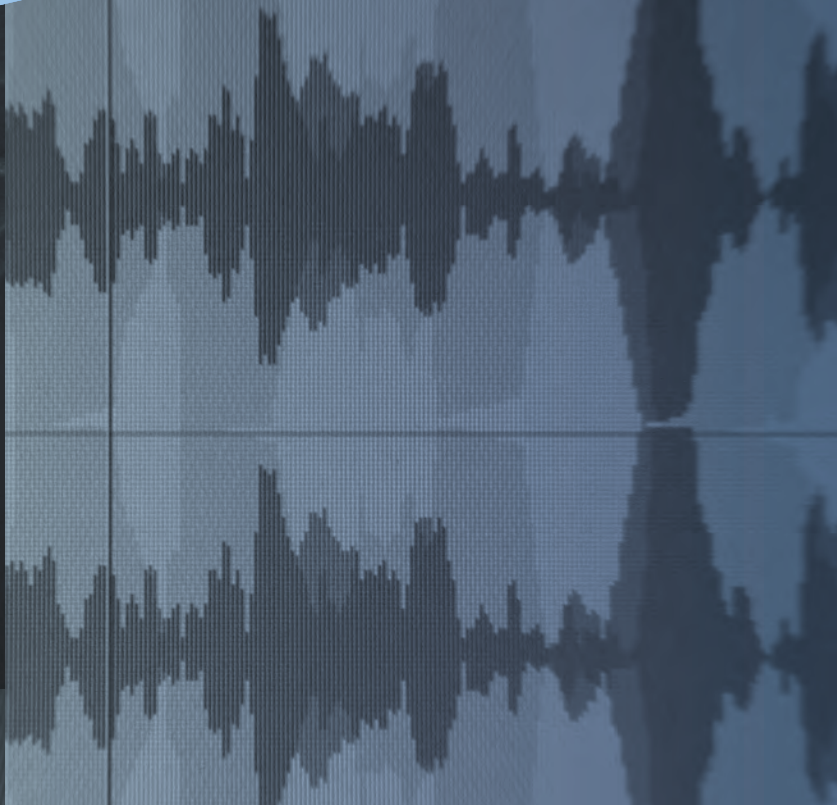
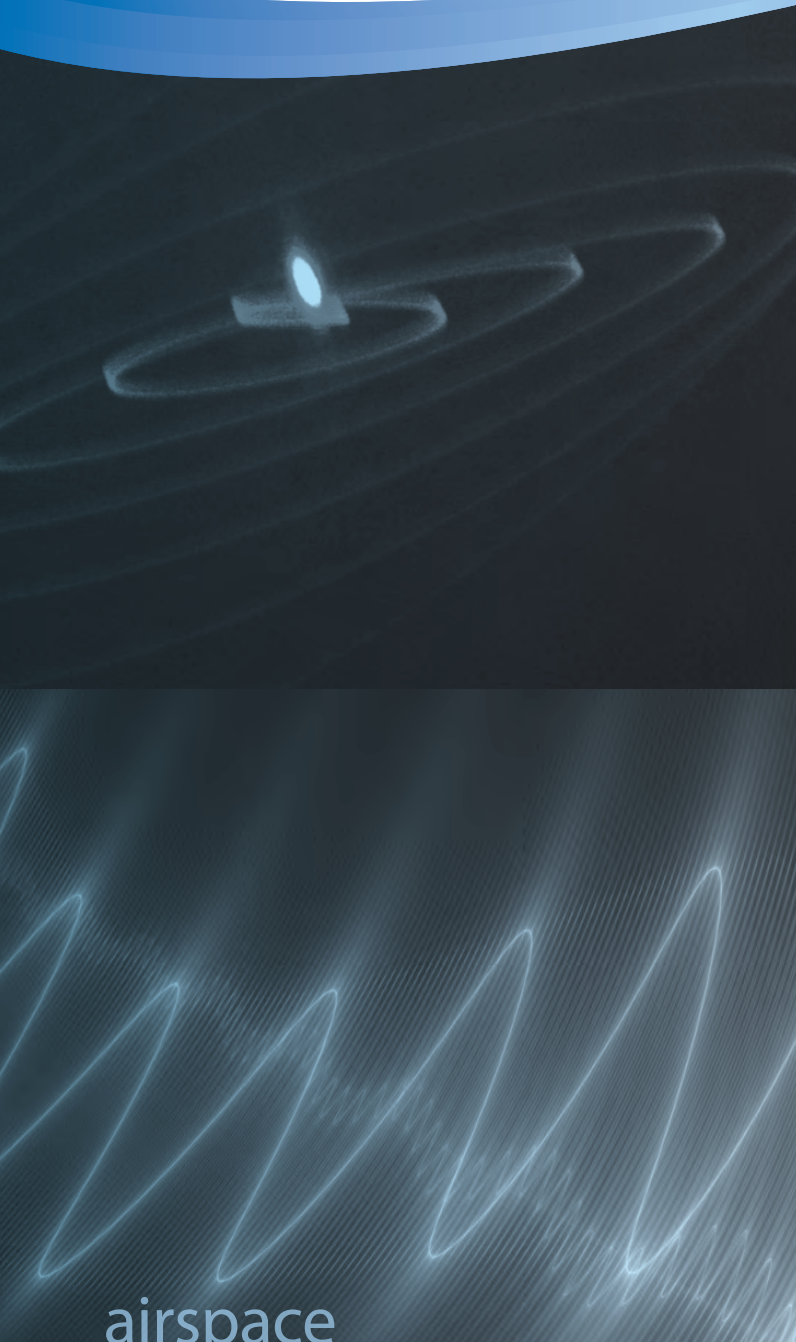
(Photo courtesy of Lost Tribe Media, Inc.)

Img. 4 Back-and-forth motion

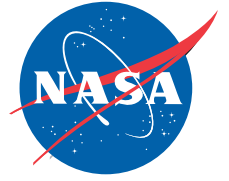


(Photo courtesy of Lost Tribe Media, Inc.)

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airspace



GRADES

9-12

Speed of Sound



airspace

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Speed of Sound

Lesson Overview

As scientists and engineers work to reduce aircraft noise, a thorough understanding of the physics of sound is necessary. The speed of sound and how that speed depends on certain variables are important concepts related to the physics of sound. Engineers who design every aspect of an airplane, from the airframe through the engines, must have a thorough understanding of the speed of sound, since noise affects each component of an aircraft. In this lesson, participants will learn about motions and forces and the interactions of energy and matter as they use the principle of resonance to set up an experiment in the classroom to measure the speed of sound in air. The speed of sound will be calculated using the standard relationship between velocity, frequency and wavelength. A second activity challenges students to produce longitudinal and transverse waves in a spring. They will measure wavelength, amplitude and the period of a transverse wave. The speed of a wave in a spring will be determined.

Objectives

Students will:

1. Use experimental procedures to determine the speed of sound in a gas (air).
2. Better understand some of the principles of sound.
3. Become familiar with the wave equation: velocity = wavelength · frequency ($v = \lambda \cdot f$).
4. Measure amplitude, wavelength and the period of a wave in a spring.
5. Understand that noise from aircraft is a growing problem and that NASA is working to reduce the amount of noise.

Materials:

In the Box

Plastic tube, clear, 1" diameter, 2 ft.

PVC tube, white, ½" diameter, 2 ft.

Rubber stopper

Stop watches

Eye protection

Meter stick

Container to hold water

Tuning forks set of 4

Tuning fork, 256 Hz

Rubber activator block

Provided by User

Water, 1 gallon

Calculator

Pencils

Petroleum jelly

GRADES

9-12

Time Requirements: 1 hour 45 minutes

Background

As scientists and engineers work to reduce noise pollution from aircraft, a thorough understanding of the physics of sound is necessary. The speed of sound and how it depends on certain variables are important concepts related to the physics of sound. Sound is one of the most important ways we have of sensing our surroundings and communicating with others. Sound itself is a sensation created in the human brain in response to sensory inputs from the inner ear. However, not all sounds are desirable or beneficial. The following information is presented to help the reader develop a better understanding of sound, including how it is made and how it travels:

- Sound is produced by vibrating objects.
- Sound is transmitted through the air and can travel through solids, liquids, or gases.
- Sound cannot travel through a vacuum.
- Air is a gas, and a very important property of any gas is the speed at which sound travels through it. The speed of “sound” is actually the speed of the transmission of a small disturbance through a medium.
- The speed of sound in air is slower than it is in solids and liquids. To some this may seem counterintuitive.

	Solid Steel	Sea Water	Air
Speed of sound in m/sec at 21° C (70°F)	5,180 m/s	1,524 m/s	331 m/s
Speed of sound in mph at 21° C (70°F)	11,600 mph	3,414 mph	740 mph

Fig. 1 Speed of sound in different mediums

Given normal atmospheric conditions, the temperature, and thus speed of sound, varies with altitude:

Altitude	Temperature	m/sec	Km/h	mph	knots
Sea level	15°C (59°F)	340	1225	761	661
11,000m - 20,000m (Cruising altitude of commercial jets)	-57°C (-70°F)	295	1062	660	573
29,000m (Flight of X-43A)	-48°C (-53°F)	301	1083	673	585

Fig. 2 Speed of sound at different altitudes

- The speed of sound is dependent on temperature. As the temperature of the air increases, the speed of sound in air increases.
- Sound waves are longitudinal. They move by alternately squeezing (compression) and stretching (rarefaction).
- Wave science: frequency = number of waves/sec.
- Hertz (Hz) is a unit of frequency where one Hertz equals one cycle, or wave, per second.
- Velocity = wave length (meters) X frequency (Hz or cycles/sec).
- Frequency of sound and pitch are related. The higher the pitch, the greater the frequency.
- Frequency and pitch depend on the length of the object that is vibrating. For example, a short string vibrates faster than a long string resulting in a higher frequency and a higher pitch.
- Multiple sound waves can reinforce or interfere with each other.
- Sound insulation is designed to absorb sound energy. Many of the same materials used in temperature insulation can be used to reduce sound as well.
- The normal range of sound that a human can hear is between 40 – 18,000 Hertz (Hz).
- Many animals can detect a wider range of sound frequencies than humans can.
- Sound can be reflected (bounced off) or refracted (bent) or absorbed.
- Sound levels decrease rapidly as the distance from the point of origin to the receiver increases. If the distance from the source is doubled, then the intensity decreases about one-fourth.
- The decibel is a unit that expresses the relative intensity of sound.

As an aircraft moves through the air, the air molecules near the aircraft are disturbed and begin to move around the aircraft. If the aircraft passes through the air at a low speed, typically less than 250 mph, the density of the air remains the same. But when aircraft travel at higher speeds, some of the energy from the aircraft goes into compressing the air and locally changes the density of the air. This compressibility effect alters the amount of resulting force on the aircraft. The effect becomes more important as speed increases. Near and beyond the speed of sound, about 330 m/s or 760 mph, small disturbances in the flow are transmitted to other locations on the aircraft. But a sharp disturbance generates a shock wave that affects both the lift and drag of an aircraft. The ratio of the speed of the aircraft to the speed of sound in the gas determines the magnitude of the many compressibility effects. Because of the importance of this speed ratio, aerodynamicists have designated it with a special parameter called the Mach number in honor of Ernst Mach, the late 19th century physicist who studied gas dynamics. The Mach number (M) allows us to define flight conditions in which compressibility effects vary.

Jet plane at takeoff	110-140dB
Loud rock music	110-130dB
Chain saw	110-120dB
Thunderstorm	40-110dB
Vacuum cleaner	60-80dB
Normal voices	50-70dB
Whisper	20-50dB
Purring cat	20-30dB
Falling leaves	10dB
Silence	0dB

Fig. 3 Examples of sound intensity

1. Subsonic conditions occur for Mach numbers less than one ($M < 1$). For the lowest subsonic conditions, compressibility can be ignored.
2. As the speed of the object approaches the speed of sound, the flight Mach number is nearly equal to one ($M \approx 1$), and the flow is said to be transonic. At some places on the object, the local speed exceeds the speed of sound. Compressibility effects are most important in transonic flows and led to the early conclusion that a sound barrier existed. Historically, a flight faster than the speed of sound was thought to be impossible. Some engineers thought that the aircraft would self-destruct in this region of flight. We now know that there is no “sound barrier”. In fact, the sound barrier is only an increase in the drag near sonic conditions because of compressibility effects. Because of the high drag associated with compressibility effects along with the variability of the aircraft’s performance due to fluctuations in airflow around different components on the aircraft (for example, some sections

of the plane experiencing effects of air faster than the speed of sound while others are experiencing subsonic conditions), aircraft do not cruise near Mach 1.

- Supersonic conditions occur for Mach numbers greater than one, ($1 < M < 5$). Compressibility effects are important for supersonic aircraft, and shock waves are generated by the surface of the object. For high supersonic speeds ($3 < M < 5$), aerodynamic heating also becomes very important in aircraft design. Even at ($M=2$) heating was an issue for the Concorde. During supersonic flight, the fuselage expanded by a foot due to heating. The nose of any supersonic aircraft is generally the hottest part of the aircraft other than the engines. During supersonic flight, the nose temperature of an aircraft can approach 260°F , almost 50° hotter than boiling water.
- For speeds greater than five times the speed of sound ($M > 5$), the flight is said to be hypersonic. At these speeds, some of the energy of the object goes into exciting the chemical bonds, which hold together the nitrogen and oxygen molecules of the air. At hypersonic speeds, the chemistry of the air must be considered when determining the forces on the object. The Space Shuttle re-enters the atmosphere at high hypersonic speeds, ($M \sim 25$). Under these conditions, the heated air becomes ionized gas, or plasma, and the spacecraft must be insulated from the high temperatures of the plasma.



Fig. 4 Mach number divisions

Standing Waves and Resonance

Imagine that you have a long rope attached to a wall. If you vibrate the end of the rope by shaking it, you can send a wave down the rope. When the wave reaches the other end of the rope it will be reflected back, but it will interfere with the oncoming wave. In most cases there will be a jumble. If you shake the rope at just the right frequency, a standing wave will be created as shown in Fig. 9. A standing wave is produced when two waves traveling in opposite directions interfere with each other and produce a large amplitude wave. When a standing wave is created, then resonance occurs. Another form of resonance occurs when one object is vibrating at the same natural frequency of a second object, which forces that second object into vibration. The frequency at which you are shaking the rope is called the resonant frequency.

In Activity 1: Measuring the Speed of Sound Using Resonance, you will use this wave principle as it applies to sound waves. Instead of vibrating a rope, you will vibrate a column of air in a closed pipe.

Activity 1

Measuring the Speed of Sound Using Resonance

GRADES 9-12**Time Requirements:** 60 minutes**Materials:**In the Box

None

Provided by User

Water, 1 gallon
 Petroleum jelly (optional)
 Calculator
 Pencils
 Copies of the worksheet

Worksheets

None

Reference Materials

None

Key Terms:

Amplitude
 Frequency
 Inteference
 Resonance
 Sound wave
 Standing wave
 Wavelength

Objective:

The purpose of this activity is for students to learn about motion and forces and interactions of energy and matter as they measure the speed of sound in air. Students will become familiar with some of the variables that affect the speed of sound in air. The concepts of resonance and interference will also be introduced.

Activity Overview:

Using a closed pipe and a tuning fork, students will determine the speed of sound in air using a classic physics experiment. In this experiment the tuning fork produces a sound wave that travels down a closed pipe. As the sound wave is reflected off the top of the water in the pipe and returns to the open end, interference between the two sound waves occurs. If the length of the closed pipe is one-fourth of a wavelength, then a standing wave is set up and resonance occurs. The velocity of sound is then calculated using the following equation:

$$v = \text{wavelength} \cdot \text{frequency} = 4(l + .3d) \cdot \text{frequency}$$

where:

l = length (meters) of the closed tube (Fig. 5) when resonance occurs

d = inside diameter (meters) of the clear plastic tube

frequency = 256 Hz, or the number inscribed on the tuning fork

Activity:

1. **A minimum of two people are needed for this activity.**
2. **Place a rubber stopper in the bottom of the clear plastic tube.**
3. **Secure the apparatus so that it will not fall over.**
4. **Pour a small amount of water into the tube and make sure that no leaks occur.** Petroleum jelly around the part of the stopper that contacts the glass will stop leaks if they happen.

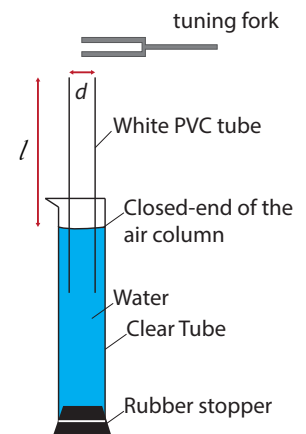


Fig. 5 Apparatus setup

5. **Fill the tube with water as shown in Fig. 5.** The water should be near the top but not overflowing.
6. **Place the white PVC tube in the water (Fig. 5).**
7. **Strike the tuning fork (256 Hz) on your knee or the rubber block activator that comes with the tuning fork kit.** Striking the tuning fork on hard objects produces higher pitched vibrations called harmonics, which will interfere with the experiment. When properly activated, you should have to bring the vibrating tuning fork within a few inches of your ear to hear it well.

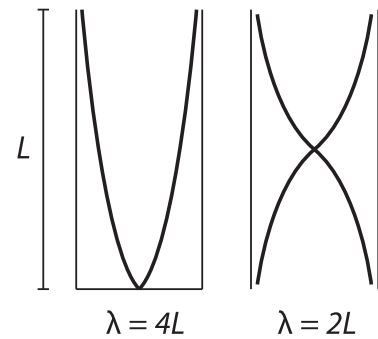


Fig. 6 Resonance in closed and open pipes
(λ = wavelength)

8. **Hold the vibrating tuning fork as shown in Fig. 5.** It is important to keep the vibrating tuning fork directly over the opening of the PVC tube.
9. **Slowly move the white PVC tube AND the tuning fork up and down and listen for the volume of the sound to change.** When you think you've found the length of the tube that produces the loudest sound (resonance), strike the tuning fork again and check your results. You may need to repeat this step several times.
10. **Hold the white PVC tube in the position where resonance is heard.**
11. **Measure the length l (centimeters) and record in the worksheet.** Note: the length l is the distance from the top of the white PVC tube to the top of the water (Fig. 5).
12. **For the 256 Hz tuning fork the volume should increase somewhere near $l = .32$ meters.**
13. **You have just determined $\frac{1}{4}$ of a wavelength for a sound that has a frequency of 256 Hz (see Fig. 6).**
14. **Measure d (Fig. 5) and record on the worksheet.**
15. **Measure the air temperature inside the PVC tube.** Record on the worksheet.
16. **Use the formula given above to calculate the speed of sound in air.**
17. **If time permits, repeat the experiment using tuning forks with different frequencies (320-E, 385-G and 512-C).** Predict how a higher frequency tuning fork will affect. (If the frequency increases, then l should decrease)
18. **Again, if time permits, predict how a change in temperature will affect the speed of sound in air.** Find an environment with a significant change in temperature. Allow sufficient time for the air temperature inside the PVC tube to adjust to the new environment.

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

SCIENCE IN PERSONAL AND SOCIAL PERSPECTIVES

- Science and technology in local, national, and global challenges

HISTORY AND NATURE OF SCIENCE

- Science as human endeavor
- Nature of scientific knowledge
- Historical perspectives

NATIONAL MATH STANDARDS K-12

NUMBER AND OPERATIONS

- Understand numbers, ways of representing numbers, relationships among numbers, and number systems
- Understand meanings of operations and how they relate to one another
- Compute fluently and make reasonable estimates

ALGEBRA

- Represent and analyze mathematical situations and structures using algebraic symbols
- Use mathematical models to represent and understand quantitative relationships

MEASUREMENT

- Understand measurable attributes of objects and the units, systems, and processes of measurement
- Apply appropriate techniques, tools, and formulas to determine measurements

DATA ANALYSIS AND PROBABILITY

- Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them

PROCESS

- Problem Solving
- Communication
- Connections
- Representation

Activity 2

Determining the Speed of a Wave in a Spring

GRADES 9-12**Time Requirements:** 45 minutes**Materials:**In the Box

Safety glasses
Wave modeling spring
(one per group)
Stopwatch
(one per group)
Masking tape

Provided by User

Gloves
(for holding the spring)
Calculator

Worksheets

None

Reference Materials

None

Key Terms:

Amplitude
Frequency
Period
Longitudinal wave
Sound wave
Standing wave
Transverse wave
Wavelength

Objective:

This activity will show students how to determine the speed of a wave using the wave equation. Students will be introduced to the following wave terms: amplitude, wavelength, period, standing waves and frequency. Transverse and longitudinal waves will be demonstrated and compared.

Activity Overview:

Participants are introduced to motions and forces and interactions of energy and matter through standing waves in a wave modeling spring. They will measure the amplitude, wavelength and period of a standing wave. The wave equation will be used to calculate the speed of the wave in the spring. The spring will be used to demonstrate longitudinal and transverse waves.

Caution: Safety glasses should be worn by participants and any students nearby. This activity involves using a stretched spring. If released while stretched, personal and/or property damage could result. Caution should be maintained while holding a stretched spring.

Activity:**Demonstrating a Transverse Wave (Requires at least two people)**

1. **Person One will hold one end of the spring (Fig. 7).** Person One should grasp their end of the spring with both hands and hold the spring against their body. The idea is to keep their end of the spring from moving as little as possible. Using a piece of masking tape, mark the spot where Person One stands. Person One should always stand in this spot.
2. **Person Two will provide the up-and-down motion to produce the standing wave.**
3. **Person Two should take two or three steps backward to stretch the spring.**
4. **Person Two will then begin moving their hands up and down to produce a transverse standing wave.**
5. **Have students try to produce all of the harmonics shown in Figs. 9, 10, 11.**

6. Let the spring come to a rest. Have Person Two flick their wrist up-and-down once. This will produce a small transverse wave that will travel down the spring.
7. Observe the wave when it reaches Person One.
8. Record your observations on the worksheet.

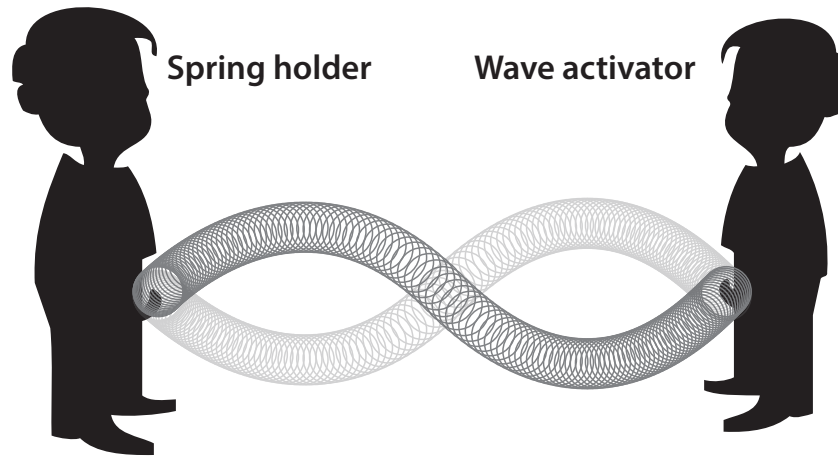


Fig. 7 Transverse wave

Demonstrating a Longitudinal Wave (Requires at least two people per group)

1. Lay the spring flat on the floor and have Person One and Person Two slightly stretch the spring.
2. Have Person One compress a short portion of the spring, then release it.
3. Watch the wave travel down the spring.
4. Observe the wave when it reaches the Person Two.
5. Record your observations on the worksheet.

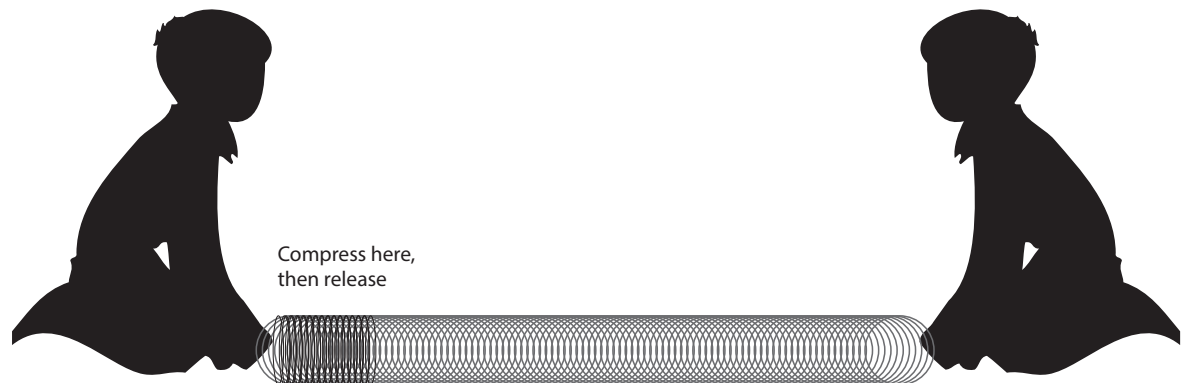
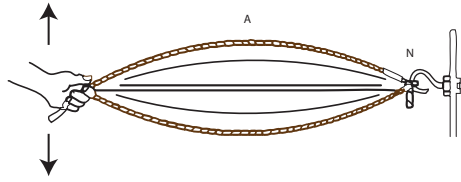


Fig. 8 Longitudinal wave

Measuring Wave Speed (Requires at least three people per group.)

1. **Begin with the fundamental (first harmonic) standing wave as shown in Fig. 9.** The first harmonic is the simplest resonant frequency of a standing wave.
2. **Measure the distance between the hands of Person One and Person Two.** Mark the distance on the floor with pieces of masking tape. This is one-half of the wave length. Multiply by two to find the wavelength.
3. **Record the wavelength on the worksheet.**
4. **A third person will use a stopwatch to time ten periods of oscillation (a period is the time it takes for any part of the spring to go through one complete cycle).** One way to do this is to watch the hands of Person One. Begin when the hands are at the highest point. One cycle is completed when the hands return to that same point.
5. **Record the time for ten cycles on the worksheet.**
6. **Calculate the period, T, for the standing wave by dividing the time for ten cycles by ten.**
7. **Record the period, T, on the worksheet.**
8. **The frequency is the reciprocal of T, or $1/T$ where T is in seconds.**
9. **Record the frequency on the worksheet.**
10. **Calculate speed, V (meters/second) of the wave using the wave equation:**

$$v = \text{wavelength} \cdot \text{frequency}$$
11. **If time permits, repeat the above procedure using a first overtone (second harmonic) and second overtone (third harmonic) as shown in Fig. 10 and 11.** The second harmonic is a resonant frequency of a standing wave that has three nodes. In Fig. 10 the hand is a node. A third harmonic has four nodes, Fig. 11.
12. **It will be helpful to time 20 periods for the second harmonic and 30 periods for the third harmonic.**
13. **For the second harmonic the distance between the hands of Person One and the hands of Person Two is the wavelength.**
14. **For the third harmonic the distance between hands is 1.5 wavelengths.** To find the wavelength multiply the distance between the hands of Person One and the hands of Person Two by $2/3$.



A = Antinode N = Node

Fig. 9 Fundamental or First Harmonic

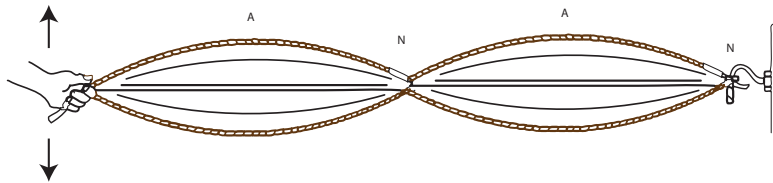


Fig. 10 First Overtone or Second Harmonic

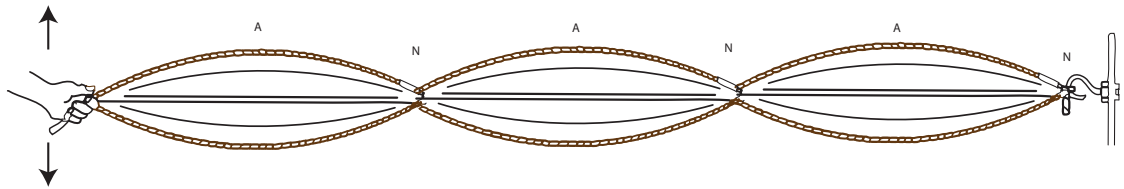
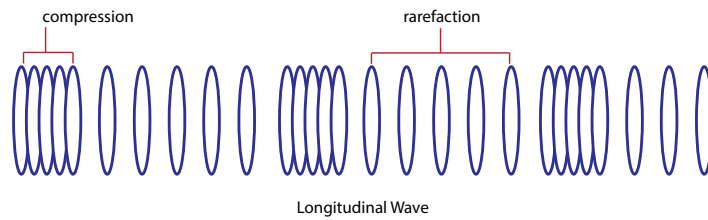
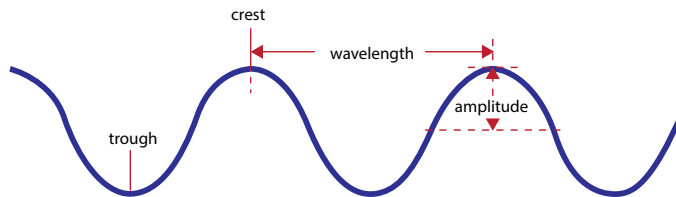


Fig. 11 Second Overtone or Third Harmonic



Longitudinal Wave



Transverse Wave

Fig. 12 Longitudinal and Transverse waves

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- Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them

PROCESS

- Problem Solving
- Communication
- Connections
- Representation



Reference Materials

Glossary

Acoustics:

The study of sound

Amplitude:

The height of a wave; the amplitude determines the amount of energy a wave carries; high volume sounds have large amplitudes

Antinode:

A point of destructive interference in a standing wave

Decibel:

A unit that expresses the relative intensity of sound

Frequency:

The periodic change in sound pressure; frequency is measured in cycles per second or in Hertz (Hz); in music it is called pitch; in music pitch can be high (soprano) or low (bass) or somewhere in between

Hertz:

Hertz (Hz) is a unit of frequency where one Hertz equals one cycle, or wave, per second second

Intensity:

The average rate at which sound energy is transmitted through an area between a source and a receiver. Sound energy is measured in watts/cm² or in decibels (dB)

Interference:

Occurs when two waves interact with each other; in some cases the waves will reinforce one another and the volume or intensity will increase (constructive interference); at other times the waves will cancel each other out and little or no sound will be heard (destructive interference)

Longitudinal wave:

The oscillations are in the same direction as the line of travel; a sound wave is an example

Node:

A point of constructive interference in a standing wave

Noise:

Sound with no set patterns in rhythm or frequency

Period:

The time it takes for two successive wave crests to pass a given point; also given as the reciprocal of the frequency

Pitch:

The highness or lowness of a sound

Resonance:

The vibration of an object when exposed to sound at its own natural frequency, as in a window pane vibrating when a helicopter flies overhead; also occurs when two sound waves reinforce one another

Sound wave:

Produced whenever a vibrating object creates changes in the pressure of a medium, such as air

Speed:

How fast an object is moving with respect to another object; for example, how fast an airplane moves with respect to the ground

Standing wave:

Produced when two waves traveling in opposite directions interfere with each other and produce a large amplitude wave

Transverse wave:

The oscillations are perpendicular to the direction of travel

Ultrasound:

Sound that is too high in frequency to be heard by the human ear

Wavelength:

The distance between two successive crests in a wave

Velocity

Speed and direction; for example, an airplane moving at 350 kilometers per hour going East

Fig. 1 Speed of sound in different mediums

	Solid Steel	Sea Water	Air
Speed of sound in m/sec at 21° C (70°F)	5,180 m/s	1,524 m/s	331 m/s
Speed of sound in mph at 21° C (70°F)	11,600 mph	3,414 mph	740 mph

Fig. 2 Speed of sound at different altitudes

Altitude	Temperature	m/sec	Km/h	mph	knots
Sea level	15°C (59°F)	340	1225	761	661
11,000m - 20,000m (Cruising altitude of commercial jets)	-57°C (-70°F)	295	1062	660	573
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Fig. 3 Examples of sound intensity

Jet plane at takeoff	110-140dB
Loud rock music	110-130dB
Chain saw	110-120dB
Thunderstorm	40-110dB
Vacuum cleaner	60-80dB
Normal voices	50-70dB
Whisper	20-50dB
Purring cat	20-30dB
Falling leaves	10dB
Silence	0dB

Fig. 4 Mach number divisions



Fig. 5 Apparatus setup

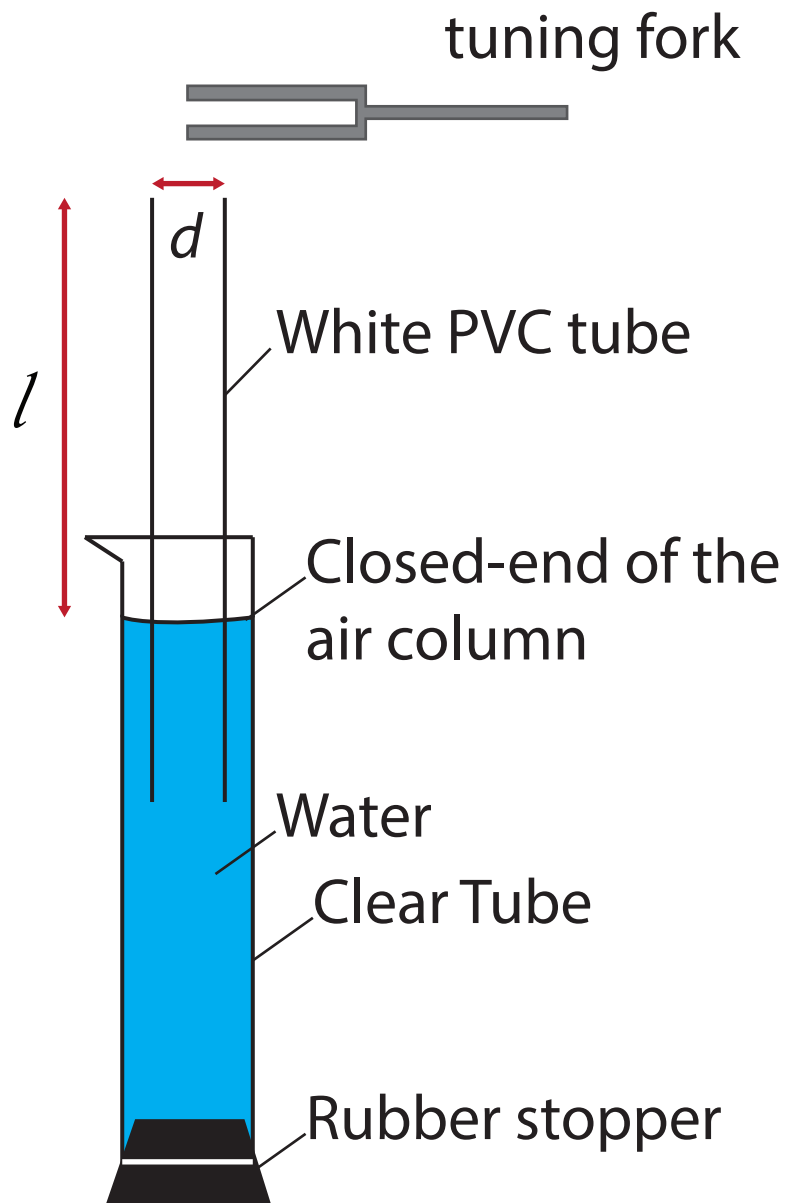


Fig. 6 Resonance in closed and open pipes (λ = wavelength)

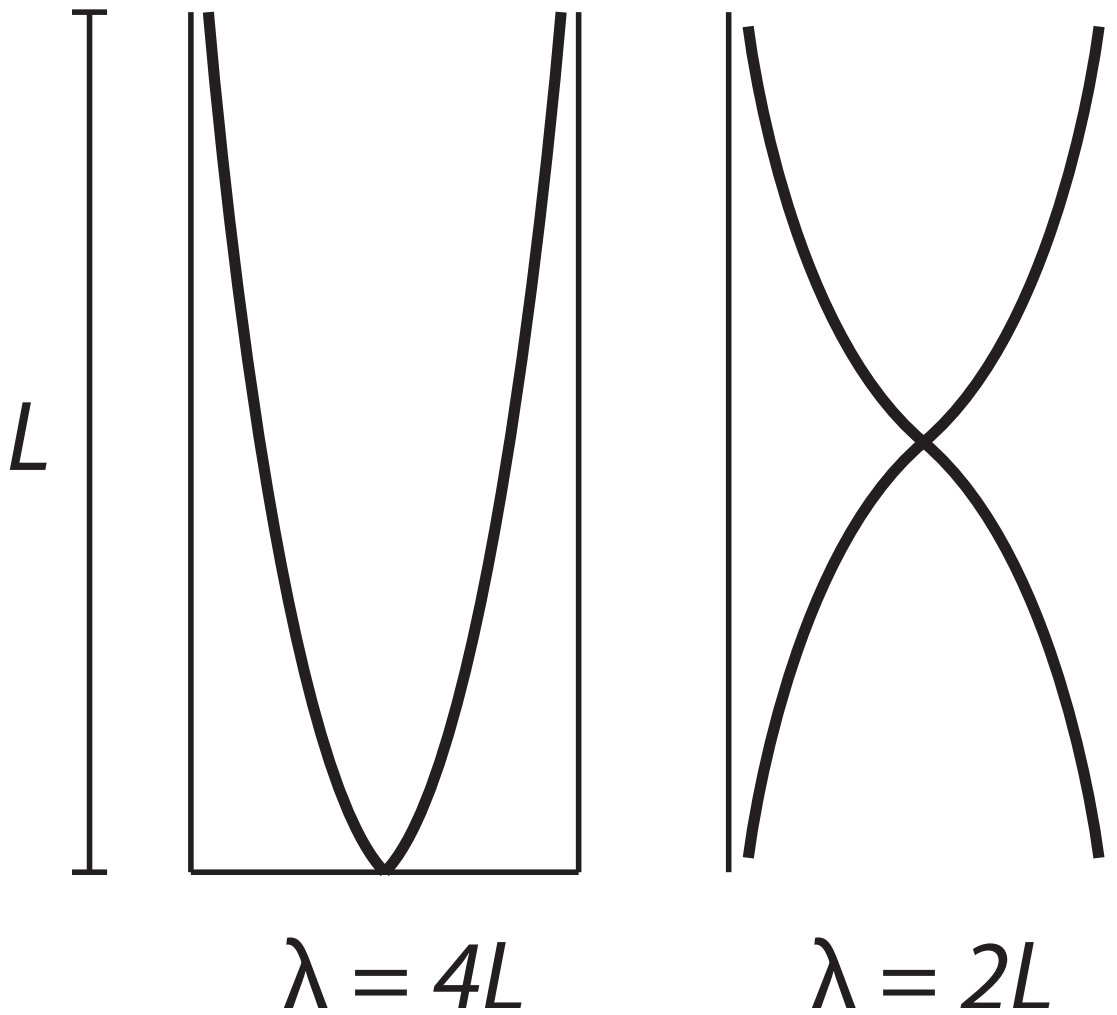


Fig. 7 Transverse wave

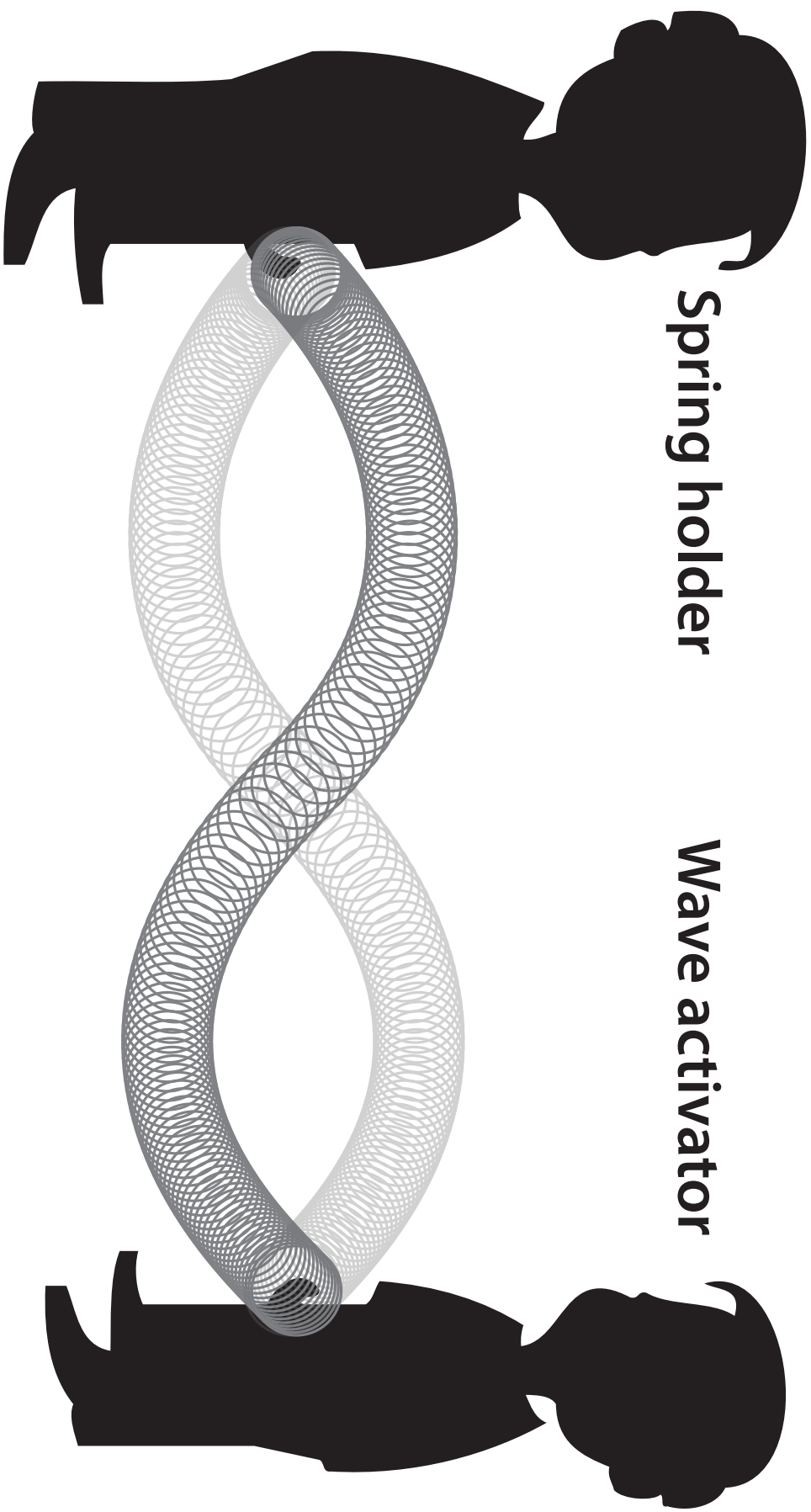


Fig. 8 Longitudinal waves

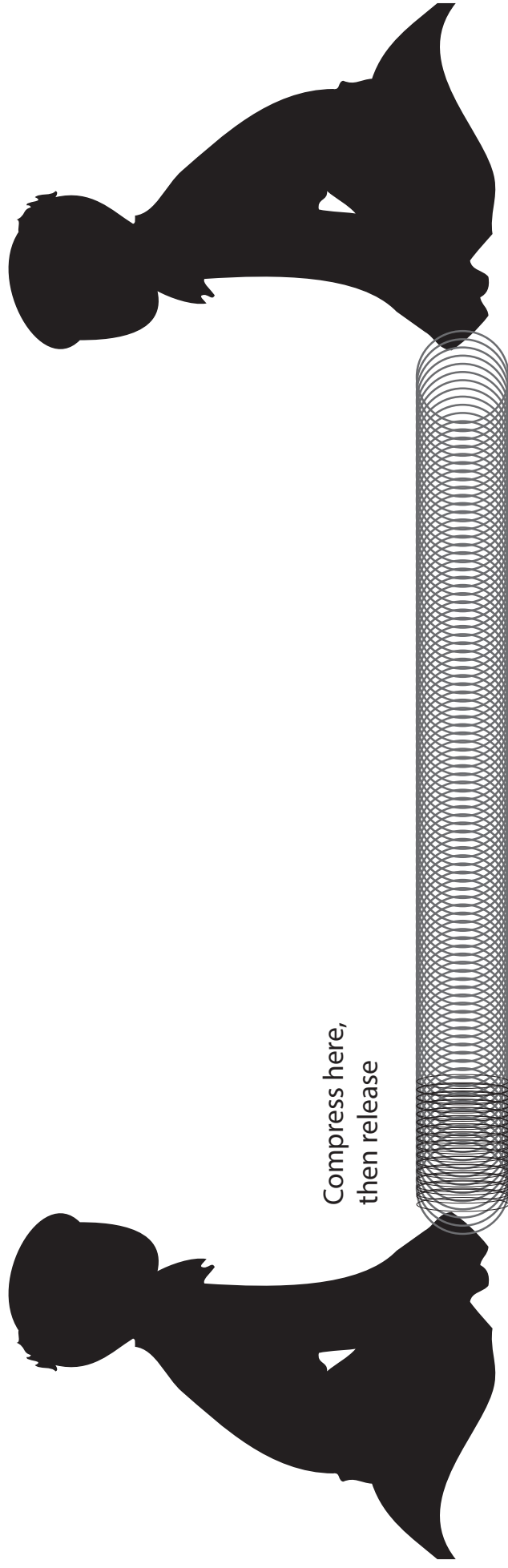
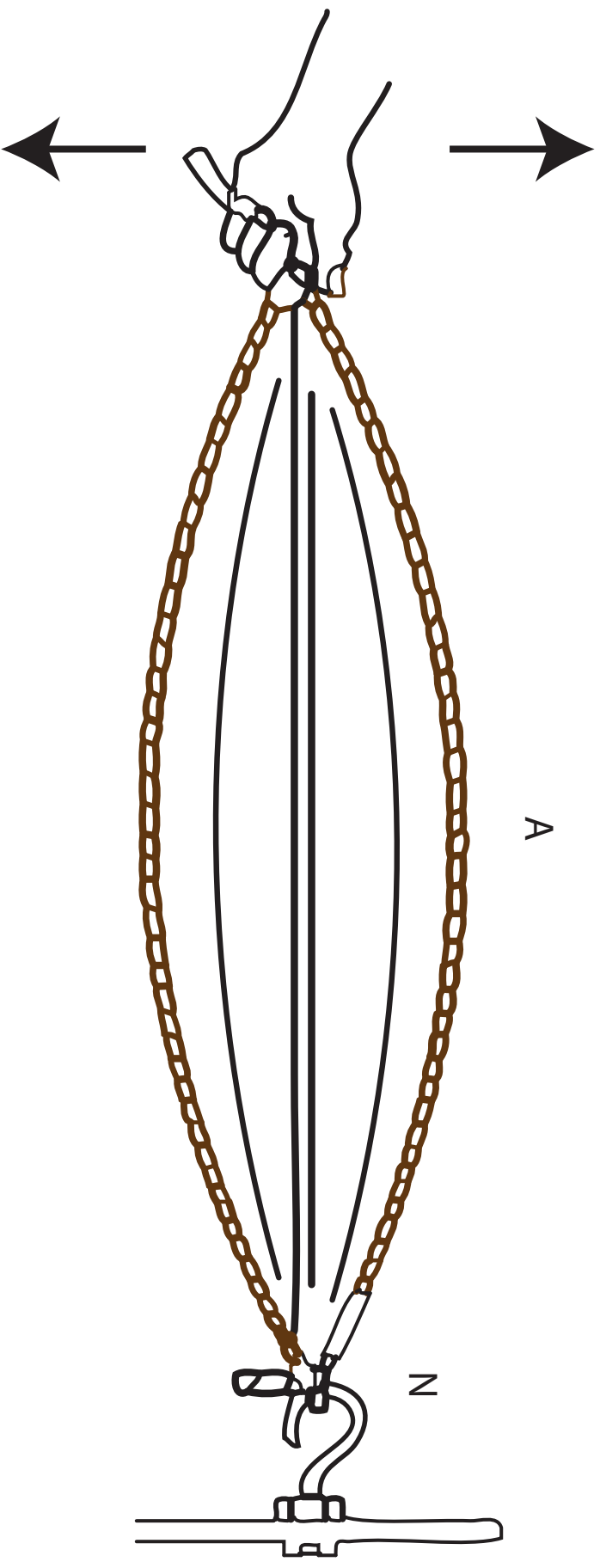


Fig. 9 Fundamental or First Harmonic



A = Antinode N = Node

Fig. 10 First Overtone or Second Harmonic

A = Antinode N = Node

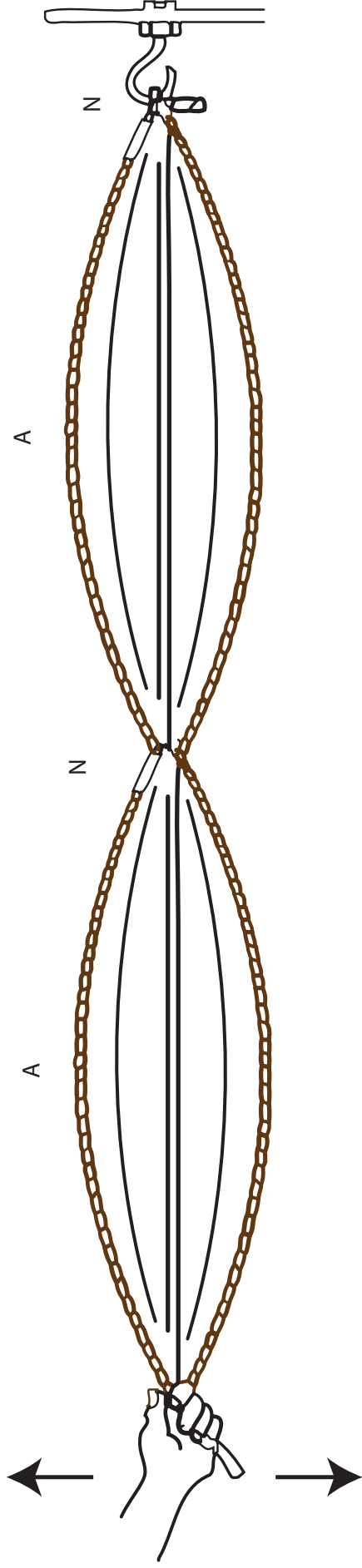
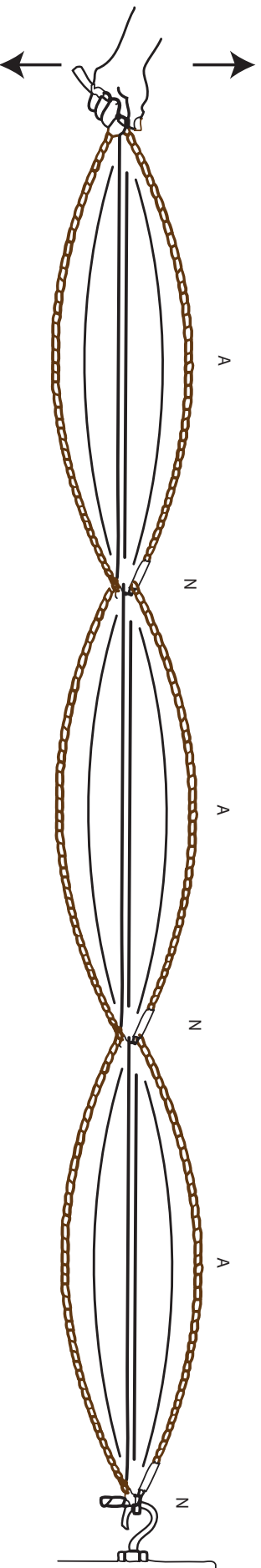
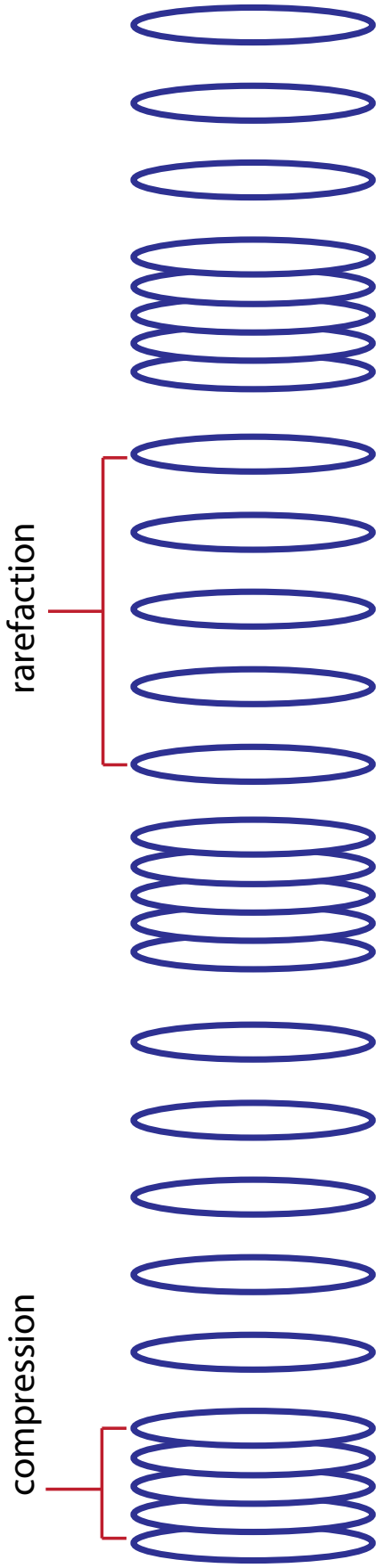


Fig. 11 Second Overtone or Third Harmonic

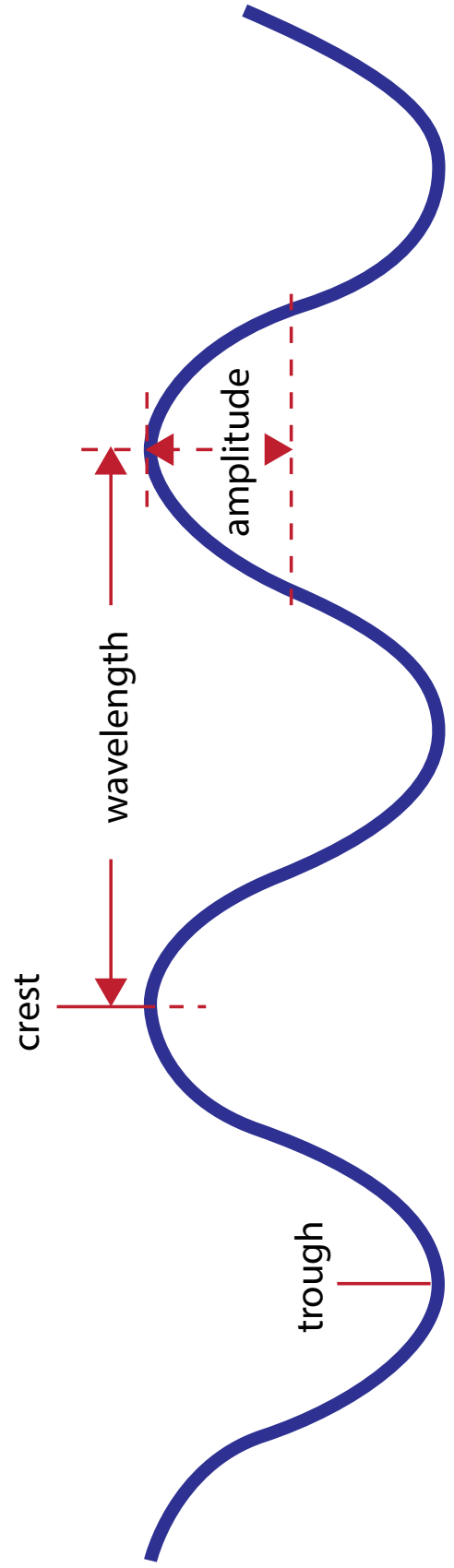


A = Antinode N = Node

Fig. 12 Longitudinal and Transverse waves



Longitudinal Wave



Transverse Wave



Worksheets

Tuning Fork Frequency (Hz)	d (meters)	Wavelength $4l$ (meters)	Velocity (meters/sec)	Temperature $^{\circ}\text{C}$	Accepted Value for Velocity (meters/sec)

$v = \text{wavelength} \cdot \text{frequency} = 4(l + .3d) \cdot \text{frequency}$

where:

l = length (meters) of the closed tube (Fig. 5) when resonance occurs

d = inside diameter (meters) of the clear plastic tube

frequency = 256 Hz, or the number inscribed on the tuning fork

- 1. In a transverse wave does the spring vibrate perpendicular to or in the same direction as the wave travels?

For a longitudinal wave?

- 2. When the small transverse wave traveled down the spring and reached Person Two, what happened?

- 3. Did the reflected transverse wave return on the same side of the spring or did it invert? For example, if the pulse traveled down the spring on the top, did the return pulse travel on the top or bottom?

- 4. Describe what happened when the longitudinal wave pulse reached Person Two's hands.

Harmonic (1st, 2nd, or) 3rd	Wavelength (m)	Time for 10 cycles (sec.)	Period, T (sec.)	Frequency, F (Hz)	Speed of the wave (m/sec.)

¹See Fig. 9, 10 and 11.

²Frequency is the reciprocal of T, or 1/T where T is in seconds.

1. In a transverse wave does the spring vibrate perpendicular to or in the same direction as the wave travels?

Perpendicular to

For a longitudinal wave?

In the same direction as the wave travels

2. When the small transverse wave traveled down the spring and reached Person Two, what happened?

It reflected off the hands of the Spring Holder

3. Did the reflected transverse wave return on the same side of the spring or did it invert? For example, if the pulse traveled down the spring on the top, did the return pulse travel on the top or bottom?

It inverted

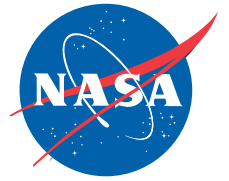
4. Describe what happened when the longitudinal wave pulse reached Person Two's hands.

It also reflected

Aeronautics
Research
Mission
Directorate



airspace



GRADES

5-12

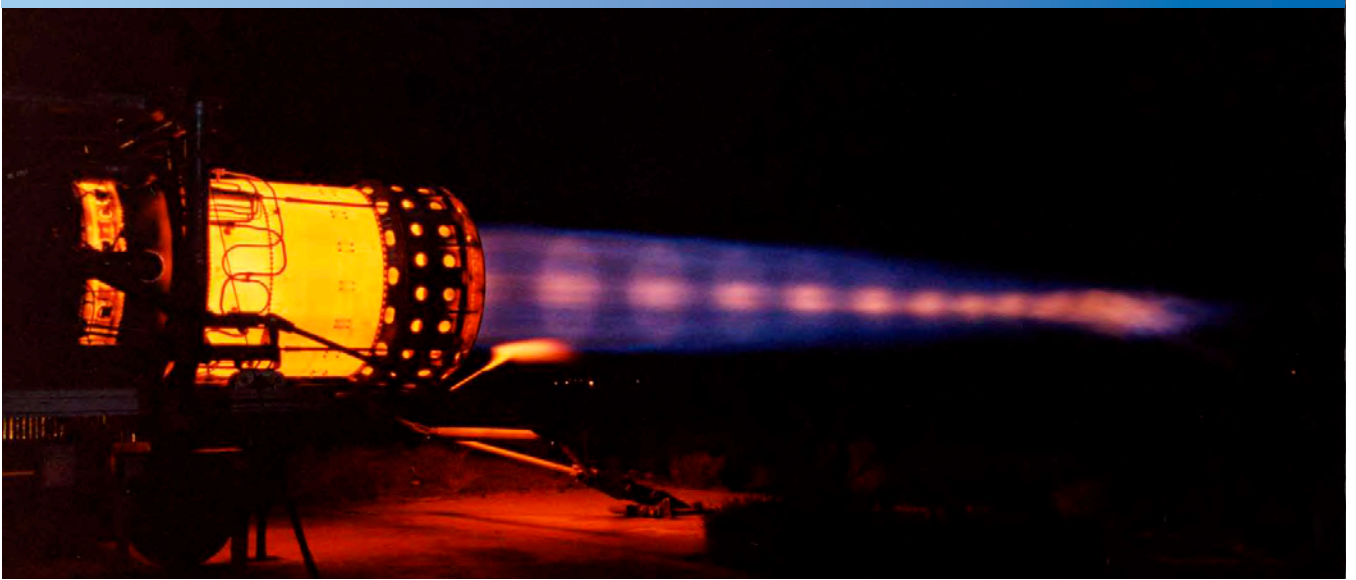
Quieting the Popper



airspace

Aeronautics
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Quieting the Popper

Lesson Overview

In this lesson, students will learn about motions and forces, transfer of energy, and the abilities of technological design as they attempt to silence the noise created by a piezoelectric “Popper”. This activity will teach students how sound waves travel and what methods can be employed to suppress them.

Objectives

Students will:

1. Use a variety of materials and methods to reduce or eliminate the noise created by a piezoelectric “Popper.”

Materials:

In the Box

Piezoelectric “Popper”
 Pipette
 Ear protection (2)
 Decibel meter
 Goggles (2)

Provided by User

Combustible fluid
 (see warning box in [Activity 1](#) for details)
 Sound dampening materials such as:
 Blankets
 Pillows
 Towels
 Heavy coats
 Cardboard boxes/tubes
 Scissors
 Tape
 Metric ruler
 Hairdryer (optional)

GRADES

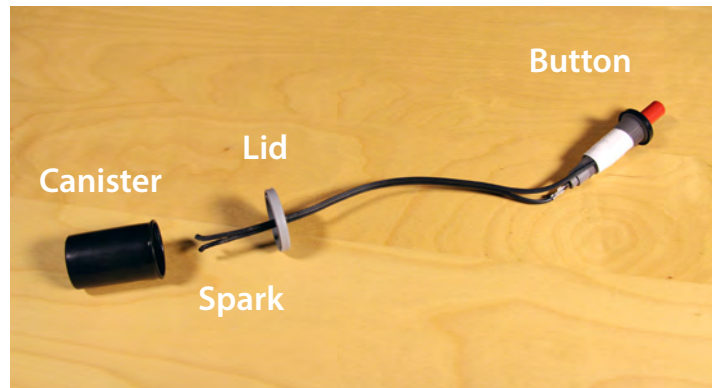
5-12

Time Requirements: 2 hours

Background

The Mechanics of the Popper

The “Popper” is a piezoelectric device used to create a spark, which ignites the vapor released by a combustible fluid. (Piezo is derived from the Greek word meaning to squeeze or press.) The spark itself is simply an electrical spark, no different to that produced by a faulty electrical cable or used in certain types of welding. It is created by applying pressure to a special crystal, typically quartz, which, due to its molecular properties, produces electricity. That electricity is then transmitted along a copper wire where normally it would be used to power a circuit. In this case though, the electricity is allowed to spark by “jumping” between two copper wires.



In addition to the spark, the device also needs a combustible substance to make the explosion. The vapor ignited by the “Popper” is produced by allowing a small amount of combustible liquid with a low flash point, such as ethanol, to evaporate.

The Science of Sound

Sound is something most of us take for granted and rarely do we consider the physics involved. It can come from many sources – a voice, machinery, musical instruments, computers – but all are transmitted the same way: through vibration.

In the most basic sense, when a sound is created it causes the molecule nearest the source to vibrate. Since this molecule is touching another molecule, it causes that molecule to vibrate too. This continues, from molecule to molecule, passing the energy on as it goes. This is also why at a rock concert, or even being near a car with a large subwoofer, you can feel the bass notes vibrating inside you. The molecules of your body are vibrating, allowing you to physically feel the music.

As with any energy transfer, each time a molecule vibrates or causes another molecule to vibrate, a little energy is transferred to the atoms and molecules the wave touches, which is why sound gets quieter with distance (Fig. 1) and why louder sounds, which cause the molecules to vibrate more, travel farther. The loudness of a sound is measured in decibels, or dB, with sounds above 120dB having the ability to cause permanent hearing loss to humans.

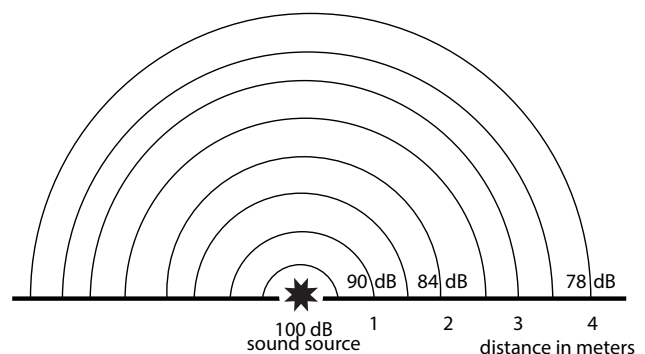


Fig. 1 Sound vs Distance

The loudness of a sound is more of a human perception and interpretation than a scientific quantity or property. However, volume can be measured in terms of the amount of energy that travels over a specified distance within a specific period time. This is measured in watts per square meter, where a watt is energy/time (joules/sec). Another important point of note is that it takes ten times as much energy to produce a noise that sounds only twice as loud as another. Correspondingly, in order to halve the noise something produces, we have to reduce its energy by a factor of 10.

Jet plane at takeoff	110-140dB
Loud rock music	110-130dB
Chain saw	110-120dB
Thunderstorm	40-110dB
Vacuum cleaner	60-80dB
Normal voices	50-70dB
Whisper	20-50dB
Purring cat	20-30dB
Falling leaves	10dB
Silence	0dB

Sound Suppression

Sometimes loud sounds are desirable and in some cases, can even be beneficial. Burglar alarms, police sirens or the loud “ping” of a piece of medical equipment are necessary to signal that assistance is required. Other times however, loud noise is potentially hazardous to health, or simply unwelcome, as in the case of the engine noise of an aircraft.

Over the years, manufacturers have had to make significant changes to the design of aircraft engines in order to reduce the noise they produce. In the 1950s and ‘60s, the raw thrust of a jet engine could be heard from almost a mile away, yet today their noise levels are tolerable from very short distances. With most older jet-powered engines, called turbo-jet engines, the noise predominately came from the exhaust, where the extremely hot gasses mixed with the ambient air,

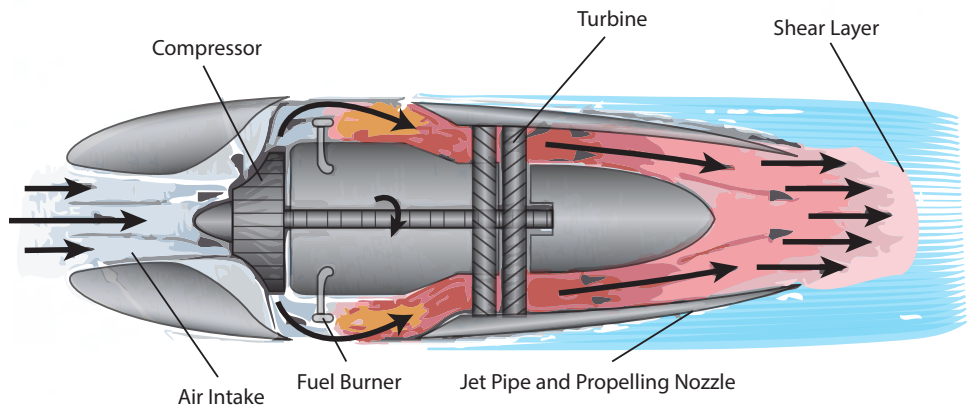


Fig. 2 Turbo-jet engine

creating a shearing effect, where the fast moving exhaust gasses rub against the slower moving ambient air (Fig. 2). This in turn produced a very loud, hissing noise. In modern turbo-fan engines however, cold bypass air is mixed with the exhaust gasses, cooling it in a controlled way and greatly reducing the noise produced (Fig. 3).

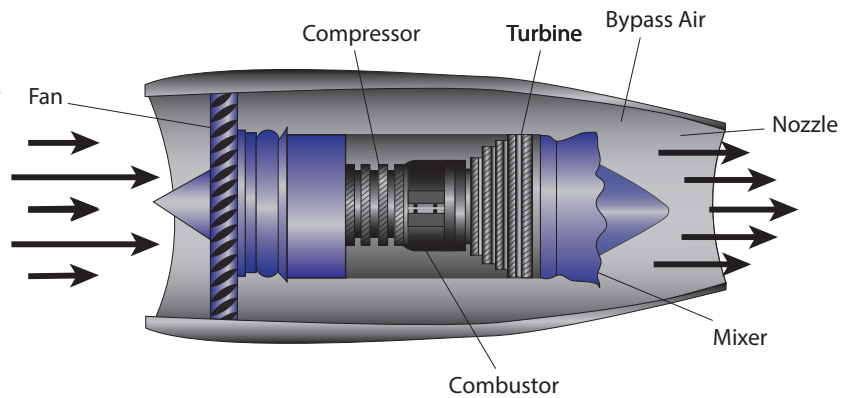


Fig. 3 Turbo-fan engine with mixer

The Boeing 787 Dreamliner, Boeing's latest passenger aircraft, takes this approach one step further with the introduction of chevrons on the exhaust nozzle. This further reduced engine noise by four decibels.



Fig. 4 The Boeing 787 Dreamliner

as such, sound cannot travel away from the origin of the noise, regardless of how loud the original sound may be. Another method is to reduce its energy in a controlled way so that by the time it reaches our ears, its level is safe. The muffler of a car's exhaust (Fig. 5), for example, uses baffle to increase the distance the gases have to travel, as well as constantly changing its direction, with each turn further reducing the energy available for noise production. The downside to this method is that this muffler style is fairly large, so cannot be used on smaller vehicles such as motorcycles. With motorcycles, the muffler uses a combination of tubes with holes and fiber glass padding (Fig. 6), similar to that used in insulating a home. The tubes make it harder for the sound to escape and when it eventually does, it is predominately absorbed by the padding before being released into the atmosphere.

New techniques for reducing noise emissions from engines are constantly being developed. For more information on the science of sound, please refer to the Museum in a Box lessons "Good Vibrations" and "Seeing Sound".

For decades, NASA has been studying aircraft noise in order to reduce the impact jet aircraft have on the world. In 1992, NASA initiated the Advanced Subsonic Technology (AST) program, a partnership between NASA, the U.S. aviation industry, and the Federal Aviation Administration. The goal of the AST program was to develop technologies that enabled a safe, highly productive global air transportation system, without increasing the manufacturing or operating costs of the aircraft.

The simplest way of reducing noise is to reduce the number of molecules available to vibrate. In a vacuum for example, there are no air molecules to vibrate and

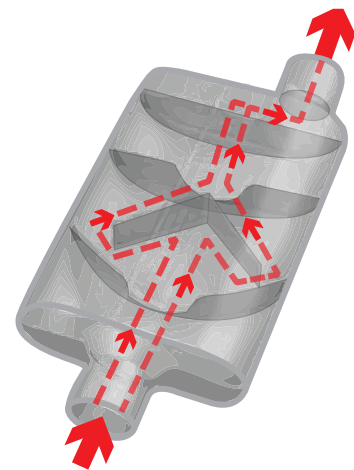


Fig. 5 Car muffl

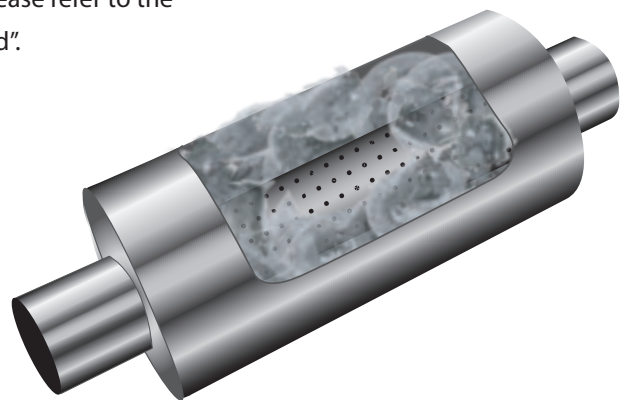


Fig. 6 Motorcycle muffl

Activity 1

Quieting the Popper

GRADES 5-12**Time Requirements:** 2 hours**Materials:**In the Box

Piezoelectric “Popper”
 Pipette
 Ear protection (2)
 Decibel meter
 Goggles (2)

Provided by User

Combustible fluid
 (see warning box)

Sound dampening materials
 such as:
 Blankets
 Pillows
 Towels
 Heavy coats

Cardboard boxes/tubes

Scissors

Tape

Metric ruler

Hairdryer (optional)

Worksheets

Sound Suppression
 Experiments
 (Worksheet 1)

Reference Materials

Decibel Meter Instructions

Objective:

In this activity, students will learn about motions and forces, transfer of energy, and the abilities of technological design as they use a variety of materials and methods to reduce or eliminate the noise created by a piezoelectric “Popper.”

Activity Overview:

Students will use a piezoelectric “Popper”, a device that ignites a small amount of flammable vapor in order to generate a loud bang. Then, by using simple household materials, they will try to reduce or eliminate that noise as much as possible.

WARNING: This activity uses a small amount of flammable liquid and explosive vapor. It is imperative that the students are properly briefed on the safety measures described below while performing this activity. While the chances of fire are very low if the instructions below are followed correctly, you may want to consider having a fire extinguisher readily available, if only to visually reinforce the inherent dangers of working with combustible fluid.

The lesson requires the use of a combustible liquid that vaporizes at a low temperature. As such, only perfume, nail polish remover, ethanol or rubbing alcohol should be used.

1. **Explain to the students that this activity uses a device that creates a loud bang, similar in sound and volume to a gunshot.** Ask if anyone is sensitive to loud noises or has a medical condition which may preclude them from taking part in the experiment.

While most students will have no issues with loud noises, there might occasionally be a student with a medical or psychological condition that would preclude them from participating. If you are working near other classrooms or groups, you should alert them of the loud noises you are about to produce as well.

Key Terms:

Attenuation
Decibel
Muffl
Piezoelectricity
Turbo-jet engine
Turbo-fan engine
Vacuum
Vaporize



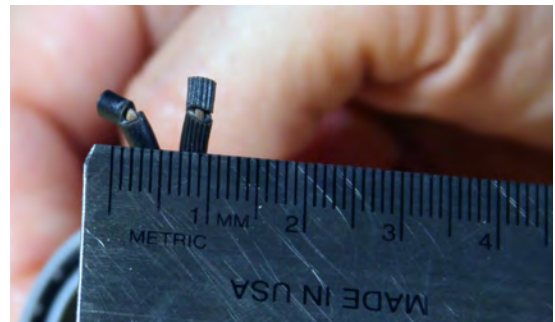
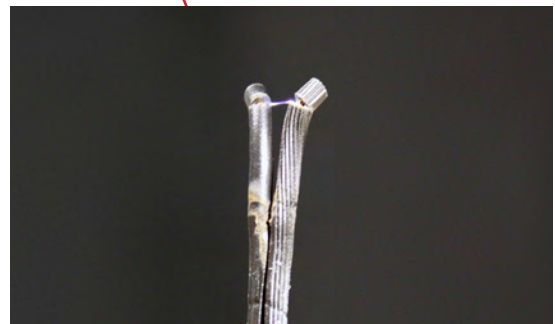
Correct Way



Incorrect Way

WARNING: Do not hold "Popper" as pictured above right. Use caution not to touch the exposed metal at the base of the popper.

2. **Begin by explaining how a piezoelectric device works using the [Background](#) information provided.** You can also demonstrate this by removing the cap from the "Popper" and pressing the igniter button. Ensure that the students see the spark jumping between the two copper wires. *If the gap between the two wires is excessive, the piezoelectric element will be unable to produce a sufficient charge to create the spark. Ensure that the gap between the two wires is no greater than 1cm (3/8").*



3. **Give each student a copy of the Sound Suppression Experiments worksheet.**

4. **Using the pipette, place two drops of fuel into the “Popper’s” combustion chamber and reattach the lid.** Explain to the students that the liquid is slowly evaporating, turning into a vapor (or a gas) which can be ignited.

It may be necessary to hold the combustion chamber snugly in order to allow heat from your body to accelerate the process. If faster results are desired, a hairdryer can be used instead. Tests have shown that isopropyl alcohol will take approximately 5 minutes to reach a combustible state if left unattended in a room with an air temperature of 22°C (72°F).

WARNING: Under no circumstances should more than 2 drops of liquid be placed into the combustion chamber. It will not produce a louder bang, but WILL GREATLY increase the chance of fire!



5. **Explain that the purpose of this activity is to try, as much as possible, to stop the sound produced by the “Popper” from reaching the decibel meter.**
6. **Set up a control shot.** Continue to explain that before any experiments can be made, a control firing is needed to determine how loud the “Popper” is without any attenuation (sound dampening).

7. **Select a volunteer student.** Give the student (Student A) a pair of ear protectors, goggles and the decibel meter. Next, have Student A stand at “the listening point”, approximately 2 meters (6 feet) away from where the “Popper” will be fired (the firing point). Note the points where you and the student stand so that each test can be performed from the same places. You may want to put pieces of tape on the floor to make placement more accurate. *Instructions on using the decibel meter can be found in the [Reference Materials](#) section.*



8. **Ask the other students to stand at least 5 meters (15 feet) behind Student A while the “Popper” is fired.** Their role is to find where the “Popper” lands and retrieve it.
9. **Warn everyone within earshot that you are about to fire the “Popper”.** Ensure that Student A is ready, with the decibel meter set correctly (90db) and pointed towards the “Popper”. When ready, put on your ear protection and goggles. Hold the “Popper” correctly and press the igniter button. *The igniter may require more than one press before the spark is produced. If after a few presses it fails to ignite, remove the igniter cap completely from the “Popper” and move it a safe distance from the combustion chamber. Check to see if a spark is being produced by pressing the igniter button. If it is sparking correctly, then the liquid did not vaporize sufficiently. Reset the experiment and consider using a hairdryer to warm the combustion chamber and speed up the process. If the igniter failed to spark, try moving the two wires closer to each other and retest.*
10. **Have the students record the decibel reading of the control test on their worksheets for later reference.**
11. Using the [Background](#) information, explain how sound is produced and how it can be reduced or eliminated.

12. **Next, divide the students into pairs.** Assign each pair the task of producing a device which will attempt to reduce the noise produced by the “Popper”. The winning design will be the one that obtains the largest reduction in noise in relation to its size. Students can use any items around the classroom, including those in the Materials list.

If necessary, you can inspire the students by suggesting various ideas for them to try. Examples might include:

Filling a box with pillows and placing the “Popper” in the center.



Placing a large book between the “Popper” and the decibel meter.



Wrapping the “Popper” in a scarf.



Caution: Remove flammable materials immediately after firing the “Popper” to reduce fire hazard.

For the contest, the size of the suppressor is taken into consideration to prevent students from grabbing handfuls of items and silencing the “Popper” by simply suffocating it.

13. **After each team has constructed their device, have them predict the level of reduction it will achieve.** This encourages students to use good estimating practices in order to select the appropriate decibel range setting on the decibel meter.
When estimating the reduction, remind students that they have to reduce the energy by a factor of 10 to reduce the number of decibels by half.
14. **Re-arm the “Popper” with two more drops of fluid , reattach the cap and warm if necessary.**
15. **Have one member of the team place their silencing device at the firing point while the other team member sets the decibel meter to the proposed level and stands at the listening point.** Then, place the “Popper” assembly into the noise attenuating device. Ensure that both students are wearing hearing and eye protection.
16. **Ensure the area is clear and then have one student activate the “Popper” while the other records the decibel reading onto the worksheet.**
 - If the decibel meter reads LO, then the selected range was too high, meaning the students underestimated the ability of their silencing device. Set the meter to a lower threshold and try again.
 - If the number on the decibel meter flashes , the selected range was too low, meaning the students overestimated the ability of their silencing device. Set the meter to a higher threshold and try again.
17. **Repeat steps 14 through 16 for each pair of students until all students have a successful test.** If desired and time permits, afford the students an opportunity to modify their devices based upon what was witnessed during testing. Use a fresh worksheet to record the results of the modified device.
18. **Have the students complete the math portion of the worksheet.** Here they will calculate the level of sound reduction in relation to the size of the device constructed. The winner is the team with the highest effectiveness rating.

Discussion Points:

1. **Based upon what was demonstrated today, what materials made the most efficient sound reducer?**

Answers will vary depending on the materials and methods used, but in general, less dense materials such as furnishings and fabrics will perform better than denser ones such as wood, metal or paper.

2. **Why do you think that was?**

Again, answers will vary depending on the materials and methods used but typically speaking, the molecules in the softer items are farther apart, meaning that it takes more energy to make them vibrate, as opposed to dense objects whose tightly packed molecules can vibrate and transfer energy easily and efficiently.

3. **Apart from the ones we discussed earlier (planes, cars and motorcycles), what other objects use a device to reduce noise?**

Answers will vary by student, but may include:

- *Some computers use soundproofing to reduce the noise of the fan*
- *Helicopters*
- *Lawn mowers*
- *Headphones/ear plugs*

4. **Are there any other benefits to reducing noise other than for comfort?**

Yes. In the case of a car for example, a gallon of gasoline will always produce a fixed amount of energy. In an ideal world 100% of it would be converted to motion energy by the engine and sent to the wheels but in actuality, a lot of it is wasted as heat and noise. By reducing the unwanted forms of energy, such as sound, we can increase the amount of kinetic motion produced, thereby increasing the fuel efficiency (miles per gallon) for that vehicle.

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Properties and changes of properties in matter
- Transfer of energy

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Structure and properties of matter
- Interactions of energy and matter
- Conservation of energy and increase in disorder
- Interactions of energy and matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology



Reference Materials

Glossary

Attenuation:

A decrease in a property, usually energy, that occurs as a result of absorption or displacement

Decibel:

A unit of the intensity of sound

Muffle

A device designed to reduce the level of noise produced by an engine

Piezoelectricity:

Electric charge produced by a crystal or other material through a means of compression

Turbo-jet engine:

An aircraft engine whose primary means of producing thrust is through pressurized exhaust gas

Turbo-fan engine:

An aircraft engine whose primary means of producing thrust is through a ducted fan attached to the front of the engine

Vacuum:

An enclosed space in which air has been either partially or fully removed

Vaporize:

To convert a solid or liquid into a vapor

Decibel Meter Instructions



- If the decibel meter reads LO, then the selected range was too high, meaning the students underestimated the ability of their silencing device. Set the meter to a lower threshold and try again.
- If the number on the decibel meter flashes, the selected range was too low, meaning the students overestimated the ability of their silencing device. Set the meter to a higher threshold and try again.

Fig. 1 Sound vs Distance

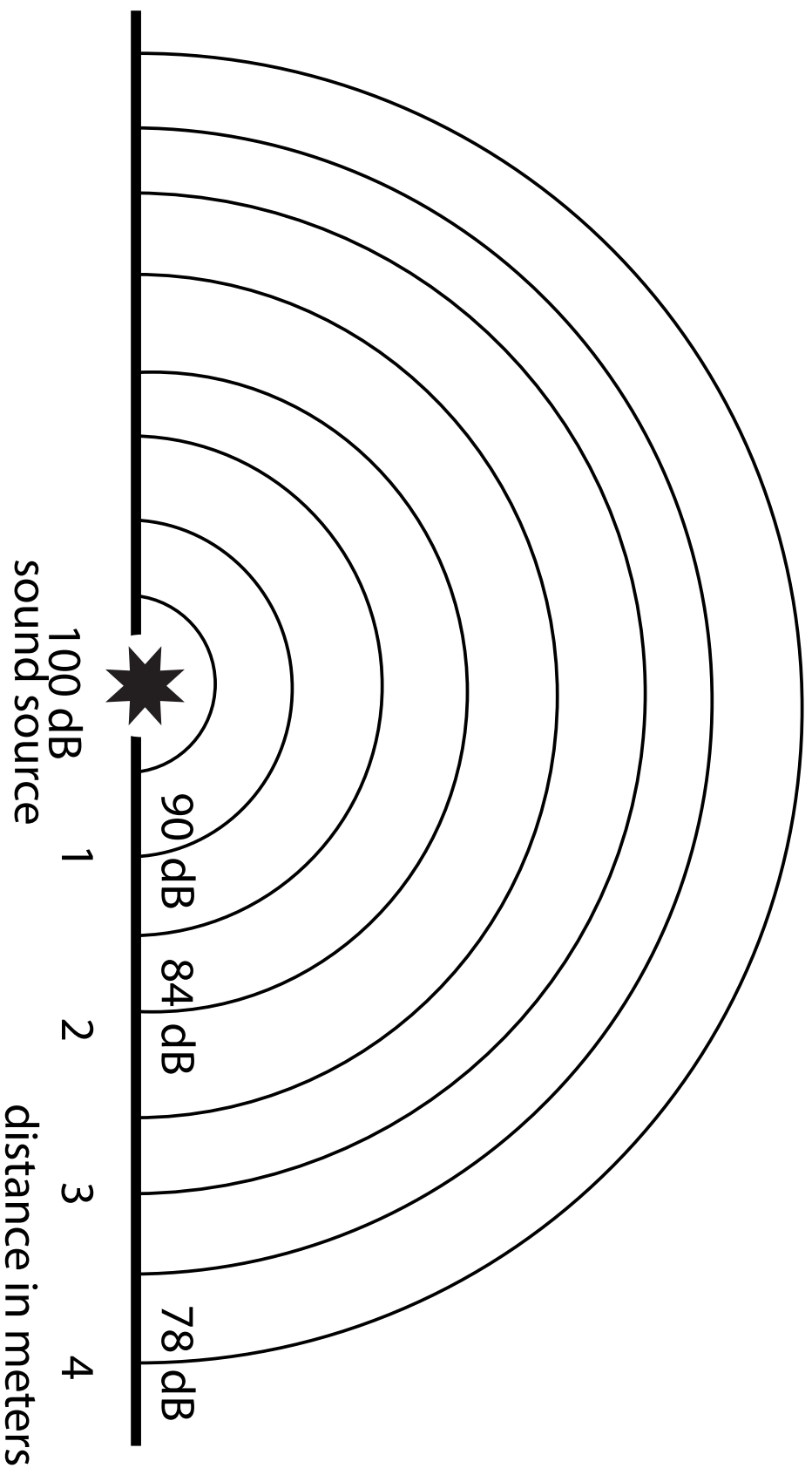


Fig. 2 Turbo-jet engine

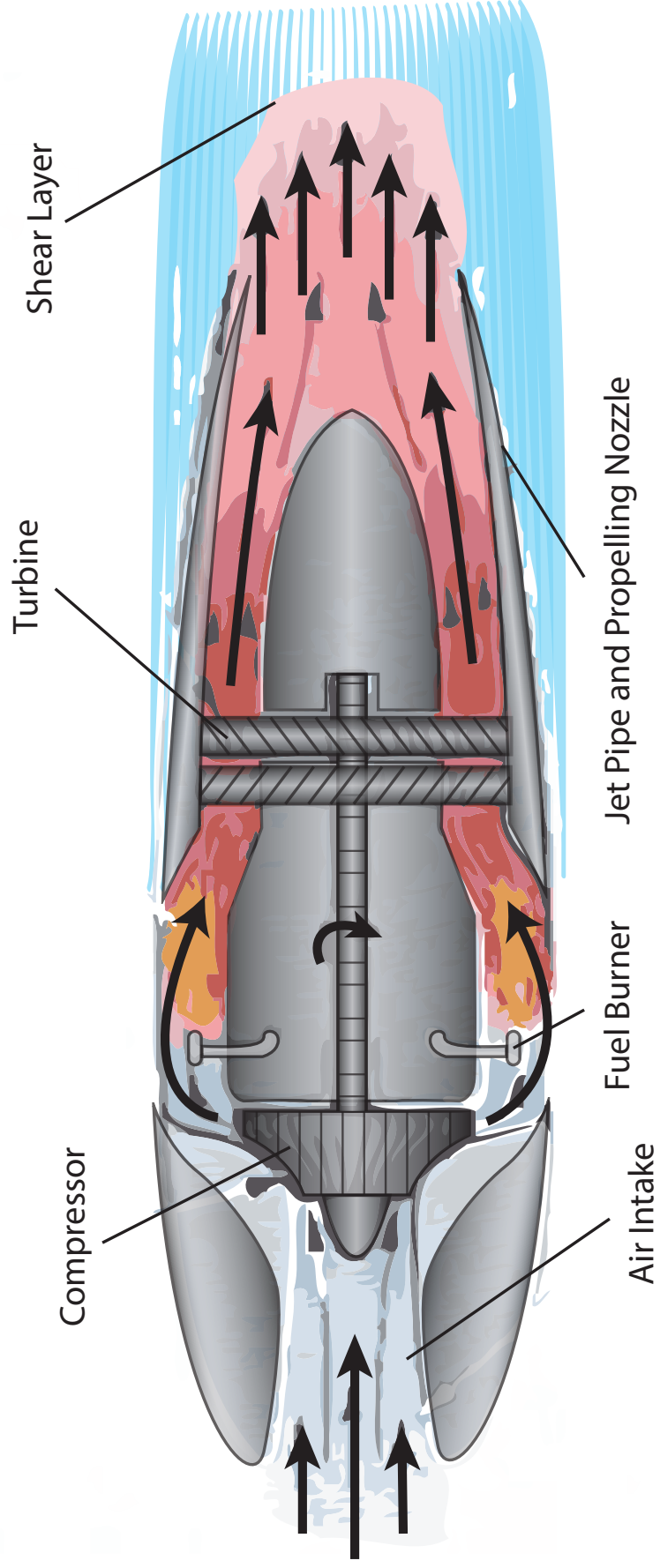


Fig. 3 Turbo-fan engine with mixer

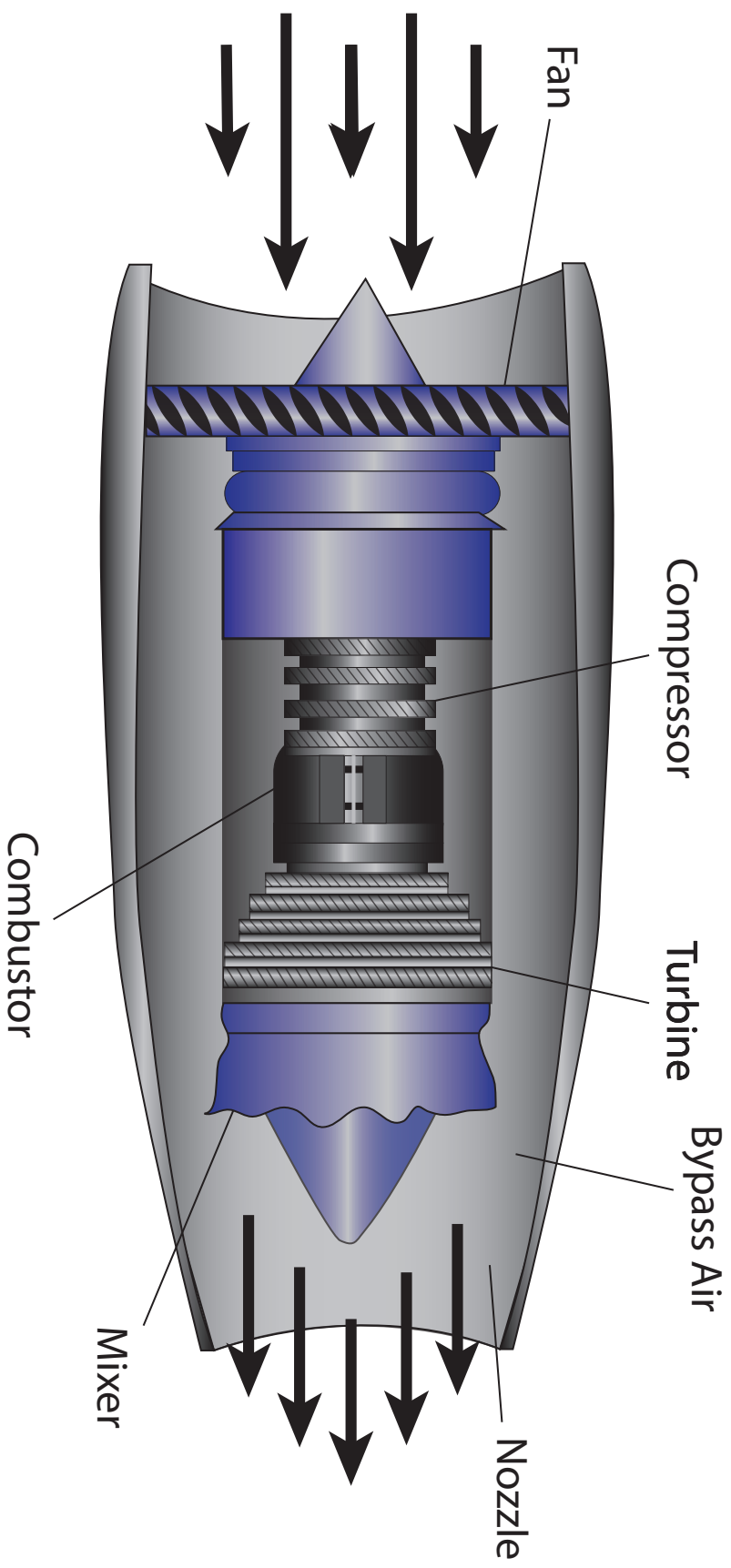


Fig. 5 Car muffl

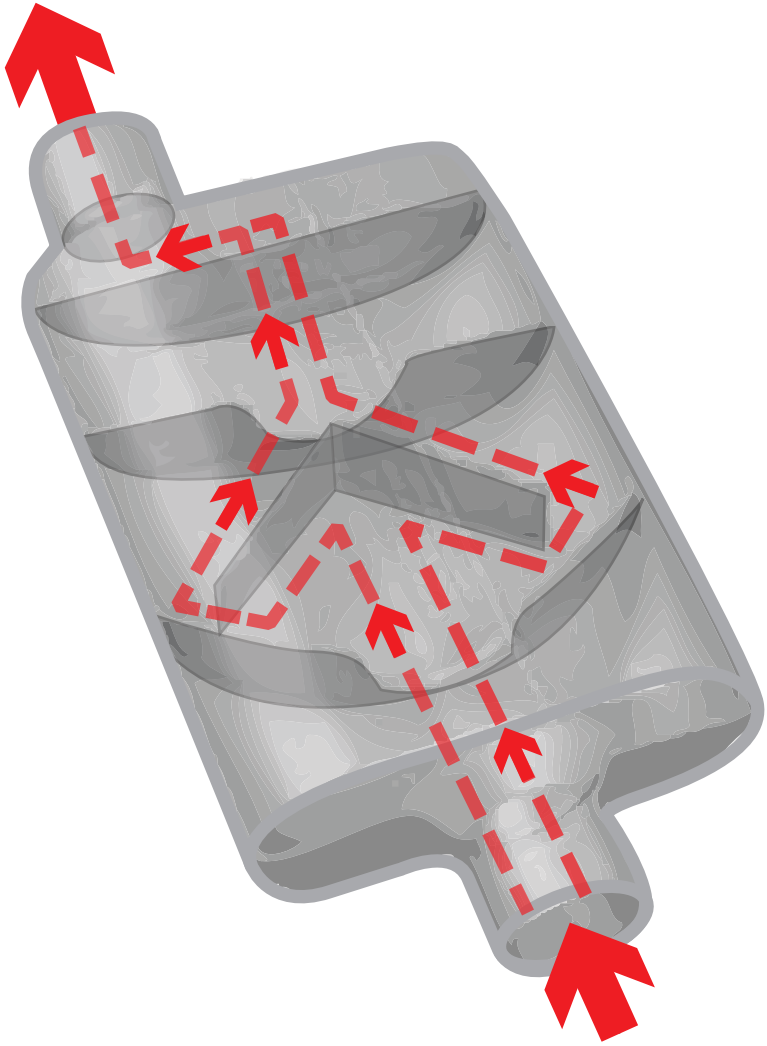
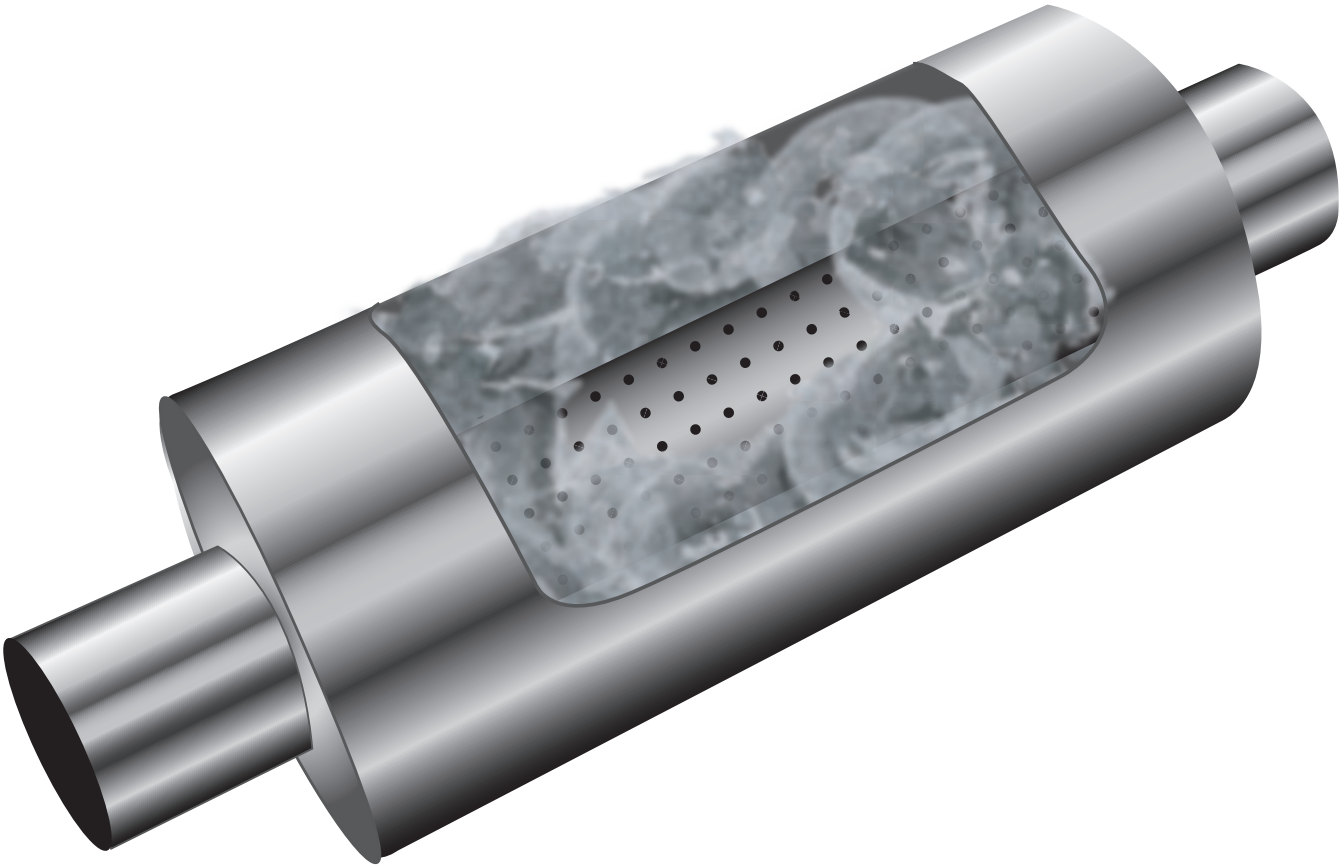


Fig. 6 Motorcycle muffl





Student Worksheets

Worksheet 1

Sound Supression Experiments

Name _____

1. Name and description of device _____

2. Control Test - Decibel Level _____ db

3. Device Used - Decibel Level

Your Results	Other Students' Results			
db	db	db	db	db

4. Decibel Difference:

Your Results	Other Students' Results			
db	db	db	db	db

5. Size of the Device:

Your Results	Other Students' Results			
Width	Width	Width	Width	Width
Height	Height	Height	Height	Height
Depth	Depth	Depth	Depth	Depth

6. Cubic Feet: (Width x Height x Depth)

Your Results	Other Students' Results			
m ³	m ³	m ³	m ³	m ³

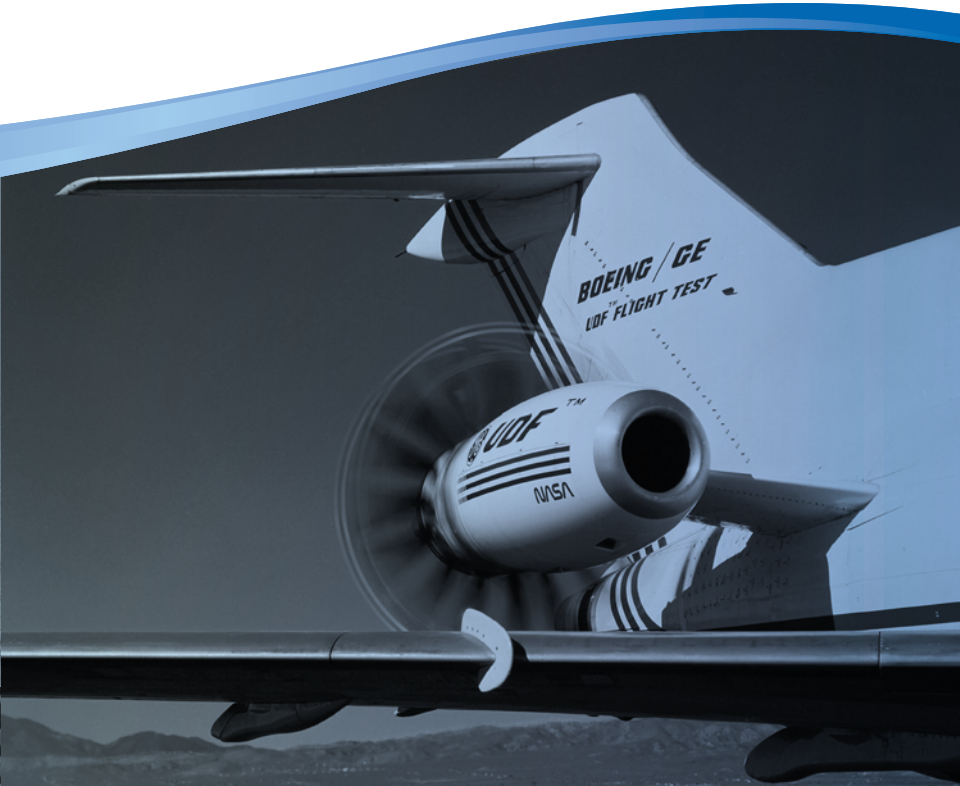
7. Device Effectiveness Rating = Decibel Difference ÷ Size (Volume) of Device

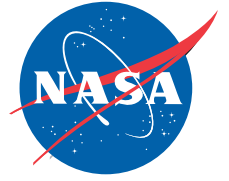
Your Results	Other Students' Results			
db ÷ m ³	db ÷ m ³	db ÷ m ³	db ÷ m ³	db ÷ m ³
db/m ³	db/m ³	db/m ³	db/m ³	db/m ³

8. What were the weaknesses of this design?

9. How could you improve the performance of this design?

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GRADES

K-8

Seeing Sound



airspace

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Mission
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Seeing Sound

Lesson Overview

In this lesson, students will use a beam of laser light to display a waveform against a flat surface. In doing so, they will effectively “see” sound and gain a better understanding of how different frequencies create different sounds.

Objectives

Students will:

1. Observe the vibrations necessary to create sound.

Materials:

In the Box

- PVC pipe coupling
- Large balloon
- Duct tape
- Super Glue
- Mirror squares
- Laser pointer
- Tripod
- Tuning fork
- Tuning fork activator

Provided by User

- Scissors

GRADES

K-8

Time Requirements: 30 minutes

Background

The Science of Sound

Sound is something most of us take for granted and rarely do we consider the physics involved. It can come from many sources – a voice, machinery, musical instruments, computers – but all are transmitted the same way; through vibration.

In the most basic sense, when a sound is created it causes the molecule nearest the source to vibrate. As this molecule is touching another molecule it causes that molecule to vibrate too. This continues, from molecule to molecule, passing the energy on as it goes. This is also why at a rock concert, or even being near a car with a large subwoofer, you can feel the bass notes vibrating inside you. The molecules of your body are vibrating, allowing you to physically feel the music.

As with any energy transfer, each time a molecule vibrates or causes another molecule to vibrate, a little energy is lost along the way, which is why sound gets quieter with distance (Fig 1.) and why louder sounds, which cause the molecules to vibrate more, travel farther. The loudness of a sound is measured in decibels, or dB, with sounds above 120dB having the ability to cause permanent hearing loss to humans. The table below shows how various sources of sound compare (Fig 2).

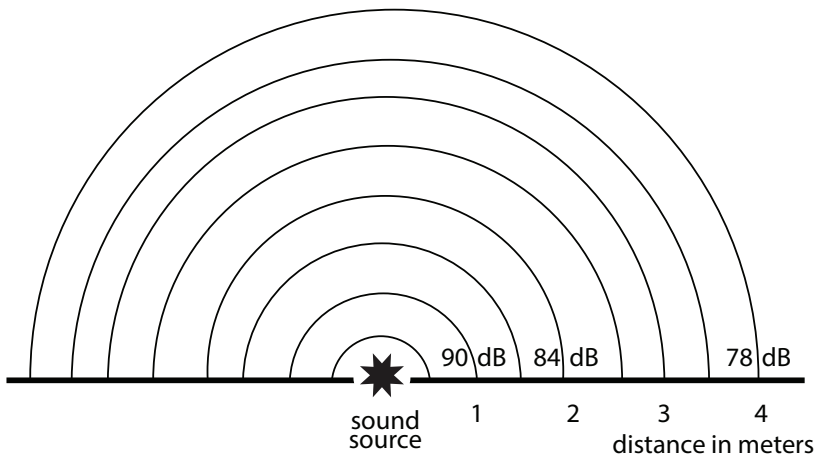


Fig. 1 Sound vs Distance

A sound wave is the name given to the pattern a sound creates and can be seen on a waveform monitor. A single tone, such as that produced by a tuning fork, creates a very uniform wave, while human speech, with all the inflections and changes in tone, causes a much more erratic-looking one (Fig. 3).

In this lesson students will create a waveform monitor by using a balloon as a sound absorbing membrane and a laser to visually display the vibrations. While the waveform produced will not have the familiar look to them due to the design of this experiment, they will allow students to physically “see” the sound waves.

Jet plane at takeoff	110-140dB
Loud rock music	110-130dB
Chain saw	110-120dB
Thunderstorm	40-110dB
Vacuum cleaner	60-80dB
Normal voices	50-70dB
Whisper	20-50dB
Purring cat	20-30dB
Falling leaves	10dB
Silence	0dB

Fig. 2 A comparison of sound levels

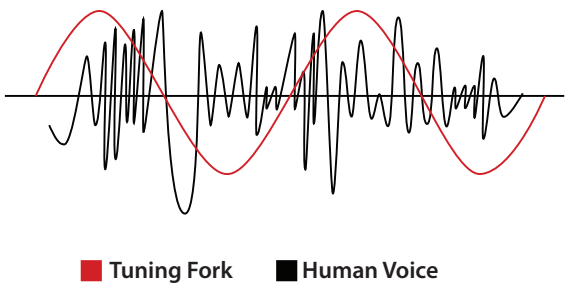


Fig. 3 Sample waveforms

The Sound Barrier & The Sonic Boom

Most people have heard of “breaking the sound barrier” but what does that really mean? The sound barrier is “broken” when an aircraft exceeds the speed of sound. More accurately, it is the point at which the object’s speed increases from the transonic range (slower than sound) to the supersonic range (faster than sound).

As an object passes through the air, the air resistance creates a series of pressure waves both in front of and behind that object, similar to how the hull of a boat creates wake in the water. These pressure waves travel at the speed of sound, which for most aircraft isn’t a problem. As the speed of the object increases however, the waves are forced together, or compressed, because they cannot get out of each other’s way. By the time the object reaches the speed of sound, these pressure waves are compressed so tightly they become a single wave, with the pressure being as high as 7,000 Pa, or 144 pounds per square foot. It is this increase in pressure that creates the infamous “Sonic Boom”.

In rare instances, you can actually see the sound barrier being broken. Image 1, which is also on the cover of this lesson, is an F/A-18 Hornet with a white cloud enveloping the rear of the aircraft. This cloud was created by a large drop in air pressure behind the wing at the precise moment the aircraft broke the sound barrier. Notice the smaller cloud that also formed near the rear of the cockpit, which is another sonic boom.



(Image Courtesy of the United States Navy)

Img. 1 An F/A-18 breaking the sound barrier

Pilots of jet aircraft often refer to their speed in relation to the speed of sound, using the term “mach number”, which is the ratio of the aircraft’s speed compared to that of the speed of sound. Mach 1, for example, is the speed at which sound travels, while Mach 2 equates to twice the speed of sound. Most airliners move fairly slowly for takeoff and landing but fly at approximately Mach .80 (M .80), or 80% of the speed of sound, when up at cruising altitude.

While sound waves are not usually able to be seen as they are when some aircraft break the sound barrier, the following activity will allow students to visualize sound waves firsthand .

Activity 1

Building a Waveform Monitor

GRADES

K-8

Time Requirements: 30 minutes

Materials:In the Box

PVC pipe coupling
 Large balloon
 Duct tape
 Super glue
 Mirror squares
 Laser pointer
 Tripod
 Tuning fork
 Tuning fork activator

Provided by User

Scissors

Worksheets

None

Reference Materials

None

Key Terms:

Frequency (sound)
 Pitch (sound)
 Volume
 Waveform
 Waveform monitor

Objective:

Students will observe the vibrations necessary to create sound.

Activity Overview:

In this activity, students will use a beam of laser light shined against a mirror on a vibrating balloon membrane to display a waveform against a flat surface. In doing so, they will effectively “see” sound and gain a better understanding of how different frequencies create different sounds.

Activity:

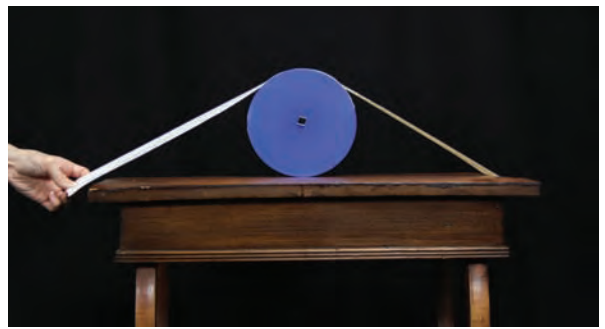
1. **Begin this activity by discussing with the students how sound waves are transmitted, using the [Background](#) information provided.**
2. **Explain how it is possible to see sound by converting the sound waves to kinetic energy (movement).** As you build the apparatus described below, explain to the students how each item works and how it can be used to see sound waves.
3. **To start, take a large balloon and cut off the neck, or the part you would normally blow into.** This is to make the opening larger and allow the balloon to be stretched more easily.
4. **Use duct tape to secure the balloon over one end of the PVC pipe, making something that looks like a drum.**



- At this stage, show the students how the balloon can vibrate by tapping on it. Explain that this device is exactly like their ears; a hollow chamber with a thin skin covering it.
- Next, glue a small square of mirror to the center of the front of the balloon. Hold it firmly for a few seconds to allow the glue to dry before letting go.

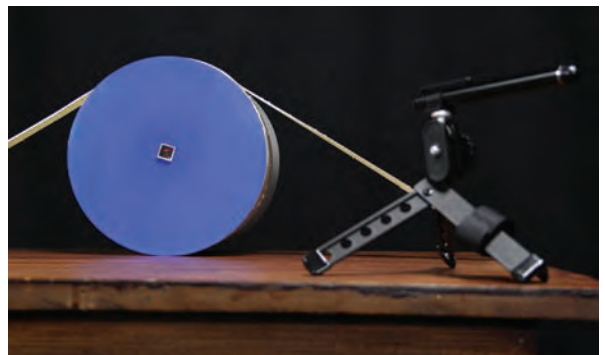


- Once the glue has dried, turn the device on its side, with the balloon end facing either a light-colored wall or a large sheet of white paper taped to a wall. Using tape, firmly secure the device to the table so it cannot move.

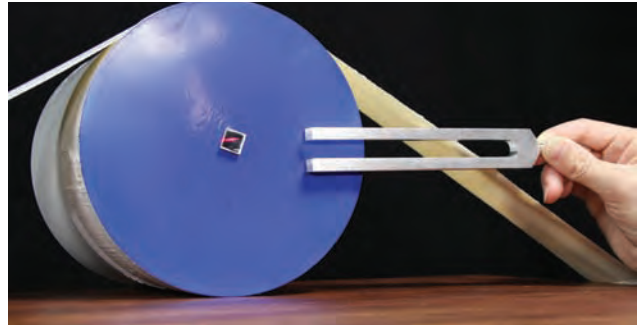


Caution: The next steps involve the use of a low power laser. While chance of injury is very low, advise the students to NEVER point the laser into someone's eyes, or to stare directly at the beam.

- Remove the laser pointer from its case and if necessary, install the batteries per the instructions.
- Explain to the students that a laser is simply a very concentrated beam of light. If desired, point the laser at the wall to show them the red dot of light that is created when the button is pushed.
- Open the legs of the tripod and place it on the table in front and to the side of the balloon assembly. Insert the laser pointer into the cradle on the top, ensuring that one of the arms is holding the button firmly in the ON position.
- Lastly, align the laser dot so that the beam of light is aimed at the mirror on the balloon and reflected onto the wall or large sheet of paper.



12. **At this point the dot on the wall should still resemble a dot, with very little movement.**
Explain that this is because there are no sound waves being captured by the balloon.
13. **Ask a student to speak loudly into the open end of the PVC pipe while the rest of the class watches the effect it has on the light on the wall.**
14. **Have the students take turns whispering, shouting or singing into the balloon device.**
If available, try other sound sources such as radios and musical instruments.
15. **Lastly, demonstrate the effect a tuning fork has on the balloon.** To do this, strike the fork firmly on the activator to start it vibrating, then place it gently against the skin of the balloon.
You should see a perfectly round sound wave pattern displayed by the laser.



Discussion Points:

1. **What causes sound?**
Sound can only be generated through vibration. When we speak, play music or otherwise produce sound, the air is vibrated which in turn vibrates our ear drums, allowing us to hear it. In a vacuum such as in space, there is no air to vibrate and therefore it is silent. Sound can also be transmitted through other solid materials although it does not do so as efficiently as air.
2. **How did things like volume and pitch change how the light reflected on the wall?**
The light pattern generated was directly related to the type of sound being made in the PVC pipe. Higher pitched voices, like those from younger children and females, had tighter, or more closely spaced waves while adults or men, with their lower voices, created waves that were further apart. The name given to this wave property is called a frequency.
3. **What happened when the tuning fork was placed against the balloon?**
It is difficult to demonstrate, however, if done correctly two things should have happened. Firstly, the sound should have been amplified by the PVC pipe in the exact same way our ears amplify the sounds we hear. Second, the waveform on the wall should have been a perfect circle, as opposed to the wavy lines seen in the students' voices. This is because the tuning fork emits a perfect, constant pitch, or frequency, unlike our voices which vary in pitch as we speak or sing.
4. **Did the pattern created by the laser light look familiar when playing music or using our voices?**
Many computer programs, such as iTunes and Windows Media Player, have a waveform monitor which is visible while the music is playing. The waveform shown on the screen will look similar in appearance to the light pattern displayed on the wall.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Properties and changes of properties in matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology



Reference Materials

Glossary

Frequency (sound):

The number of repeated cycles of a waveform in a specific unit of time

Pitch (sound):

The height of a voice or note (the pitch of a child's voice is higher than that of an adult's); higher-pitched sounds have shorter wavelengths than lower-pitched sounds

Volume:

The amplitude, or loudness of a sound

Waveform:

The shape of a soundwave illustrated by plotting the pitch value against time

Waveform Monitor:

An electronic device used to display a waveform in an electronic form

Fig. 1 Sound vs Distance

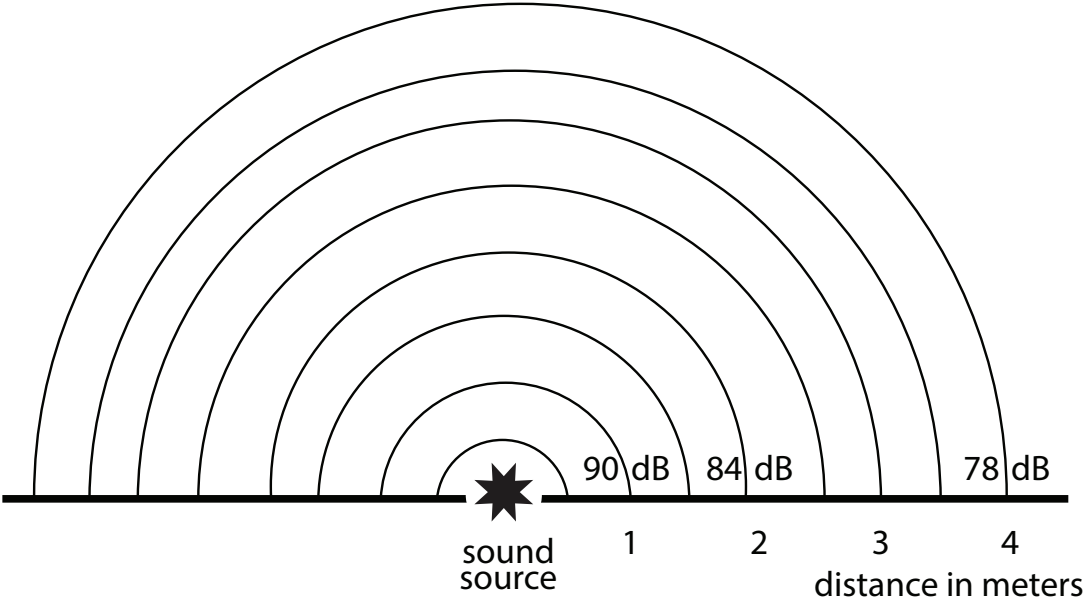
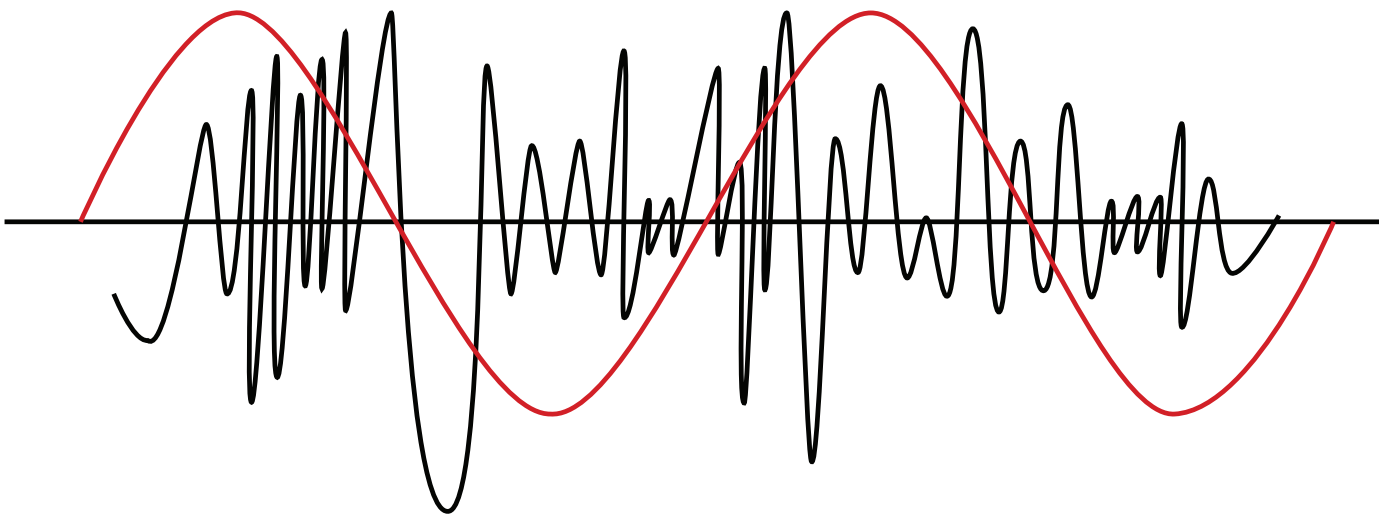


Fig. 2 A comparison of sound levels

Jet plane at takeoff	110-140dB
Loud rock music	110-130dB
Chain saw	110-120dB
Thunderstorm	40-110dB
Vacuum cleaner	60-80dB
Normal voices	50-70dB
Purring cat	20-30dB
Whisper	20-50dB
Falling leaves	10dB
Silence	0dB

Fig. 3 Sample waveforms



■ Tuning Fork ■ Human Voice



Images

Img. 1 An F/A-18 breaking the sound barrier

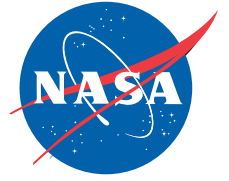


(Photo courtesy of the United States Navy)

Aeronautics
Research
Mission
Directorate



airspace



GRADES

K-12

Making Oxygen and Carbon Dioxide

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Making Oxygen and Carbon Dioxide

Lesson Overview

In this lesson, students will learn about properties and changes of properties in matter, transfer of energy, chemical reactions, geochemical cycles, changes in environments and environmental quality as they witness two methods of producing oxygen and carbon dioxide, two gases vital to life cycles on Earth. Then, they will learn how to test for each of these gases using standard scientific principles.

Objectives

Students will:

1. Learn how oxygen can be produced via the chemical reaction between yeast and hydrogen peroxide.
2. Learn how carbon dioxide can be produced via the chemical reaction between baking soda and vinegar.

Materials:

In the Box

Safety goggles
Plastic beaker
Measuring spoon
Re-sealable plastic bags
Yeast
Baking soda
Wooden splints
Matches or lighter

Provided by User

A glass of water
Hydrogen peroxide
Vinegar

GRADES

K-12

Time Requirements: 40 minutes

Background

The Earth's atmosphere is comprised of sixteen different gases (Fig. 1), each of which plays an important role in sustaining life on Earth. While Nitrogen is Earth's most abundant gas and used by every living organism to generate proteins, the two that are the subject of this lesson are oxygen and carbon dioxide.

Oxygen

Oxygen was discovered almost simultaneously by two different scientists, Carl Wilhelm Scheele from Sweden and Joseph Priestley from England, both around 1773. It is the third most abundant element in our galaxy, with only hydrogen and helium having a greater presence. While oxygen makes up just 21% of the Earth's atmosphere, it accounts for nearly 50% of the Earth's crust and almost 66% of the human body's mass! For mammals, oxygen is a vital component of life. It is in the air we breathe and the water we drink. It is necessary for a fire to burn and for rust to form. Without it, we simply wouldn't exist.

Oxygen (O₂)

At the pressures and temperatures found on the Earth's surface, oxygen atoms are typically found joined together in pairs with a double bond, making the oxygen we breathe, O₂(Fig. 2). This means there are two oxygen atoms in each molecule.

Ozone (O₃)

Another form of oxygen that is vital to life on Earth is O₃ more commonly referred to as ozone. It is comprised of three oxygen atoms joined together with single bonds (Fig 3). The vast majority of ozone gas is found anywhere from 10 to 20 kilometers (12 to 19 miles) above the Earth's surface and is commonly referred to as the ozone layer. Its primary role is to absorb the ultraviolet light being produced by the Sun and to prevent that ultraviolet light, or UV light, from reaching the Earth's surface. Without ozone, many more harmful UV-B rays (the ones that cause sunburn and skin cancer) would reach the Earth's surface with serious detrimental effects to all living organisms.

Gas	Percentage
Nitrogen (N ₂)	78.084%
Oxygen (O ₂)	20.946%
Argon (Ar)	0.9340%
Carbon Dioxide (CO ₂)	0.039%
Neon (Ne)	0.001818%
Helium (He)	0.000524
Methane (CH ₄)	0.000179%
Krypton (Kr)	0.000114%
Hydrogen (H ₂)	0.00055%
Nitrous Oxide (N ₂ O)	0.00003%
Carbon Monoxide (CO)	0.00001%
Xenon (Xe)	0.000009%
Ozone (O ₃)	0.000007%
Nitrogen Dioxide (NO ₂)	0.000002%
Iodine (I ₂)	0.000001%
Ammonia (NH ₃)	trace

Fig. 1 Gaseous composition of the Earth's atmosphere (dry)

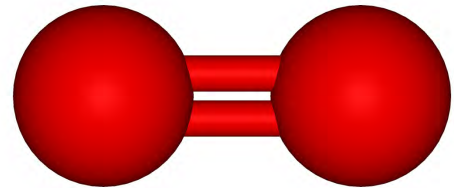


Fig. 2 An O₂ molecule consisting of two oxygen atoms

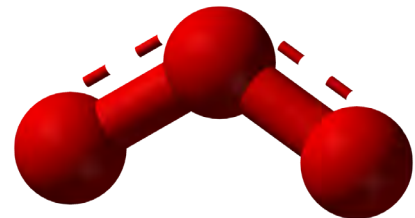


Fig. 3 An O₃(ozone) molecule consisting of three oxygen atoms

Like many things, ozone can be beneficial or detrimental, depending upon its location. While it is helpful in the upper atmosphere to block UV rays, it is extremely dangerous to life at ground-level.

In industrialized nations, manufacturing processes and automobile engines generate large quantities of ozone gas. With a strong breeze the gas is dissipated and cannot accumulate, but on calm days, ozone levels can increase to create smog, potentially making it harmful to the health and well-being of plants and animals (including humans), as well as reducing visibility. Areas such as the Los Angeles basin in California are well known for their smog days. While smog is predominantly ozone, it is technically referred to as photochemical smog, as it also contains other chemical pollutants such as nitrous oxide from vehicle exhausts and volatile organic compounds from paints and other aerosol products.

Carbon Dioxide & Greenhouse Gases

Carbon dioxide gas (Fig. 4) is released during the combustion process and as such is naturally released by volcanoes and hot springs, as well as from man-made furnaces and combustion engines. It is also released into the air by living organisms, including humans, as a large component of expelled breath.

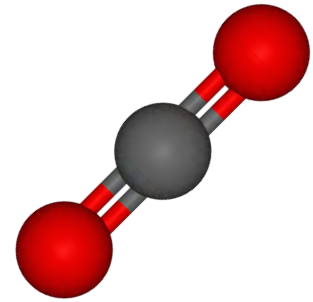


Fig. 4 A carbon dioxide gas molecule

While mammals breathe in oxygen and breathe out carbon dioxide, plants perform the opposite process. Plants and algae absorb carbon dioxide in order to produce a sugary substance on which they can feed. (This is referred to as photosynthesis and also requires energy from the Sun.) In addition to absorbing carbon dioxide, the photosynthetic process also releases oxygen as a “waste” product, which ultimately helps clean the air for mammals and produces more oxygen for us to breathe.

Unfortunately there are times when the quantity of carbon dioxide produced is greater than that which can be disposed of through photosynthesis. In this situation, the carbon dioxide accumulates in the upper layers of the atmosphere which, if left unchecked, can greatly change the environment in a way that impacts all life on Earth.

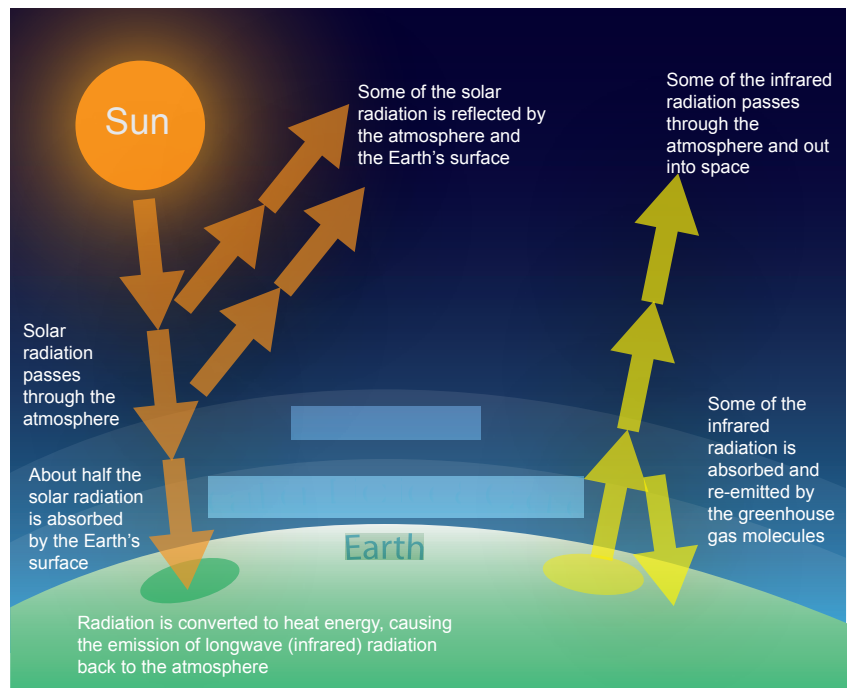


Fig. 5 The greenhouse effect

The Earth is heated by energy from the Sun. In a normal environment, the majority of the Sun's rays bounce off of the upper layers of the atmosphere and never reach the Earth's surface. The rest warm the Earth and then rise, with most leaving the atmosphere. With an increased level of carbon dioxide however, that rising heat cannot leave and is forced to stay in the atmosphere, slowly increasing the average temperature of the planet (Fig. 5). This is almost identical to how the glass in a greenhouse works, trapping the Sun's rays and keeping the air inside the greenhouse warm.

During the 20th century, Earth's average temperature has risen about 1.1°F (0.6°C). Since the 1990's that rate has accelerated, and NASA scientists have predicted that the globe will continue to warm over the course of the century. NASA's Langley Research Center's Science Directorate is a unique NASA organization devoted to discovering how the Earth and its atmosphere are interacting and changing, including what that means for the health of the planet. They search for and create better ways of gathering, measuring and analyzing atmospheric data so that others can better understand and track the effects of human activity on the atmosphere.

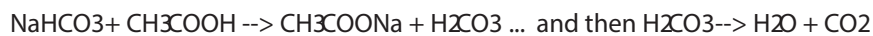
Although excessive quantities of carbon dioxide are often harmful, there are times when we can put its properties to good use. A perfect example of this is the fire extinguisher. Carbon dioxide gas is heavier than oxygen and as such, it sinks, displacing any oxygen that may be below it. When sprayed onto a fire, the carbon dioxide gas displaces the oxygen (which is required for a fire to burn), smothering the burning object and stopping the fire.

Yeast, Peroxide, Baking Soda & Vinegar

The activities on the following pages use a variety of household products to demonstrate how O₂ and CO₂ gases can be produced and detected. The following is a brief explanation as to why these gases are released when combining peroxide with yeast, and baking soda with vinegar.

Yeast contains a chemical called catalase whose purpose is to prevent toxins from becoming poisonous by converting them into harmless chemicals. One such toxin is hydrogen peroxide (H₂O₂). In order to prevent the yeast from becoming poisoned when coming into contact with peroxide, the catalase converts it into oxygen and water (2H₂O₂ → 2H₂O + O₂). Human bodies also contain catalase which is why we see bubbles after pouring hydrogen peroxide onto a cut. The catalase is preventing our bodies from being poisoned and the bubbles you see are oxygen being released while the liquid, now just water, falls harmlessly away.

Baking soda on the other hand (NaHCO₃) releases carbon dioxide in a chemical reaction when mixed with vinegar (HC₂H₃O₂). Baking Soda is a base, which in chemistry means it can readily accept hydrogen ions. (In certain scenarios, such as this one, it can also be referred to as an alkali.) Vinegar however is an acid, the opposite of a base. Whenever a base and an acid combine, they react, sometimes explosively, but always producing a different chemical in the process. When baking soda and vinegar combine there is actually a two-stage process that takes place. First, the vinegar reacts with sodium bicarbonate (the primary ingredient in baking soda) to form a mixture of sodium acetate and carbonic acid. Carbonic acid is incredibly unstable however and immediately breaks down into carbon dioxide and water.



or

Baking Soda + Vinegar → Sodium Acetate + Carbonic Acid ... and then Carbonic Acid → Water and Carbon Dioxide.

Activity 1

A Demonstration on Producing Oxygen

GRADES **K-12****Time Requirements:** 20 minutes**Materials:**In the Box

Safety goggles
 Plastic beaker
 Measuring spoon
 Re-sealable plastic bag
 Yeast
 Wooden splints
 Matches or lighter

Provided by User

A glass of water
 Hydrogen peroxide

Worksheets

None

Reference Materials

None

Key Terms:

None

Objective:

In this activity, students will learn about properties of objects and materials, properties and changes of properties in matter, chemical reactions and energy transfer, as they see how oxygen can be produced via the chemical reaction between yeast and hydrogen peroxide.

Activity Overview:

Students will watch a demonstration in which yeast and hydrogen peroxide are combined to produce pure oxygen. This will be confirmed by use of a glowing splint, a commonly used test for oxygen.

Caution: This activity uses an open flame and as such, care should be taken to avoid an unwanted fire. This is especially true when it comes to disposing of the materials afterwards. Ensure that the wooden splint is thoroughly soaked in water before disposal to prevent re-ignition while in the waste receptacle.

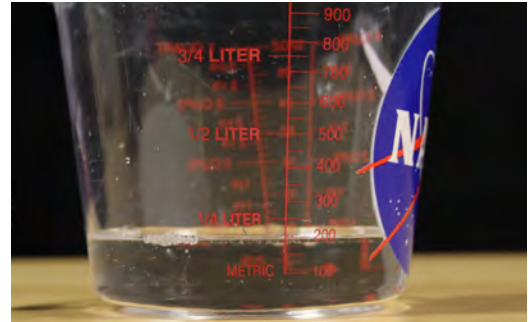
1. Using the **Background** information provided, discuss the science behind greenhouse gases, global warming and how correct levels of both carbon dioxide and oxygen are vital to the health of our planet.
2. Explain that in this activity you will demonstrate how to produce pure oxygen using yeast and hydrogen peroxide.
You may wish to explain that yeast is used in the making of bread and is responsible for creating all the little holes in each slice.
3. Place 2 teaspoons of yeast into a re-sealable bag and ensure the yeast falls to the bottom.



4. Next, place the bag flat on the table and squeeze out as much air as possible. This is to make the oxygen production more visible.



5. Using the plastic beaker, measure and pour 200ml of hydrogen peroxide into the bag and seal it as quickly as possible. Explain to the students that the peroxide is activating the chemicals in the yeast which make it produce oxygen. *If you discussed bread earlier, you can follow up by explaining that the little holes in each slice were made of bubbles of oxygen.*



6. Allow the students to move in closer to watch as the bag begins to inflate. Once fully inflated, invite the students to gently touch the bag. It should be quite warm to the touch. *This is because heat is released by the catalase in this exothermic (heat producing) chemical reaction.*



- Next, light the end of a wooden splint, allow it to burn for a few seconds and then blow it out. Explain to the students that if there is pure oxygen in the bag, the splint will reignite due to it being in the perfect environment for fire.



- Open the bag and slowly insert the splint; it should reignite quite quickly. If appropriate for the age of the students, invite them to blow out the flame from the splint and reinsert it into the bag. This can be repeated multiple times before the oxygen level in the bag is depleted.



CAUTION: Do not let the splint touch the side of the bag. It will melt the bag on contact.

- Once you have finished demonstrating this activity, insert the burned end of the splint into the glass of water and allow it to soak completely before throwing it away. You can also discard the yeast by rinsing it down a sink.



CAUTION: Failure to follow this step has led to small fires where the splint has re-ignited due to the oxygen-rich bag and the splint being disposed of together in the same waste receptacle.

Discussion Points:**1. Why did the splint re-ignite when placed in the bag?**

For a fire to exist, three things are required: (1) Fuel, which in this scenario was the carbon molecules of the wooden splint, (2) heat, produced by the glowing embers, and (3) oxygen. The bag contained an oxygen-rich environment which, when combined with the other two factors, caused a fire to start.

2. What was the difference between the oxygen in the bag and the air outside the bag?

The oxygen in the bag was almost 100% pure, whereas the oxygen in the air outside was mixed with other elements, mainly nitrogen. Typically, the air we breathe contains only 21% oxygen which, while sufficient to support an already-burning fire, is insufficient to re-ignite a smoldering ember.

3. Why did the bag become warm to the touch?

Almost every time there is a chemical reaction, there is also a transfer of heat either to or from the substance. In this case, the chemical reaction was exothermic, meaning that it released heat, which warmed the oxygen being produced.

4. What was the chemical reaction that took place here?

$2H_2O_2 \rightarrow 2H_2O + O_2$.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Properties and changes of properties in matter
- Transfer of energy

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Structure and properties of matter
- Interactions of energy and matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology
- Chemical reactions

Activity 2

A Demonstration on Producing Carbon Dioxide

GRADES **K-12**

Time Requirements: 20 minutes

Materials:

In the Box

Safety goggles
Plastic beaker
Measuring spoon
Re-sealable plastic bag
Baking soda
Wooden splints
Matches or lighter

Provided by User

A glass of water
Vinegar

Worksheets

None

Reference Materials

None

Key Terms:

None

Objective:

In this activity, students will learn about the properties of objects and materials, properties and changes of properties in matter, chemical reactions and energy transfer, as they see how carbon dioxide can be produced via the chemical reaction between baking soda and vinegar.

Activity Overview:

Students will watch a demonstration where baking soda and vinegar are combined to produce carbon dioxide. This will be confirmed by use of a burning splint.

CAUTION: This activity uses an open flame and as such, care should be taken to avoid an unwanted fire. This is especially true when it comes to disposing of the materials afterwards. Ensure that the wooden splint is thoroughly soaked in water before disposal to prevent re-ignition while in the waste receptacle.

1. If **Activity 1** has not already been completed, use the **Background** information provided to discuss the science behind greenhouse gases, global warming and how correct levels of both carbon dioxide and oxygen are vital to a healthy planet.
2. Explain that in this activity you will demonstrate how to produce pure carbon dioxide using baking soda and vinegar.
You may wish to explain that baking soda is used in cooking to create foods which need to rise, such as cakes.
3. Place 1 teaspoon of baking soda into a re-sealable bag and ensure the soda falls to the bottom.



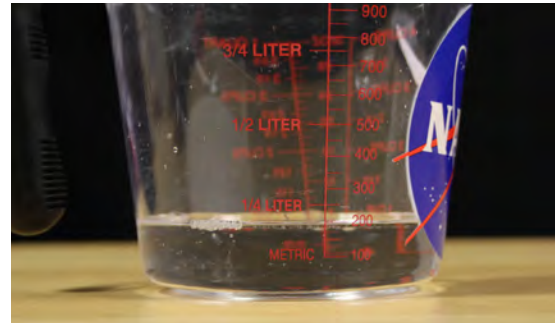
- Next, place the bag flat on the table and squeeze out as much air as possible.

This is to make the carbon dioxide production more visible.



- Using the plastic beaker, measure and pour 200ml of vinegar into the bag and seal as quickly as possible. Explain to the students that the vinegar is reacting with the chemicals in the baking soda which make it produce carbon dioxide.

If you discussed cooking earlier, you can follow up by explaining that the gas produced builds up inside the cake, pushing it upwards and out of the pan.



- Allow the students to move in closer to watch as the bag begins to inflate.

Once fully inflated, invite the students to gently touch the bag. Being an endothermic reaction, it should be quite cool to the touch.



7. **Next, light the end of a wooden splint and allow it to burn for a few seconds.**
Explain to the students that if there is pure carbon dioxide in the bag, the splint will immediately extinguish due to there being virtually no oxygen, which is necessary for fire.



8. **Open the bag and slowly insert the splint; it should extinguish immediately.**
If appropriate for the age of the students, invite them to relight the splint and reinsert it into the bag. This can be repeated numerous times if desired.



CAUTION: Do not let the flame touch the side of the bag. It will melt immediately.

9. **Once you have finished demonstrating this activity, insert the splint into the glass of water and allow it to soak completely before throwing it away.**



Discussion Points:**1. Why did the splint extinguish when placed in the bag?**

For a fire to exist, three things are required: (1) Fuel, which in this scenario was the carbon molecules of the wooden splint, (2) heat, produced by the glowing embers, and (3) oxygen. The bag contained almost no oxygen, which forced the fire to extinguish immediately.

2. What was the difference between the carbon dioxide in the bag and the air outside?

The carbon dioxide in the bag was almost 100% pure, whereas the level of carbon dioxide in the air is less than 1%. This low level of CO₂ is not enough to prevent the oxygen in the air from permitting a fire to burn in Earth's normal atmosphere.

3. Why did the bag become cool to the touch?

Almost every time there is a chemical reaction, there is also a transfer of heat either to or from the substance. In this case, the chemical reaction was endothermic, meaning that it absorbed heat, which cooled the carbon dioxide gas being produced.

4. Can you name a device that uses carbon dioxide with similar effect?

Fire extinguishers (specifically the black-colored ones) use a chemical reaction to produce large quantities of carbon dioxide. When dispensed, it smothers the fire, preventing oxygen from being able to reach it. As such, the fire goes out. This is used primarily on electrical fires where a water-based extinguisher would be dangerous.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Properties and changes of properties in matter
- Transfer of energy

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Structure and properties of matter
- Interactions of energy and matter
- Chemical reactions

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology



Reference Materials

Fig. 1 Gaseous composition of the Earth's atmosphere (dry)

Gas	Percentage
Nitrogen (N ₂)	78.084%
Oxygen (O ₂)	20.946%
Argon (Ar)	0.9340%
Carbon Dioxide (CO ₂)	0.039%
Neon (Ne)	0.001818%
Helium (He)	0.000524
Methane (CH ₄)	0.000179%
Krypton (Kr)	0.000114%
Hydrogen (H ₂)	0.00055%
Nitrous Oxide (N ₂ O)	0.00003%
Carbon Monoxide (CO)	0.00001%
Xenon (Xe)	0.000009%
Ozone (O ₃)	0.000007%
Nitrogen Dioxide (NO ₂)	0.000002%
Iodine (I ₂)	0.000001%
Ammonia (NH ₃)	trace

Fig. 2 An O₂ molecule consisting of two oxygen atoms

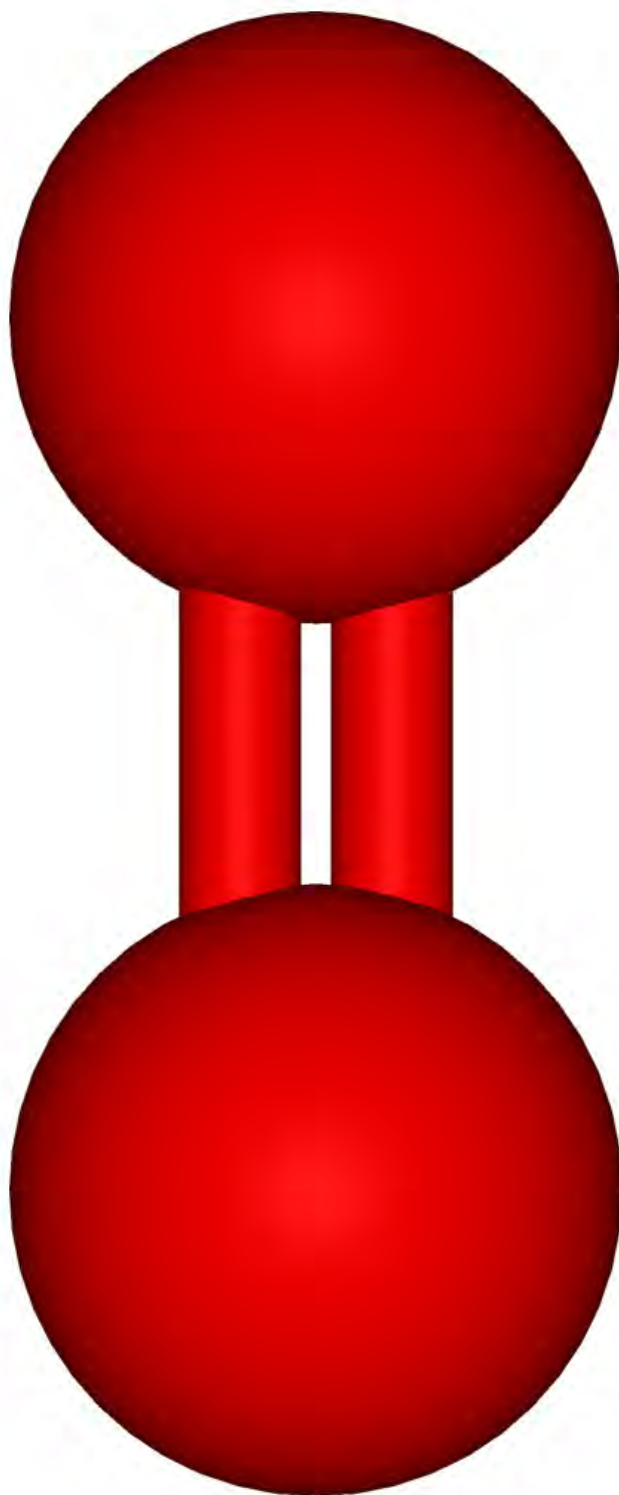


Fig. 3 An O₃(ozone) molecule consisting of three oxygen atoms

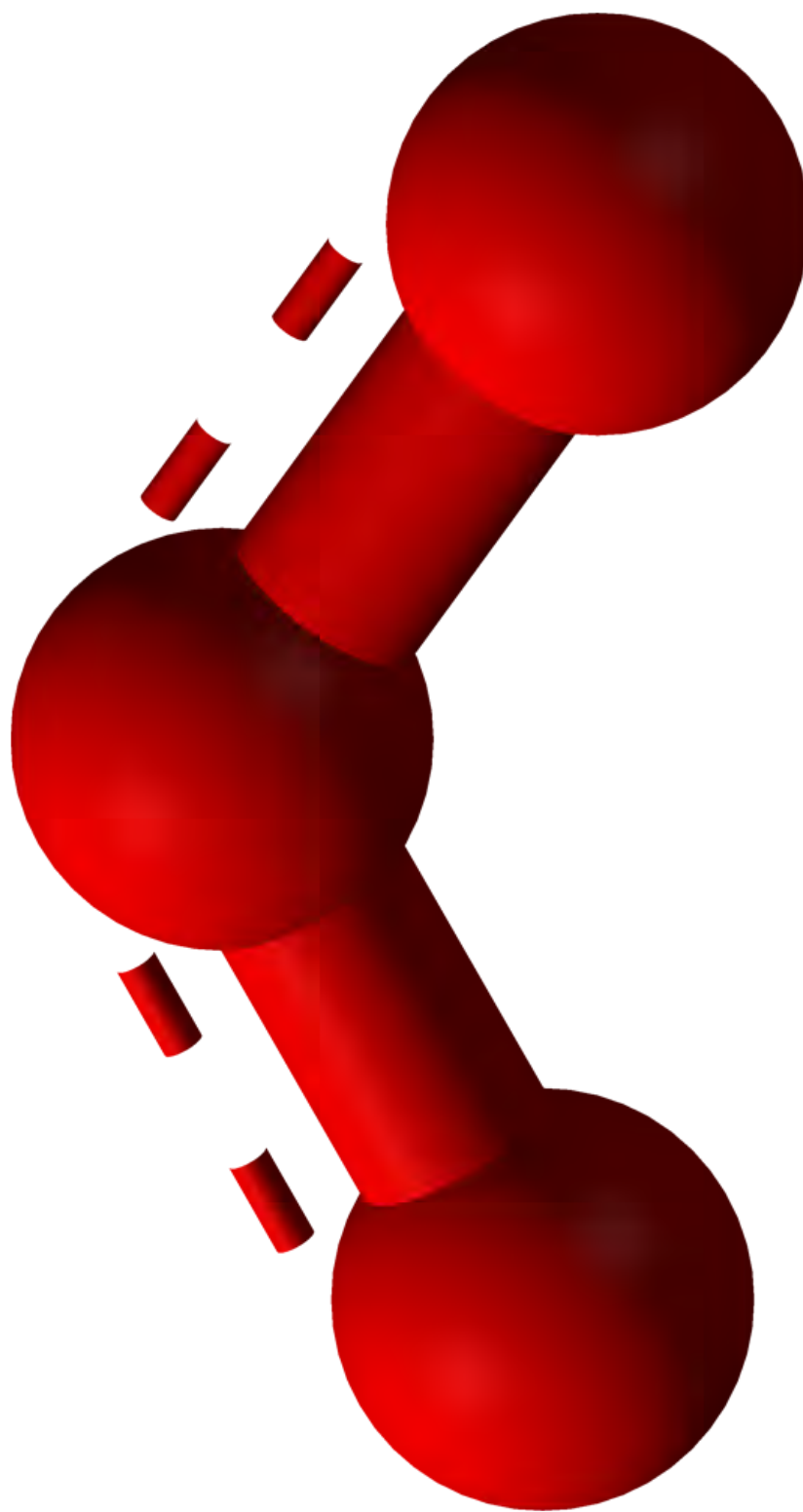


Fig. 4 A carbon dioxide gas molecule

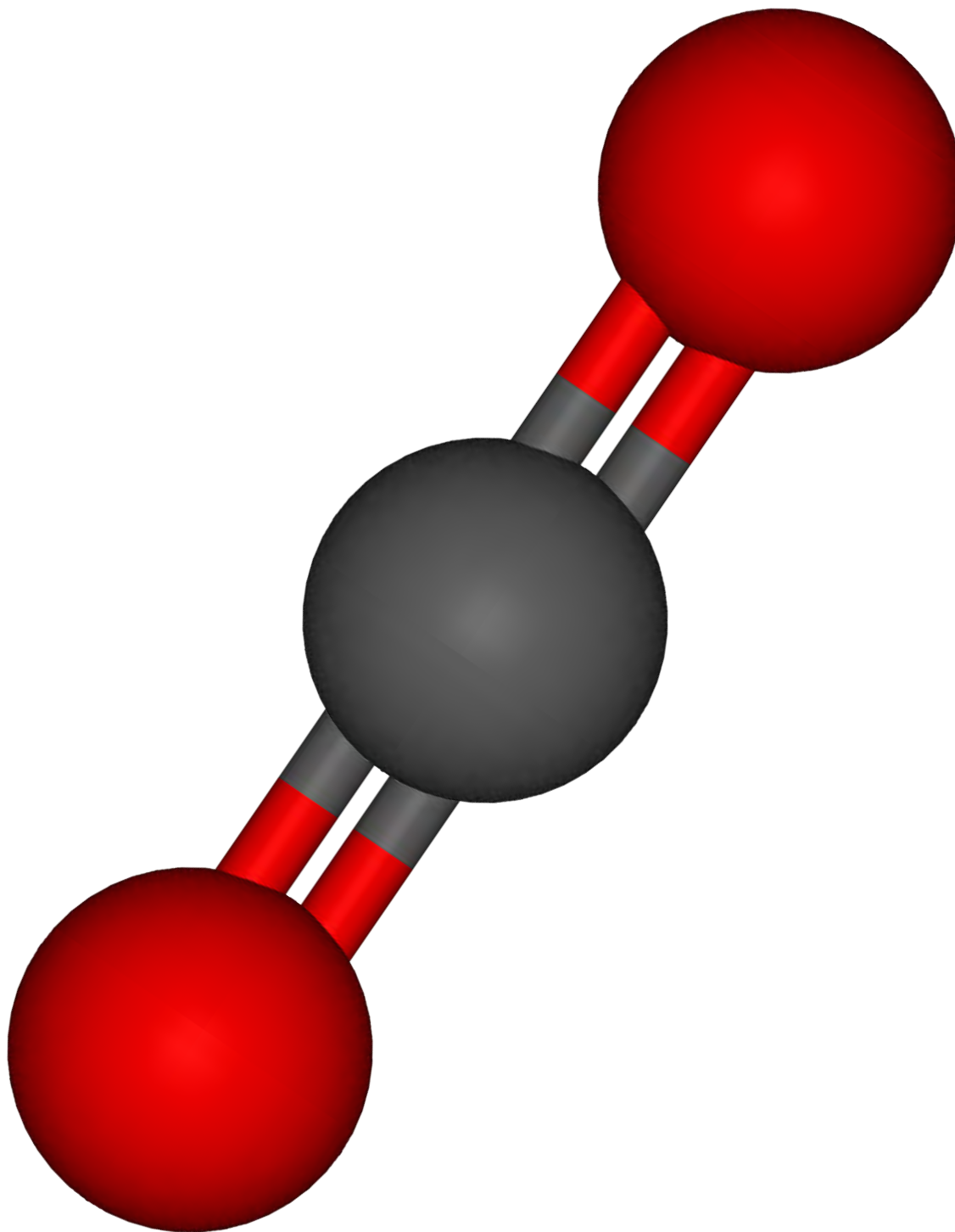
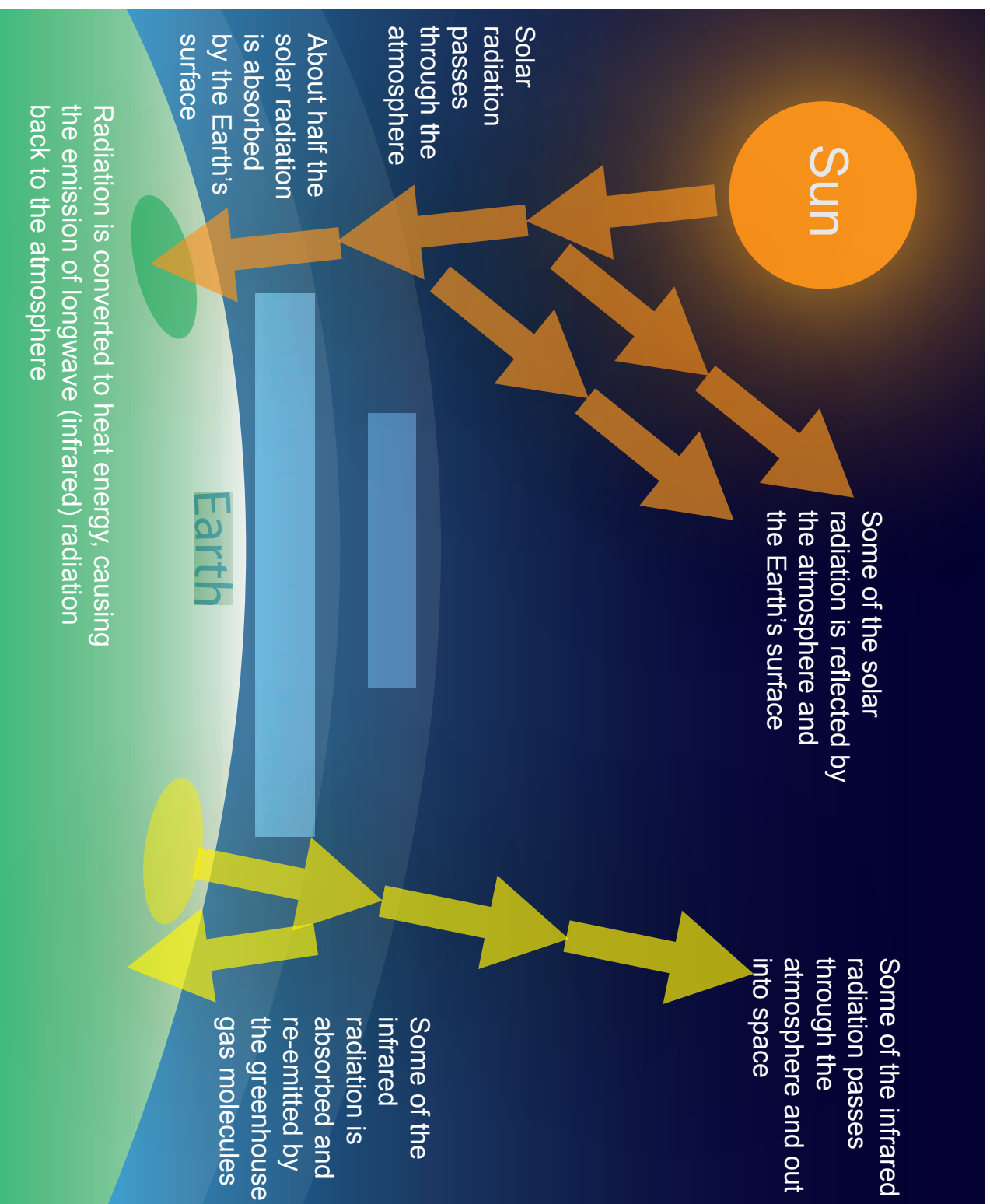
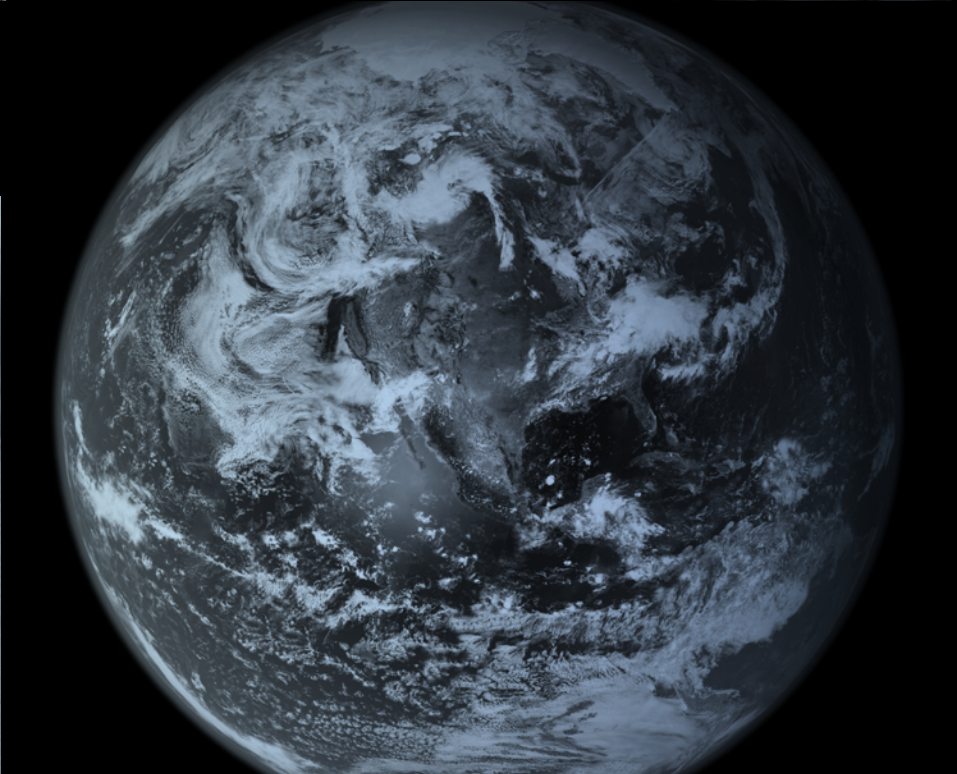
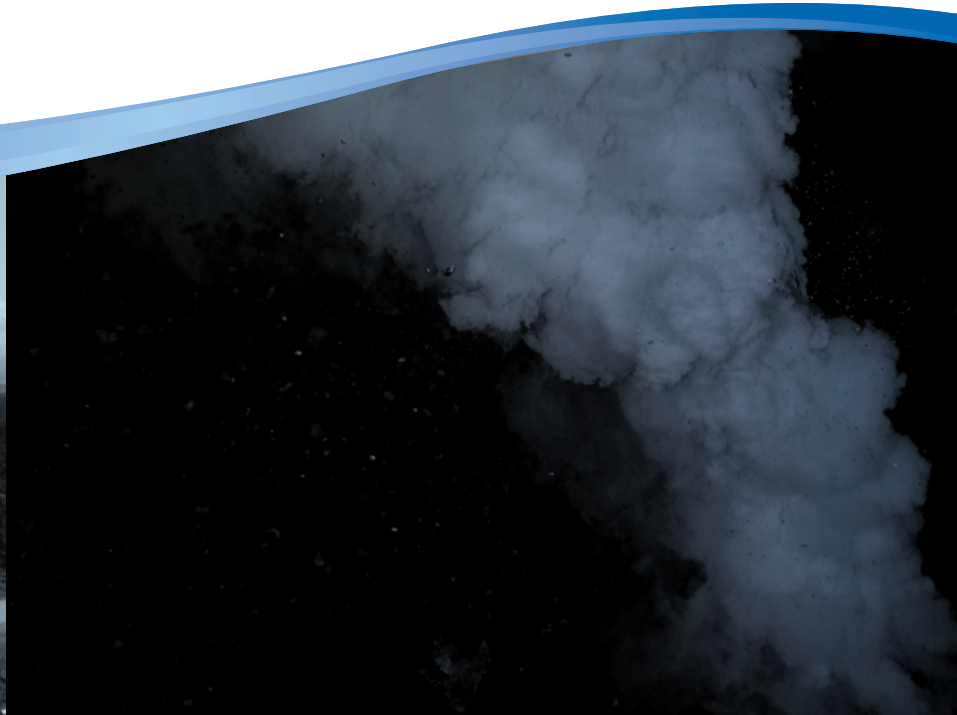
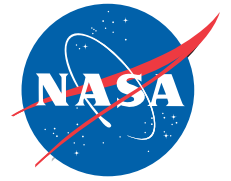


Fig. 5 The greenhouse effect



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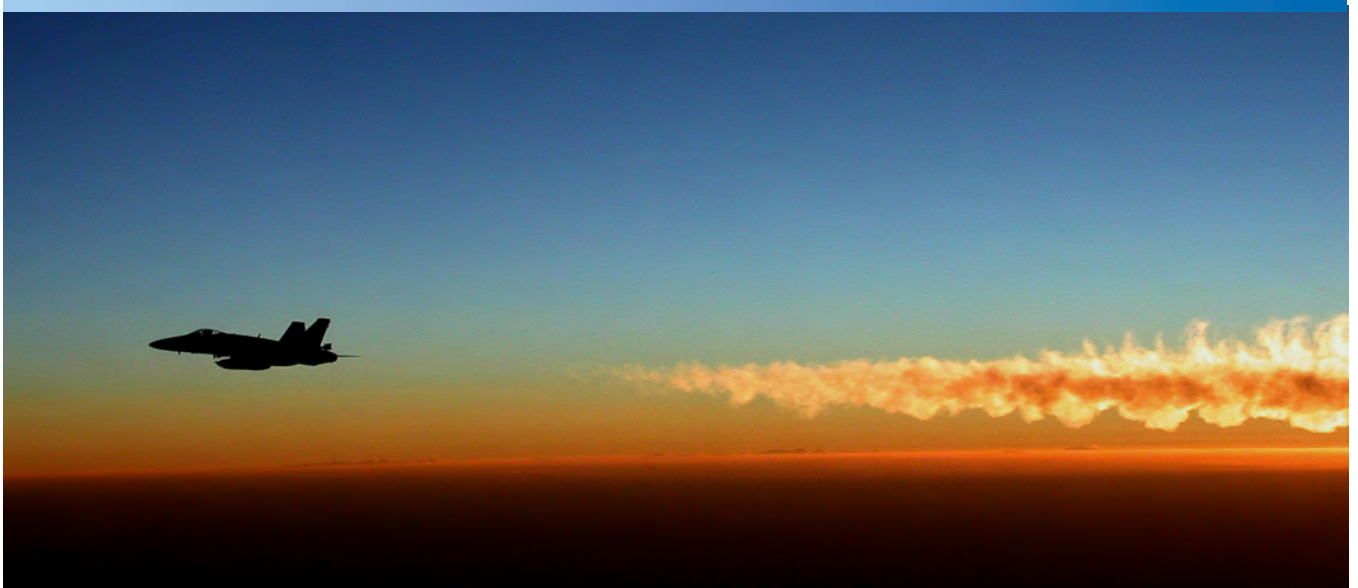
GRADES **K-12**

Contrails

airspace

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Contrails

Lesson Overview

Through demonstration, students will learn about properties and changes of properties of matter, as they witness firsthand how contrails are formed. This is shown by combining water vapor and the soot from an extinguished match within a glass flask, then adjusting the internal air pressure to form a cloud.

Objectives

Students will:

1. Learn how condensation nuclei and water vapor combine to create contrails.

Materials:

In the Box

500ml flat bottom flask
Rubber stopper & 60ml rubber bulb
Matches

Provided by User

Water

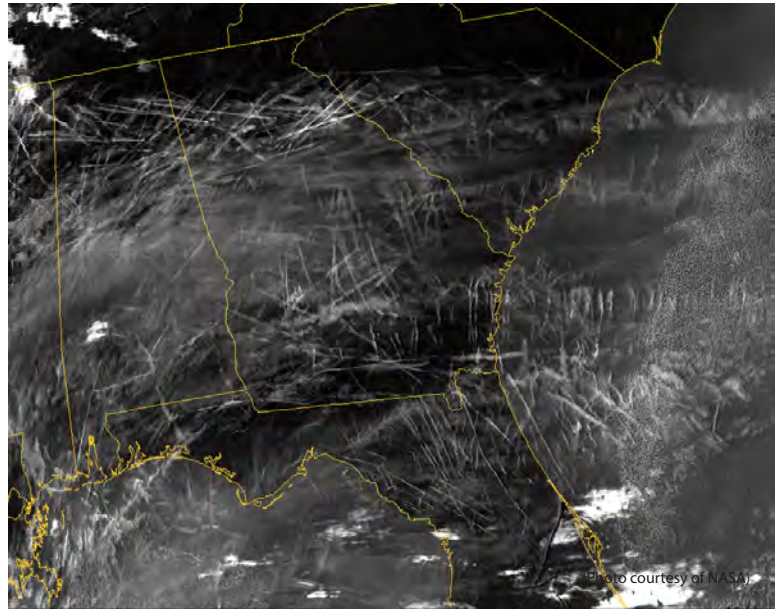
GRADES

Time Requirements: 30 minutes

Background

What are contrails?

Contrails are a type of ice cloud, formed by aircraft as water vapor condenses around small dust particles, which provide the vapor with sufficient energy to freeze. The water vapor is already in the air surrounding the aircraft while the dust, or condensation nuclei, is comprised primarily of soot particles produced during the combustion process. They can also form when water vapor from the airplane's engines collide with the water vapor in the air.



Img. 1 Contrails over the southern United States, as seen from space

Contrails were initially discovered during the first high-altitude flights in the 1920s, although scientists and engineers were not overly concerned with them until WWII, when military bombers could be seen from miles away due to the long lines of contrails left in their wake. There are numerous veteran pilots who discovered issues both in navigation and warfare due to massive contrail formations. The contrail clouds occasionally became so thick that planes could not find their targets and sometimes, although rarely, even collided with each other! In 1953, a scientist named H. Appleman published a chart (Fig. 1) that was successfully used to determine when a jet aircraft would produce a contrail.

There are three different families of contrail, but all are made from the same two components and formed in the same way. The primary difference is the amount of time the contrail remains visible. The first of the three, Short-Lived Contrails (Img. 2), appear as short white lines following along behind the aircraft, although disappear quickly - almost as fast as the airplane goes across the sky. Typically, Short-Lived Contrails survive for just a few minutes at most before the water vapor sublimates back into gas. In this scenario, the air mass through which the aircraft flies is quite dry with only a small amount of water vapor available to form the contrail.

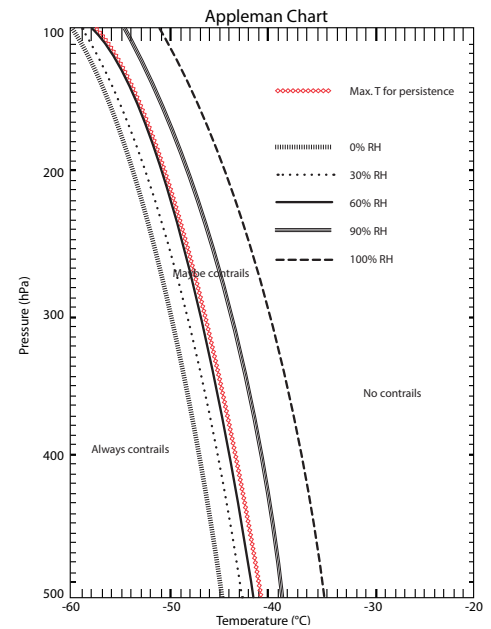


Fig. 1 The Appleman Chart for flight above 18,000 feet (500hPa)



Img. 2 Short-lived contrail

Persistent (Non-Spreading) Contrails (Img. 3) are presented as long white lines that remain visible long after the airplane has passed. A prerequisite for this type of contrail is a wet, humid atmosphere, with a large amount of water vapor/nuclei available to form the contrail. Due to the additional moisture, the ice takes much longer to sublimate, allowing the contrail to remain visible for up to an hour after the aircraft has passed. Also, the time the contrail is visible and the speed of the wind in the upper atmosphere often cause contrails to move from where they originated and have been known to travel many miles.



(Photo courtesy of NASA)

Img. 3 Persistent contrail

Persistent (Spreading) Contrails (Img. 4) are formed in an identical way to the non-spreading variety. However, the spreading occurs due to the air mass being unstable or turbulent. This turbulence dissipates the dense contrail lines and spreads them over a wide area, giving them a more cloud-like appearance.



(Photo courtesy of the United States Navy)

Img. 4 An F/A-18 Hornet in flight

Wingtip vortices (Img. 5) are often thought to be a type of contrail but are actually produced from a different process. During very specific weather conditions you may see vapor trails form at the rear of the wingtips of jet aircraft on takeoff or landing. This phenomenon occurs due to a decrease in pressure and temperature as the wing generates lift.



(Photo courtesy of the United States Air Force)

Img. 5 An F-35 departing Elgin Air Force Base, Florida

How do contrails differ from other types of clouds?

Unlike clouds which form naturally, contrails are technically manmade clouds since they are formed due to the exhaust from an airplane. Also, contrails are nearly always made of ice crystals, unlike natural clouds which are often liquid water in suspension. Finally, they can only form at very high altitudes where the air is extremely cold, whereas natural clouds can form anywhere, from very close to the ground (fog), to very high altitudes (cirrus clouds).

How and where can we see contrails?

On a clear day, the sun's rays travel to Earth's surface unimpeded. When light runs into the cloud or contrail though, it is reflected by the water molecules within them, making the cloud visible and distinguishable from its background, the sky.

Activity 1

Creating a Contrail

GRADES

Materials:In the Box

500ml fl t bottom flas
 Rubber stopper &
 60ml rubber bulb
 Matches

Provided by User

Water

Worksheets

None

Reference Materials

None

Key Terms:

Cloud
 Condensation nucleus
 Contrail
 Wingtip vortex

Time Requirements: 30 minutes**Objective:**

In this demonstration, students will learn how condensation nuclei and water vapor combine to create contrails.

Activity Overview:

By combining water vapor and the soot from an extinguished match, then adjusting the internal air pressure, students will see a cloud form within a glass flask .

Activity:

1. Using the **Background** information, discuss how condensation nuclei and water vapor combine to create a contrail.

Remember that younger students will not understand the vast majority of the concepts being presented and as such, care should be made to not confuse them with excessive specifics.

2. **Begin the demonstration by placing 5ml of tap water into the flask .** Next, insert the rubber stopper into the top of the flask and swi l the water around the sides. *5ml of water is approximately a teaspoon; a precise quantity is not important. The swirling motion is designed to help some of the water evaporate within the flask, which is vital for this experiment to work correctly.*



3. **Next, light a match and allow it burn for a few seconds.** Remove the stopper from the flask , extinguish the match and insert the burnt, smoking end into the flask . Allow some of the smoke to accumulate inside the flask and then reinsert the stopper.

The smoke contains the condensation nuclei component that is required for the cloud to form.



4. **Squeeze the rubber bulb to increase the air pressure within the flask .** Have the students watch the contents of the flask closely and when ready, release the bulb.

The rapid drop in air pressure vaporizes the water molecules and allows them to attach to the smoke molecules. This creates a cloud inside the flask in a similar way to how a contrail is formed behind an aircraft.



Discussion Points:

- 1. What are the two components required for a contrail to form?**
Water vapor molecules and condensation nuclei, such as dust, smoke or dirt, must join in order to form a contrail.
- 2. If no condensation nuclei are present, what happens to the water?**
Nothing. The water remains vaporized until another particle, required for cloud formation, becomes present.
- 3. Why can you see the “clouds”, or contrails, created by a jet engine on a clear day?**
The clear sky lets the sun’s rays travel to Earth’s surface unimpeded. When light runs into the cloud or contrail, it is reflected by the water molecules, making the cloud visible and distinguishable from its background.
- 4. Can contrails move, or do they stay in the location where they were formed?**
Because contrails are formed at high altitudes where the winds are usually very strong, they will often move away from the point where they originated. When looking up into the sky you can frequently see older persistent contrails that formed many miles away but moved into view because of the wind.

NATIONAL SCIENCE STANDARDS K-4

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Property of objects and materials

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 5-8

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Properties and changes of properties in matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology

NATIONAL SCIENCE STANDARDS 9-12

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

PHYSICAL SCIENCE

- Structure and properties of matter
- Interactions of energy and matter

SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understanding about science and technology



Reference Materials

Glossary

Cloud:

A collection of visible water droplets or frozen ice crystals suspended in the atmosphere above the surface of the planet.

Condensation Nuclei:

Small particles, typically under $0.2 \mu\text{m}$ (0.002mm), about which moisture can coalesce, or merge, in order to form a larger body such as a contrail or cloud.

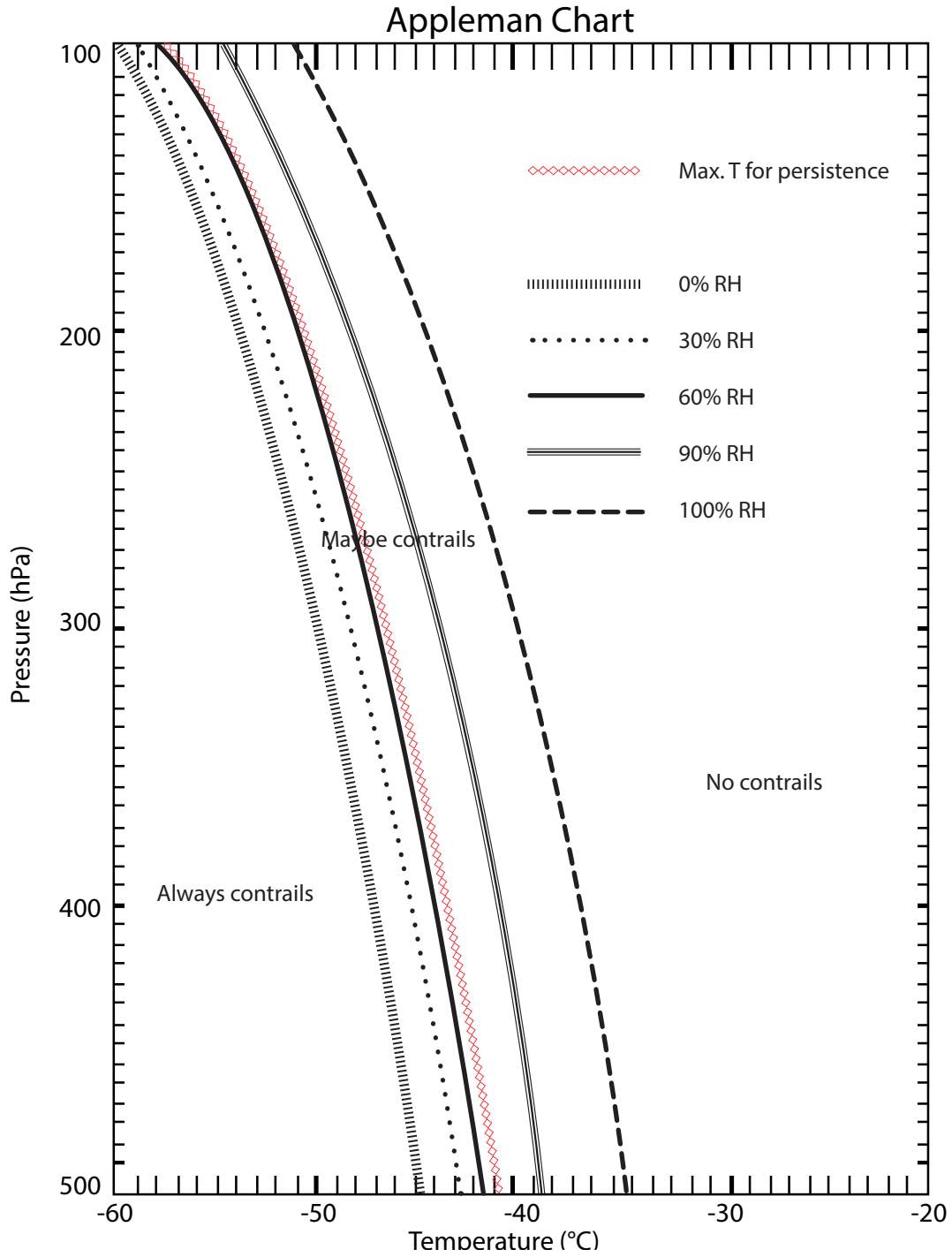
Contrail:

An artificial cloud created from the condensed, instantly-frozen water vapor and condensation nuclei

Wingtip Vortex:

A tube of circulating air that is created by an aircraft's wing as it produces lift.

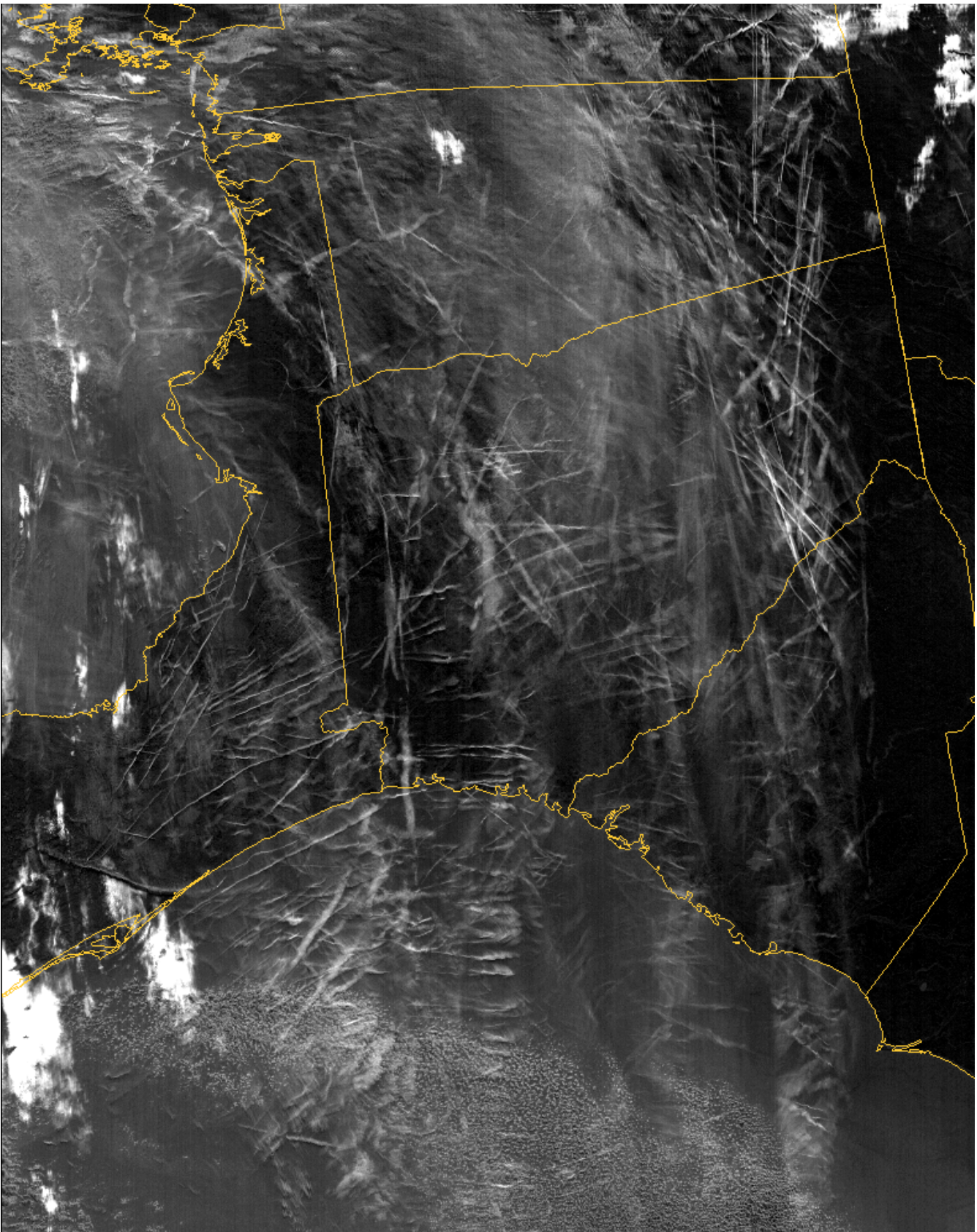
Fig. 1 The Appleman Chart for flight above 18,000 feet (500hPa)





Images

Img. 1 Contrails over the southern United States, as seen from space



(Photo courtesy of NASA)

Img. 2 Short-lived contrail



(Public Domain)

Img. 3 Persistent contrail



(Photo courtesy of NASA)

Img. 4 An F/A-18 Hornet in flight



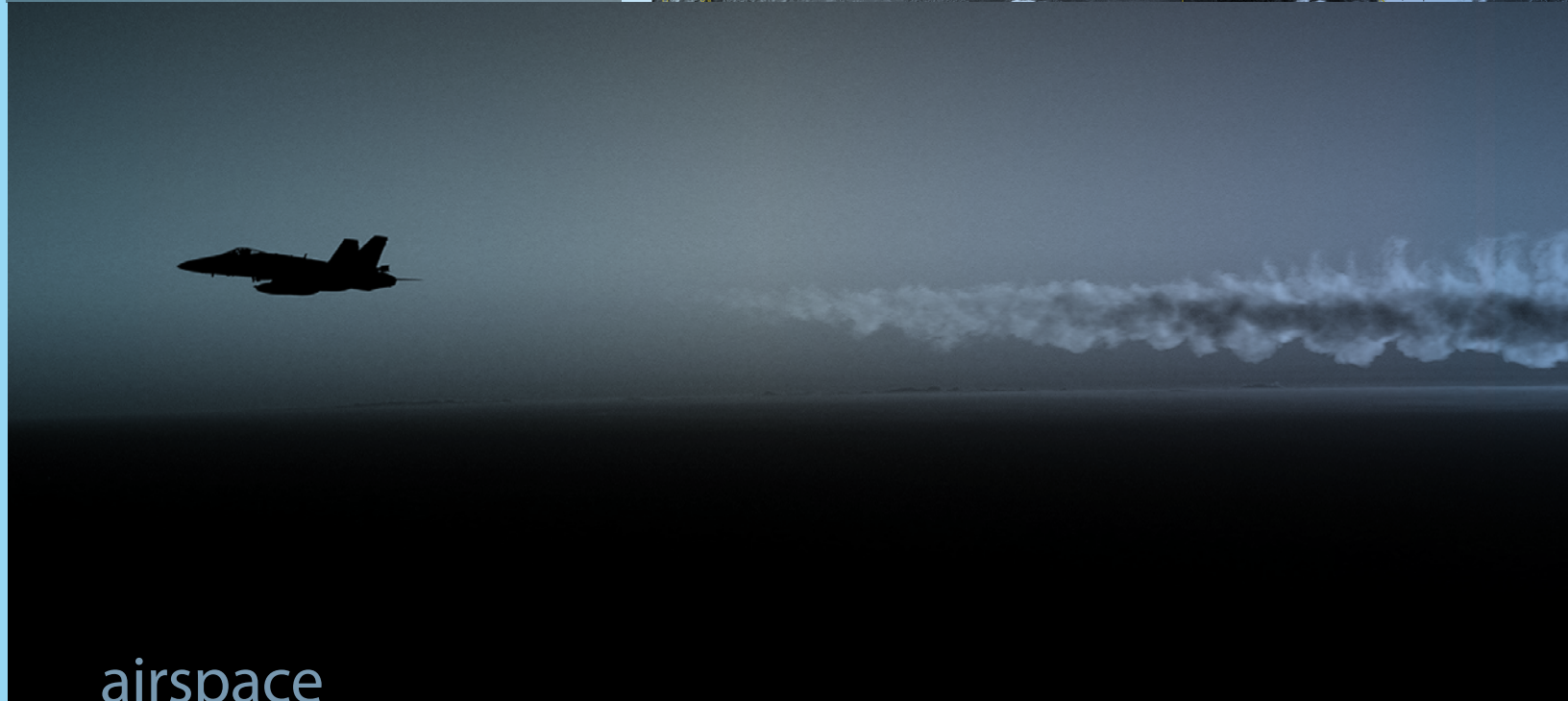
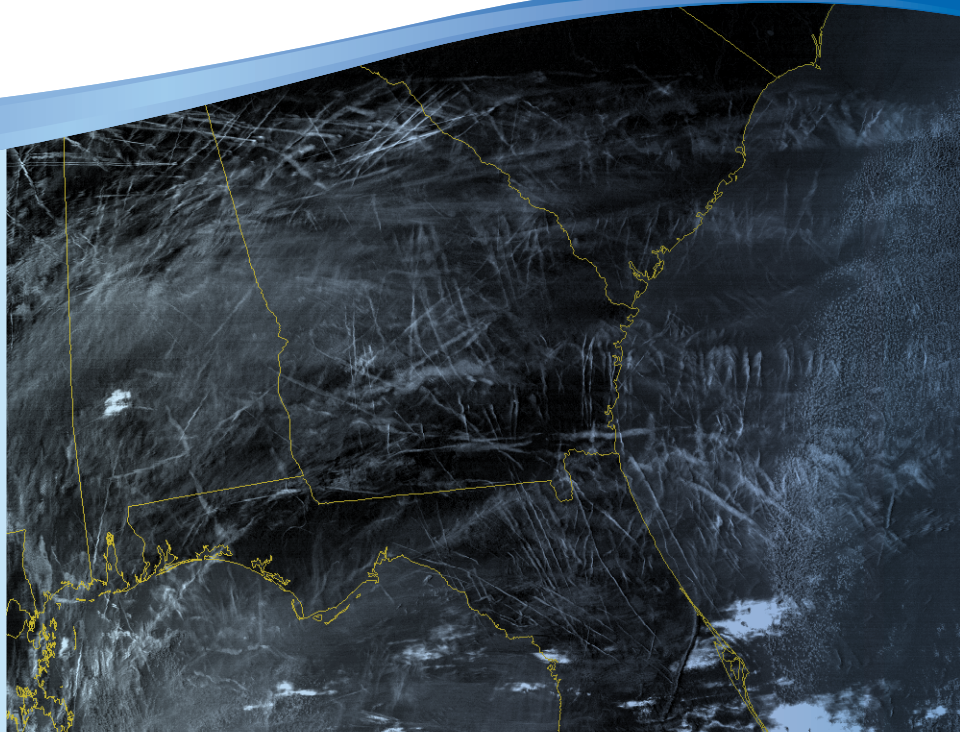
(Photo courtesy of the United States Navy)

Img. 5 An F-35 departing Elgin Air Force Base, Florida



(Photo courtesy of the United States Air Force)

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