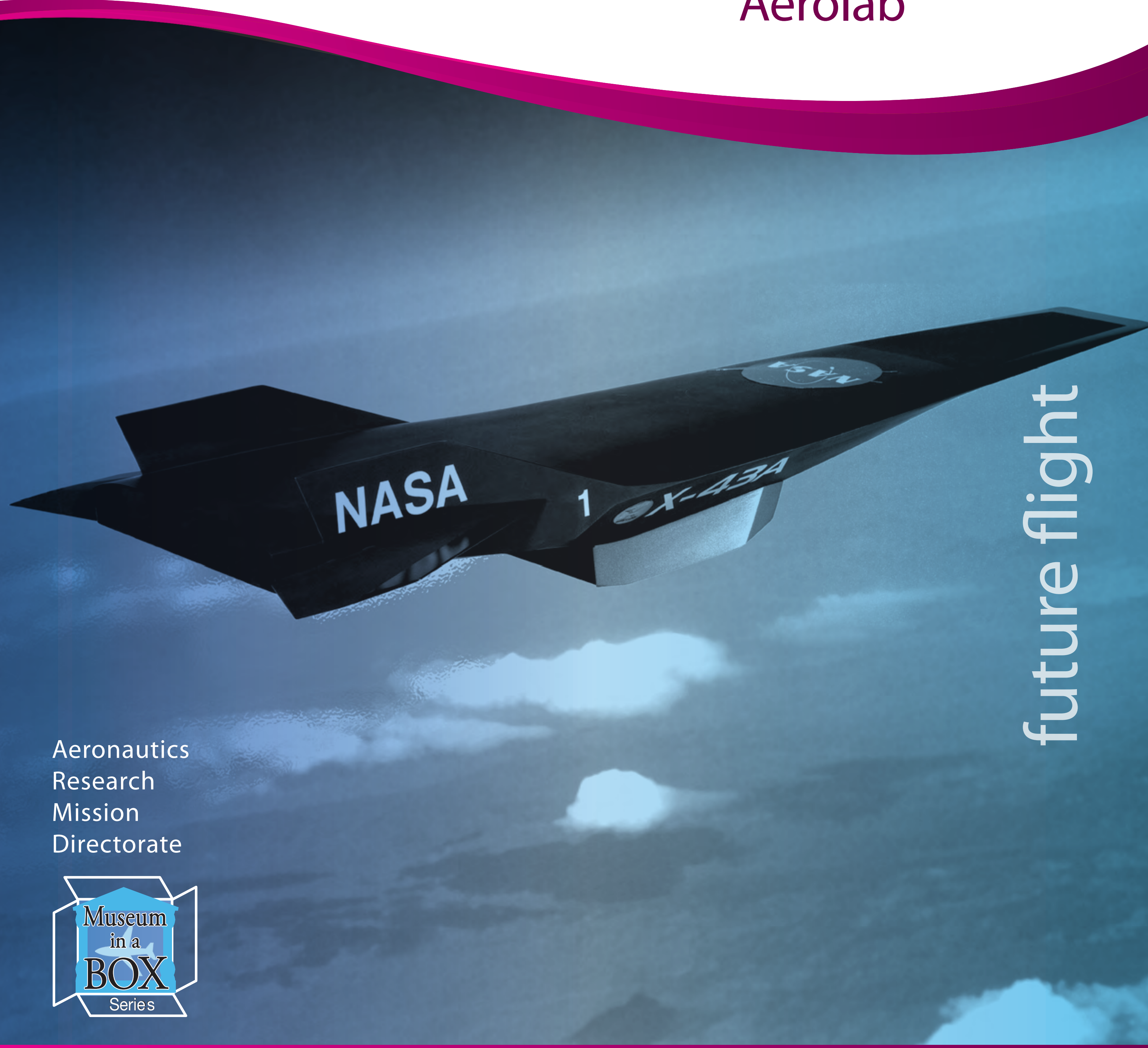
National Aeronautics and Space Administration

GRADES **5-12**

Aerolab



future flight

Aeronautics
Research
Mission
Directorate

Museum in a BOX Series

www.nasa.gov

(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.

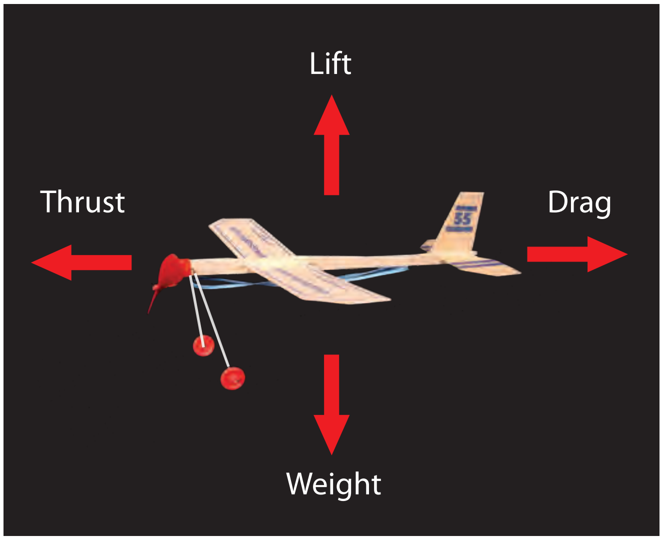


Fig. 1 Four forces of flight

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.

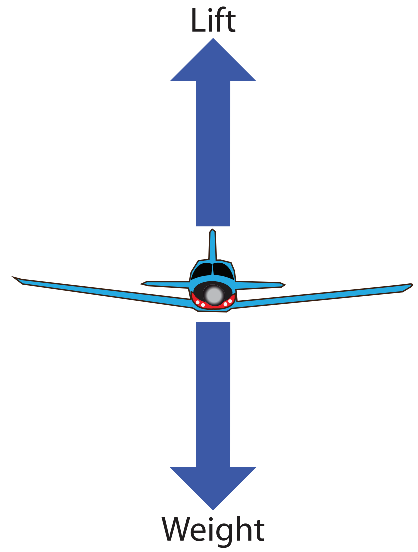


Fig. 2 Forces of straight and level flight

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.

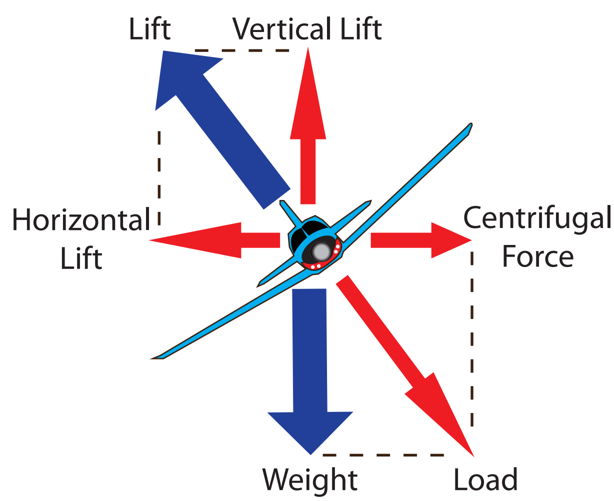


Fig. 3 Forces of turning flight

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.

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.

Img. 1 X-31 Enhanced Fighter Maneuverability Demonstrator aircraft

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.

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.

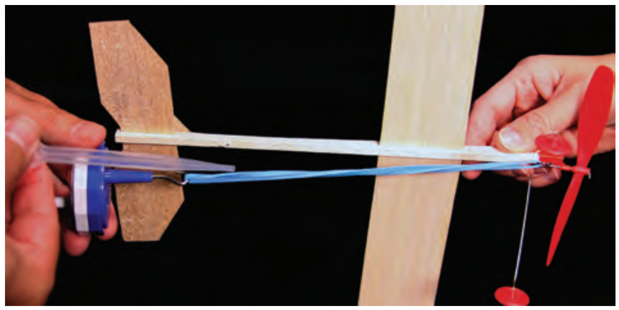
   Marker: This person will record the points of takeoff and touchdown, as well as counting the complete laps made by the airplane. Marking the points of take-off and touchdown with tape will assist in visually determining partial laps.

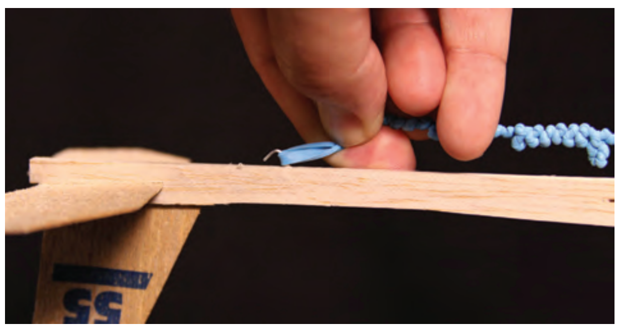
   It is recommended that the students trade roles for each subsequent launch of the airplane.

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.



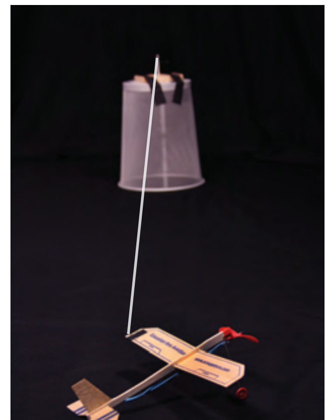


b. While holding firmly onto the airplane, attach the paperclip from the pylon to the center of the left wing. Apply a small piece of tape if desired to hold it securely in place.

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.*

(Photo courtesy of Lost Tribe Media Inc.)

Img. 2 Correct launch position

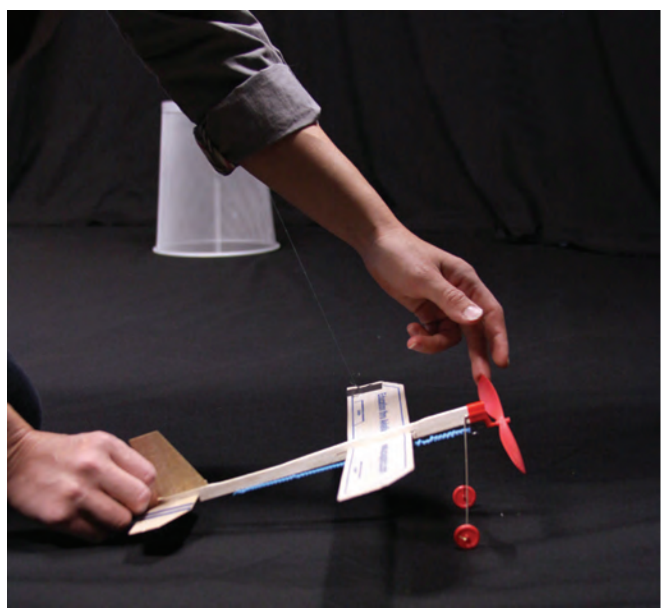


(Photo courtesy of Lost Tribe Media Inc.)

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.

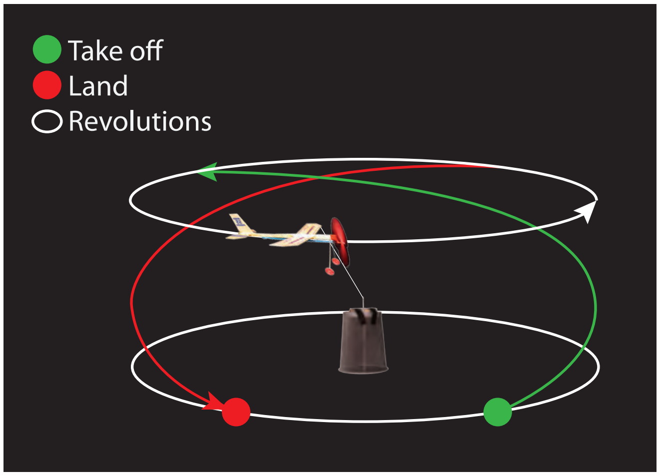


Fig. 4 Aircraft flight path

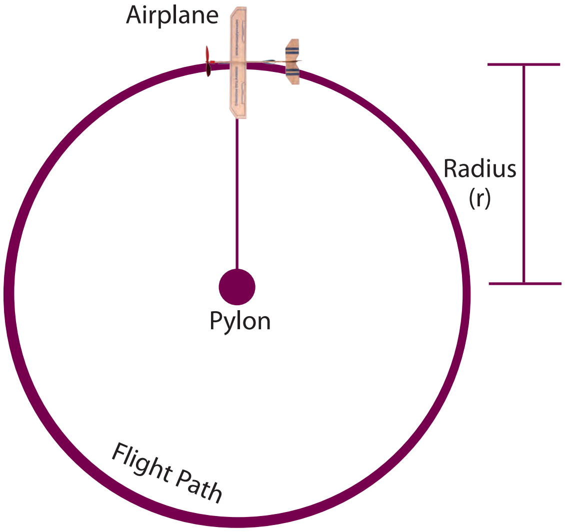
6. **Have the students complete their worksheets as follows.**
The calculations below are based upon our experiments. Your numbers will vary.

   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 = 2πr, where (r) is the radius and π = 3.14. In our example the radius is 2 meters.

   2 x π x Radius = Circumference (in meters)
   2 • π • 2 meters = 12.56m



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).

Takeoff Distance (in laps) x Circumference = Takeoff Distance (in meters)

$0.3 \cdot 12.56m = 3.77m$

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).

$$\frac{\text{Sum of Takeoff Distance (in meters)}}{3} = \text{Average Takeoff Distance (in meters)}$$

$$\frac{(3.77 + 5.02 + 3.77)}{3} = 4.19\ m$$

e. Find the average distance the airplane flew during each trial.

Average Number of Laps Flown x Circumference = Average Distance Flown

$6.1 \cdot 12.56m = 76.62m$

f. Calculate the airplane's average airspeed for all three trials.

$$\frac{\textit{Average Distance Flown}}{\textit{Average Time Airborne}} = \textit{Average Airspeed}$$

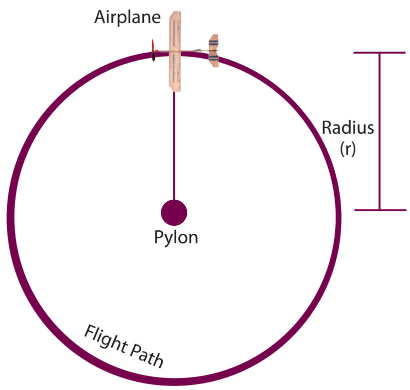
$$\frac{76.62m}{15.3\ sec} = 5.01\ m/s$$

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) = 2πr: 3.77m



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	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

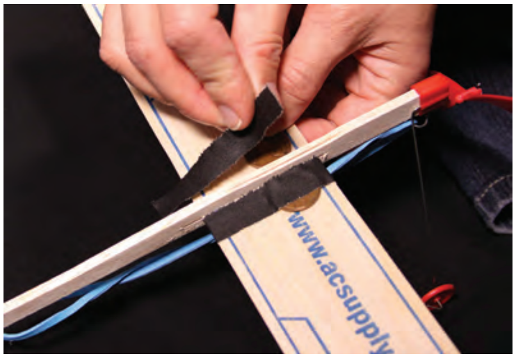
Average distance flown: 76.62m

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/s^2, 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

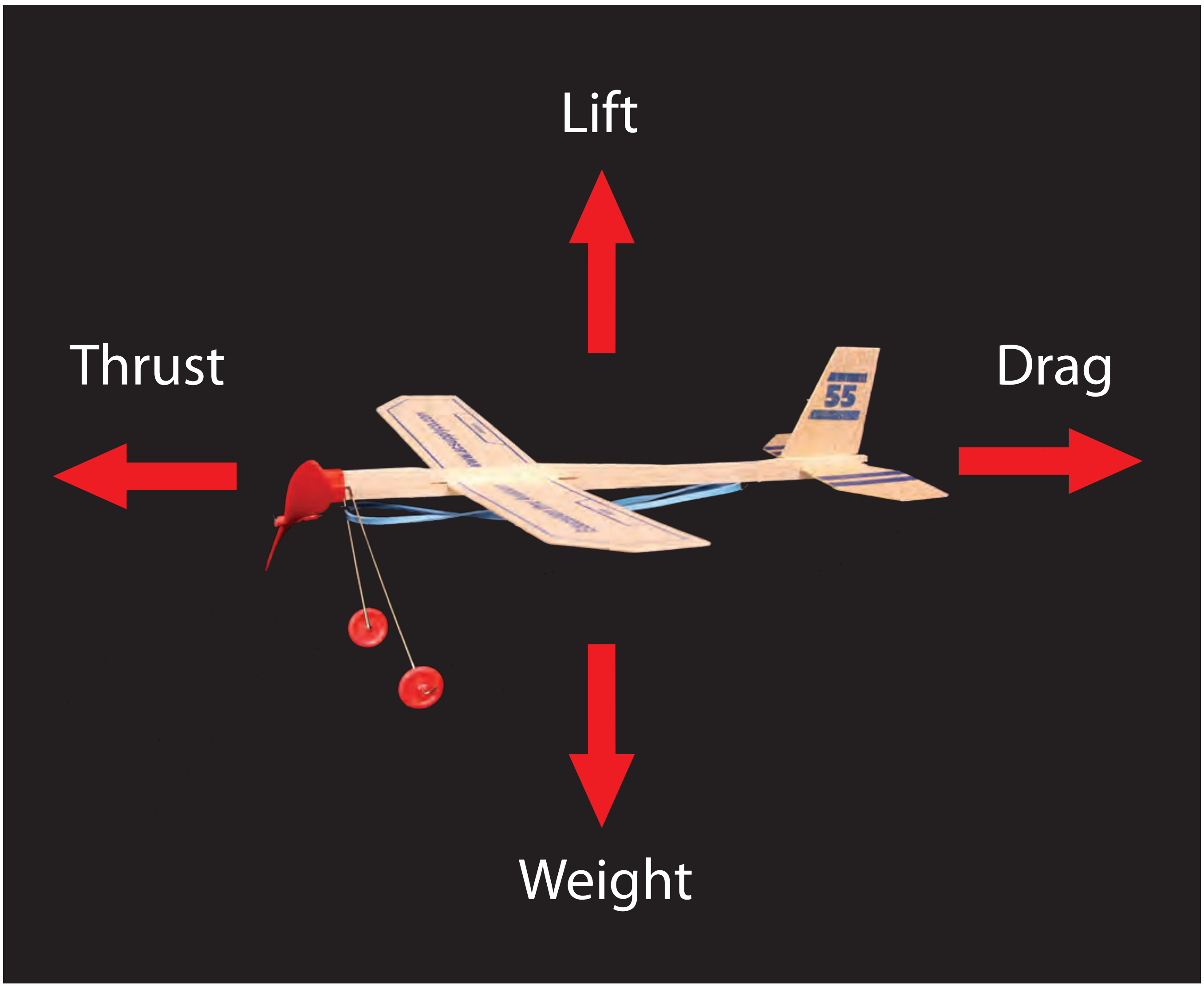


Fig. 2 Forces of straight and level flight

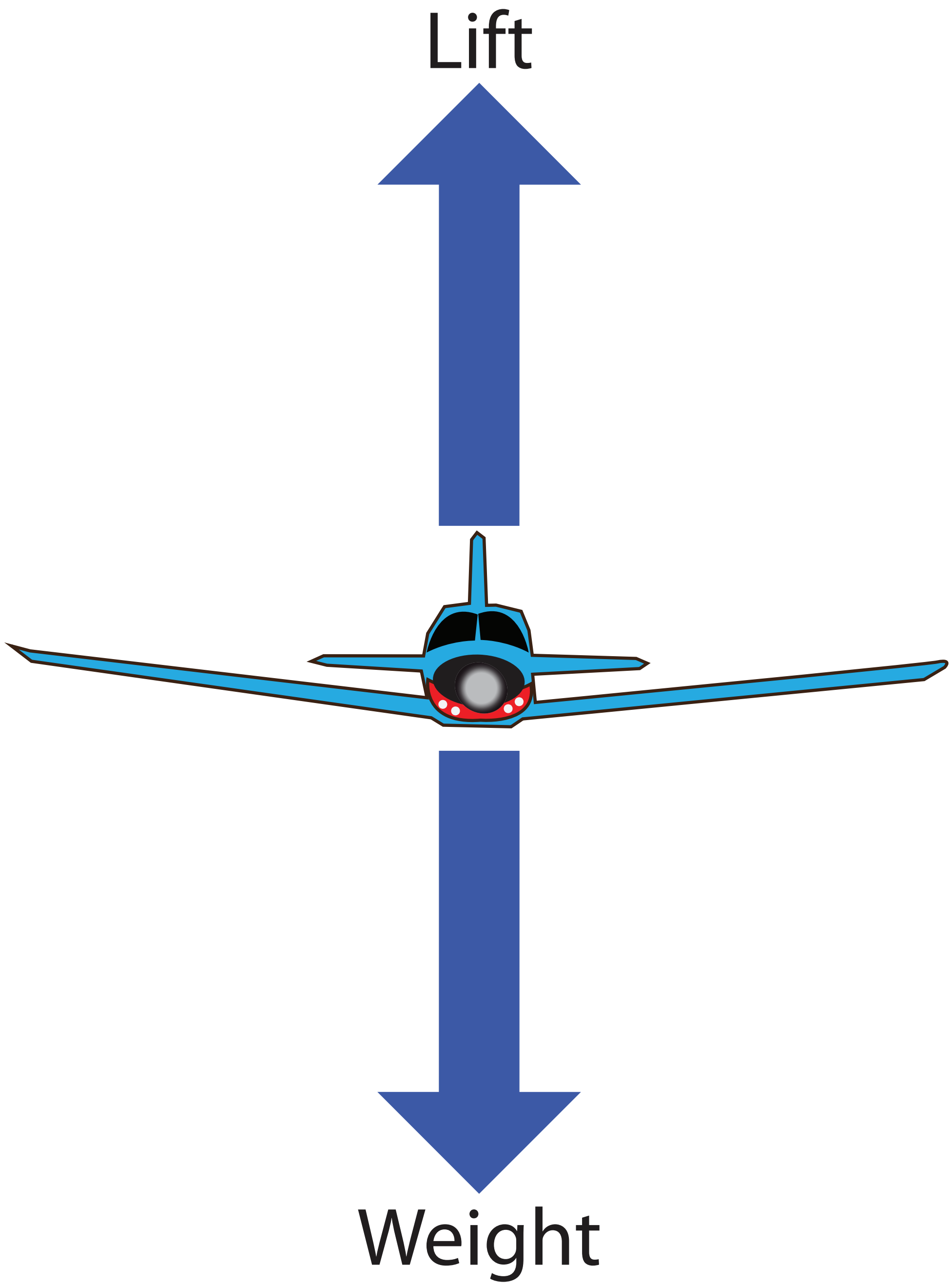


Fig. 3 Forces of turning flight

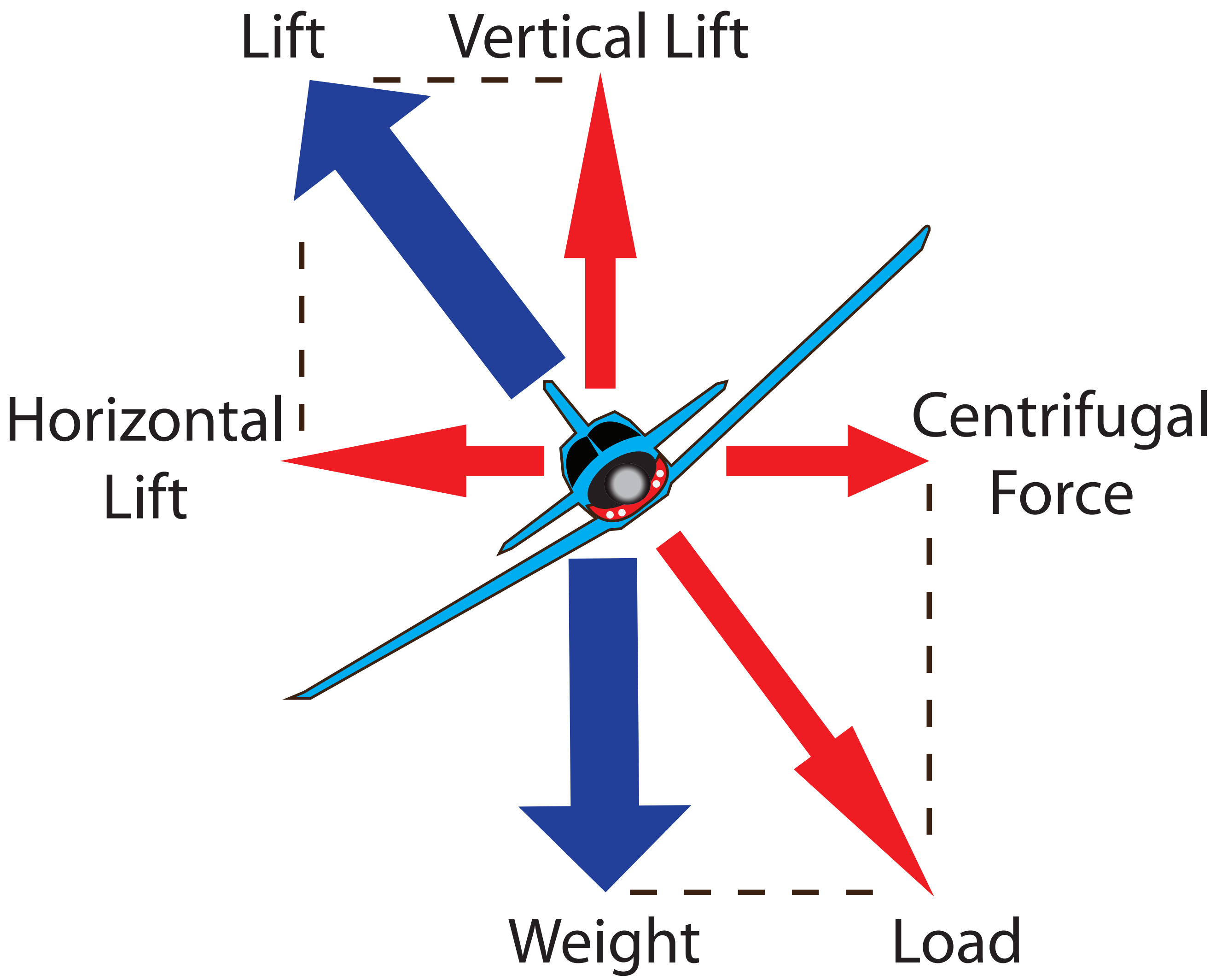
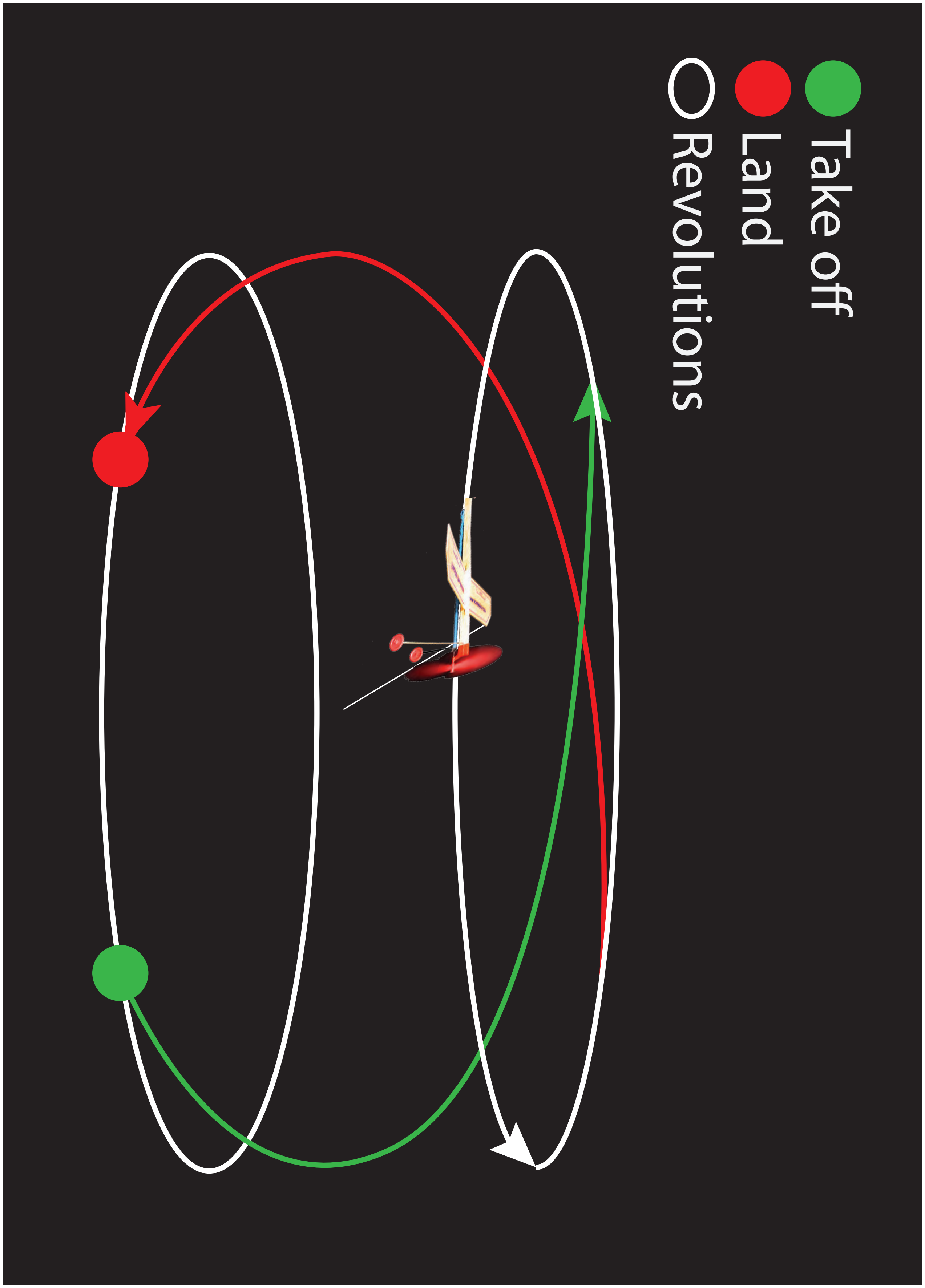
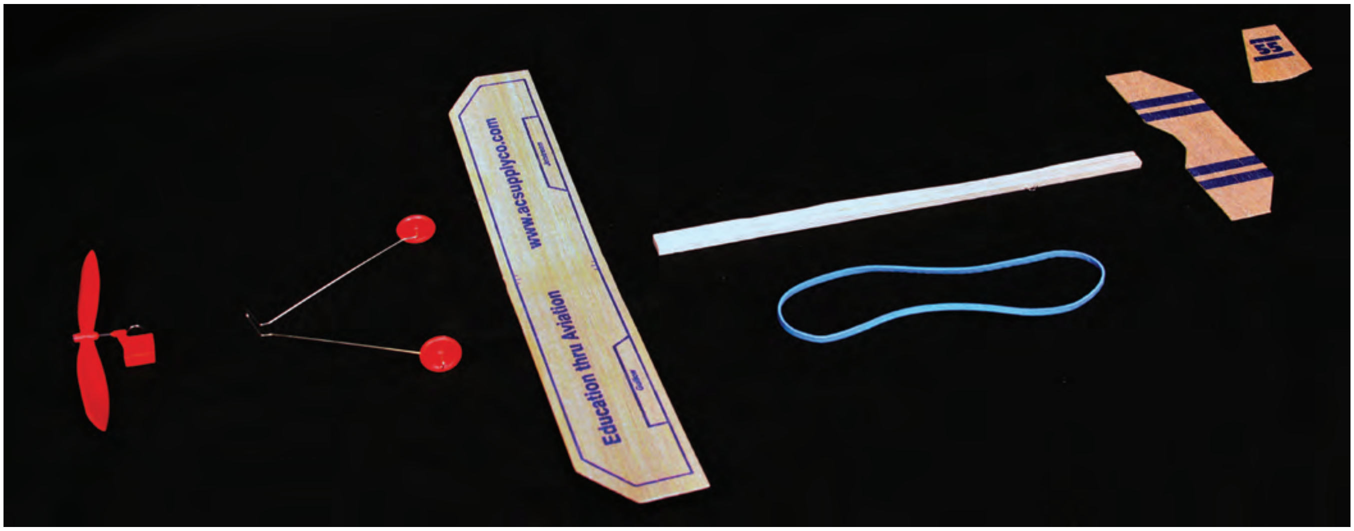


Fig. 4 Aircraft flight path

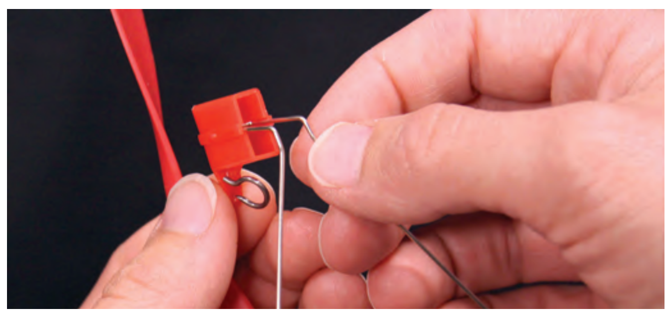


Jetstream Assembly Instructions

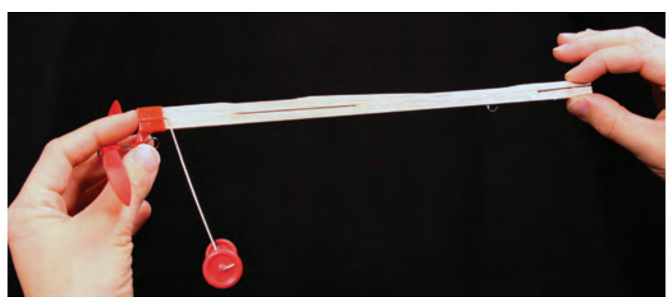


1. Before assembling the Jetstream model airplane, inspect the wings and ensure they are in line and curved slightly upwards. The wings should not be twisted or otherwise damaged; if they are, discard the kit and use another.

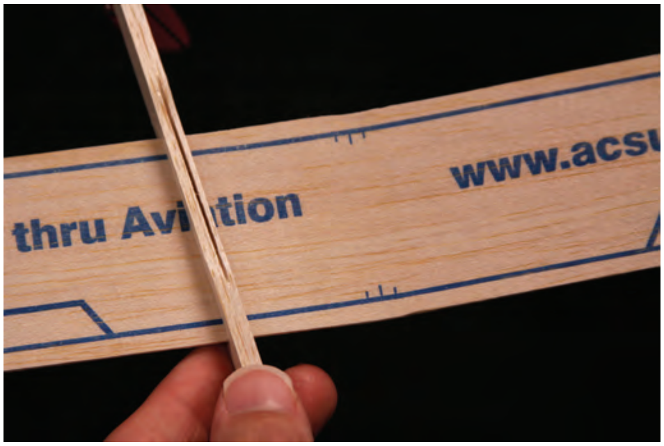
2. Insert the landing gear (wheels) into the propeller assembly.



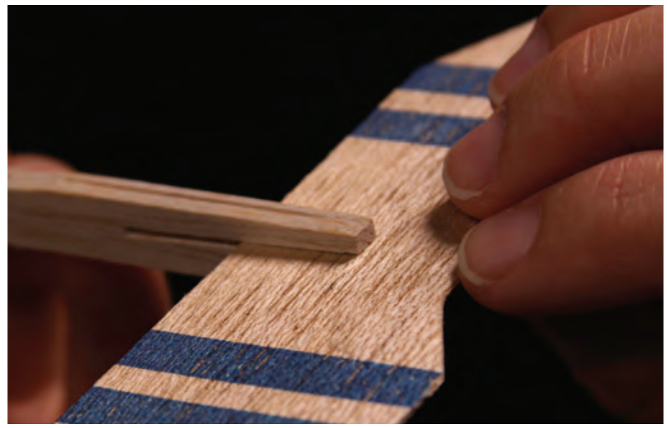
3. Insert the fuselage (the body of the plane) into the slot in the propeller assembly behind the landing gear. Ensure the metal hook on the fuselage is located at the rear of the airplane and is pointing downward.



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.

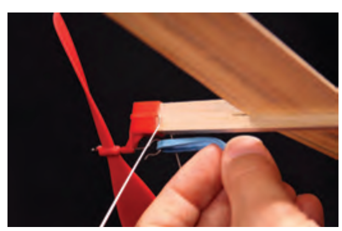


5. Slide the horizontal stabilizer into the slot on the side of the fuselage.

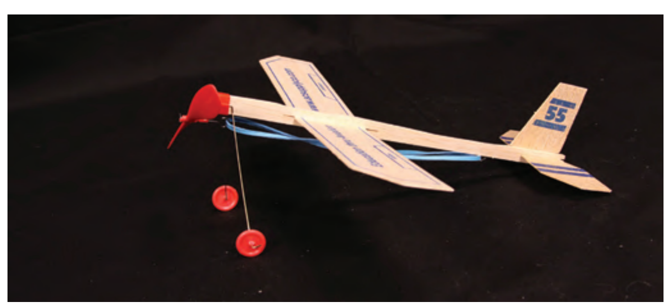


6. Place the vertical stabilizer into the slot on the top of the fuselage.

7. 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!



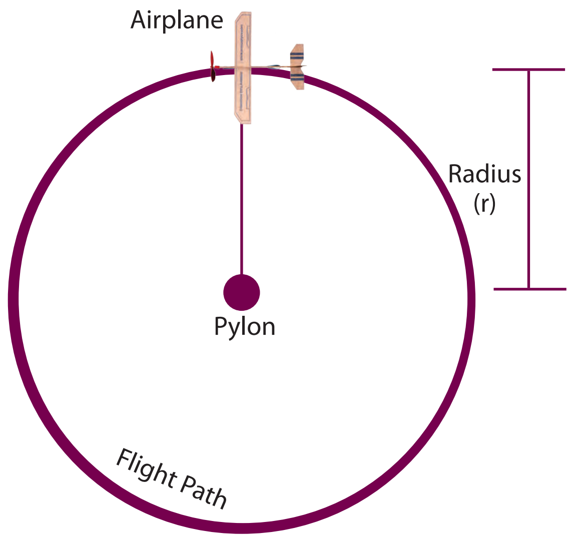
Student Worksheets

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) = 2πr: ______________



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: _______________

Worksheet 1 continued   Aerolab Flight Data

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: ______________

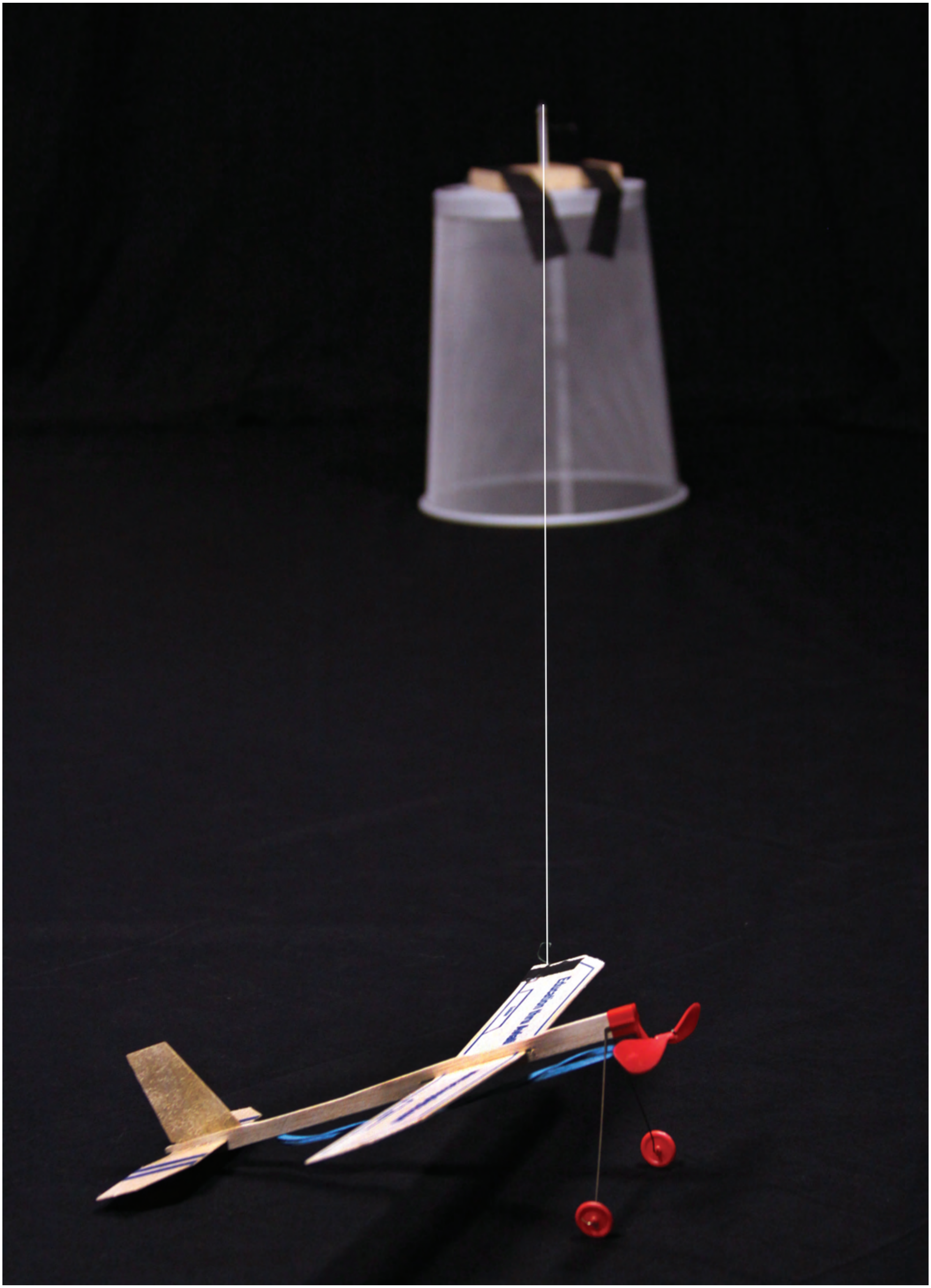
Average airspeed: ______________

Images

Img. 1 X-31 Enhanced Fighter Maneuverability Demonstrator aircraft

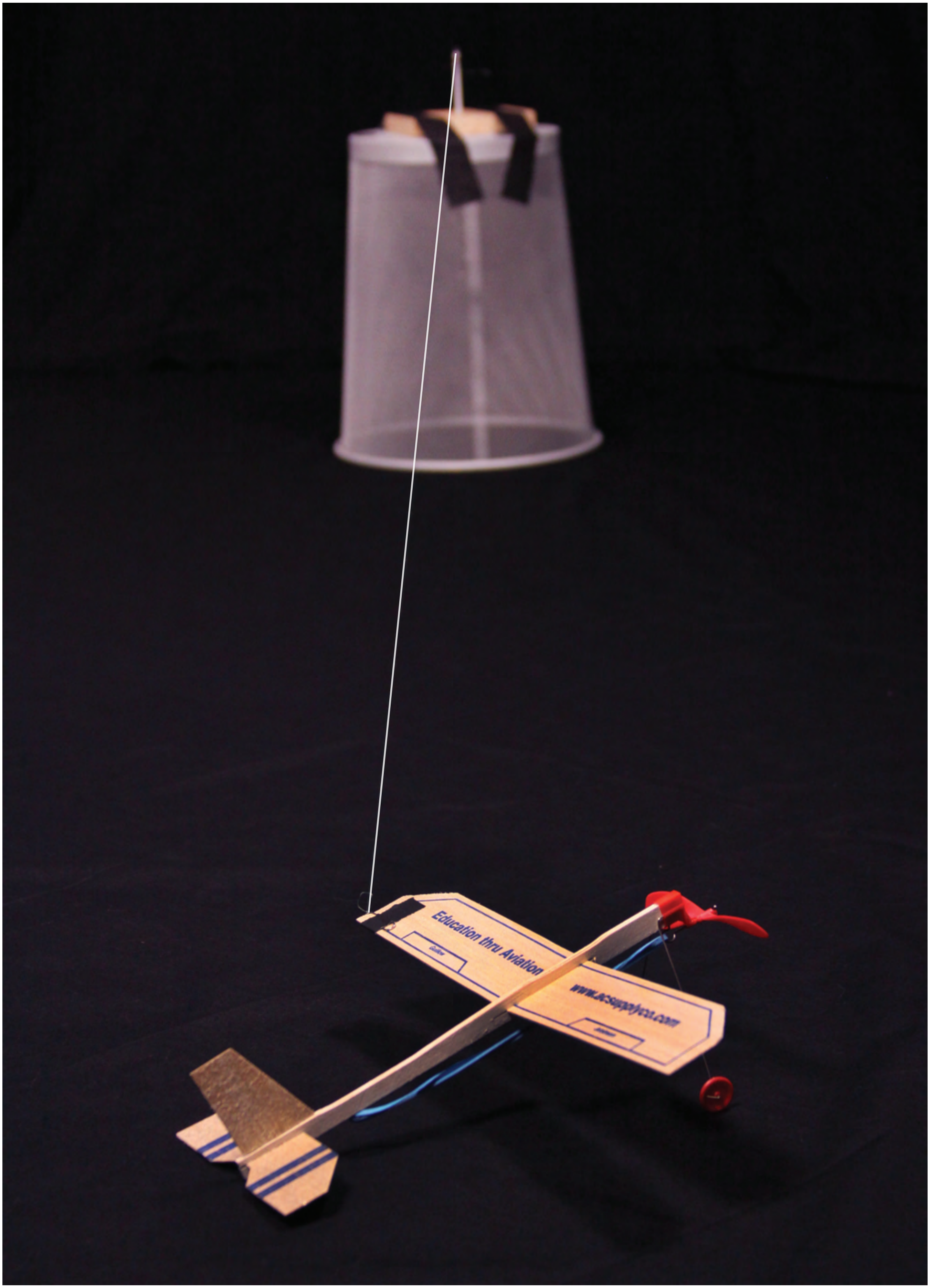
(Photo courtesy of NASA - www.nasaimages.org)

Img. 2 Correct launch position



(Photo courtesy of Lost Tribe Media Inc.)

Img. 3 Incorrect launch position



(Photo courtesy of Lost Tribe Media Inc.)

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