National Aeronautics and Space Administration

Unmanned Aircraft Systems

Educator Guide

PHYSICAL SCIENCE, ENGINEERING, AND COMPUTATIONAL THINKING

Next Gen STEM – Aeronaut-X

For more about Next Gen STEM visit https://www.nasa.gov/stem/nextgenstem/aeronaut-x

Education Product	
Educators and Students	Grades 6-8

Contents

Preface

Aeronaut-X: Unmanned Aircraft Systems was published by NASA's Office of STEM Engagement as part of a series of educator guides to help middle school students reach their potential to join the next-generation STEM workforce. The activities can be used in both formal and informal education settings as well as by families for individual use. Each activity is aligned to national standards for science, technology, engineering, and mathematics (STEM), and the NASA messaging is current as of June 2021.

STEM Education Standards

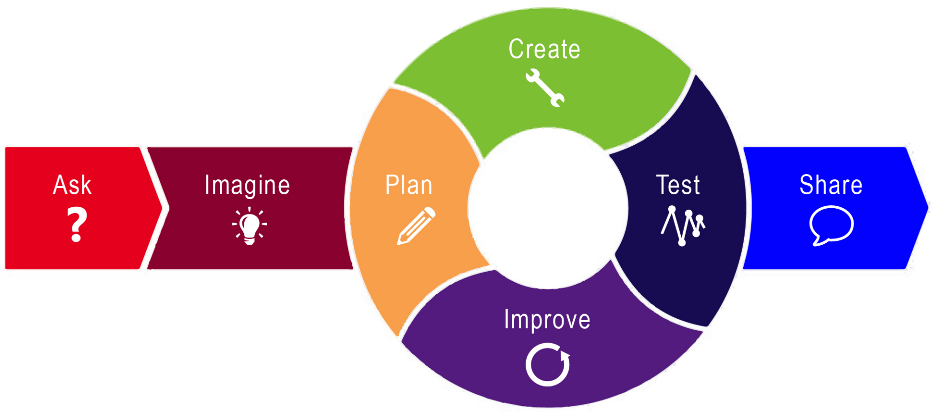
The STEM disciplines matrix shown below aligns each activity in this module to standards for teaching STEM according to four primary focus areas within each discipline. The four focus areas for science were adapted from the Next Generation Science Standards (NGSS) disciplinary core ideas. The four focus areas for technology were adapted from the International Society for Technology in Education (ISTE) Standards for Students. The four focus areas for engineering were adapted from the National Science Teaching Association (NSTA) and NGSS science and engineering practices. The four focus areas for mathematics were adapted from the Common Core State Standards (CCSS) for Math content standards by domain.

Activity	STEM Disciplines															
	Science				Technology				Engineering				Math			
	NGSS Disciplinary Core Ideas				ISTE Standards for Students				NSTA and NGSS Practices				CCSS Content Standards by Domain			
	Physical Sciences	Life Sciences	Earth and Space Sciences	Engineering, Technology, and the Application of Sciences	Knowledge Constructor	Innovative Designer	Computational Thinker	Global Collaborator	Ask Questions and Define Problems	Develop and Use Models	Plan and Carry Out Investigations	Construct Explanations and Design Solutions	Ratios and Proportional Relationships	The Number System	Statistics and Probability	Geometry
Propeller Design Challenge	✓			✓		✓			✓	✓	✓	✓		✓	✓	
Propelling the Payload With Electric Propulsion	✓			✓	✓		✓		✓	✓	✓	✓		✓	✓	
Navigate Your Zone				✓	✓	✓	✓	✓	✓			✓				
3, 2, 1… Lunch!													✓	✓		✓

Engineering Design Process

The engineering design process (EDP) is crucial to mission success at NASA. The EDP is an iterative process involving a series of steps that engineers use to guide them as they solve problems. The steps outlined below can be used by student teams to solve the challenges in this activity guide. Learn more about the EDP with NASA's Educator Professional Development Collaborative at https://www.txstate-epdc.net/models-of-the-engineering-design-process/.

1. **Ask**: Identify the problem, requirements that must be met, and the constraints that must be considered.
2. **Imagine**: Brainstorm solutions and research what others have done in the past.
3. **Plan**: Select and sketch a design.
4. **Create**: Build a model or a prototype.
5. **Test**: Evaluate solutions by testing and collecting data.
6. **Improve**: Refine the design.
7. **Share**: Communicate and discuss the process and solutions as a group.

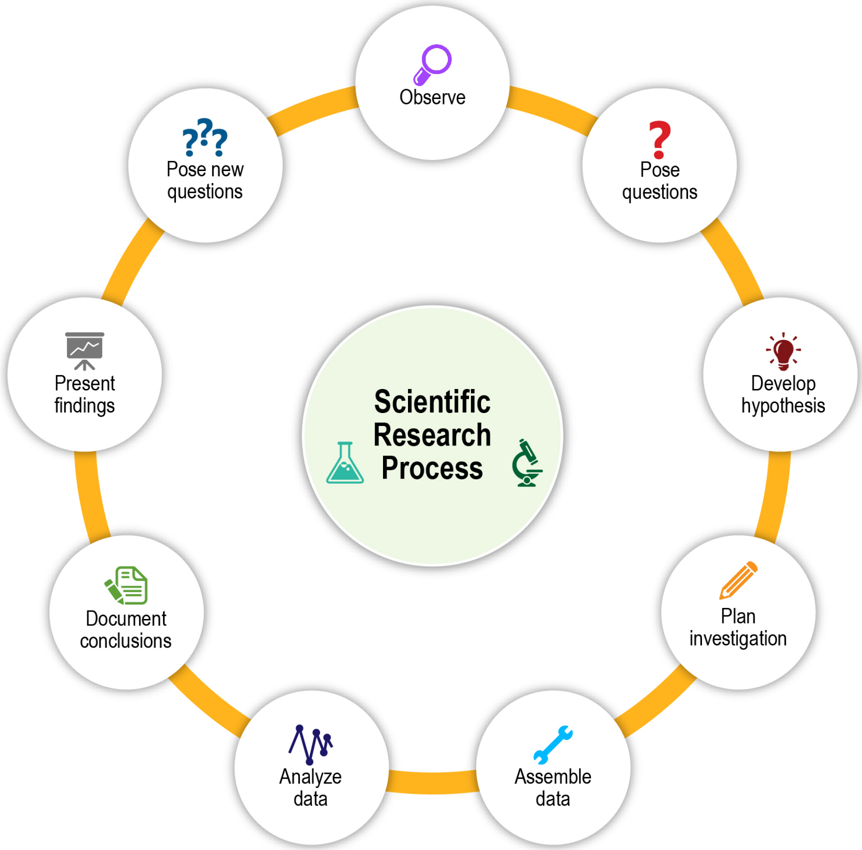


Scientific Research Process

The scientific research process (SRP) is a way to represent the sorts of things scientists do every day, regardless of whether they are chemists, astronomers, or physicists. The nine steps in the process are outlined below. Students can repeat these steps as many times as necessary, depending on the time available for the activity.

1. **Observe**: Begin the scientific research by using the five senses to make observations, identifying a problem that needs to be solved or a phenomenon that needs to be understood.
2. **Pose Questions**: Based on observations, brainstorm possible questions that are interesting and can be answered in the time available for the module.
3. **Develop Hypothesis**: Suggest an answer to the chosen question/s based on what is already known. A useful hypothesis is a testable, measurable statement.
4. **Plan Investigation**: Outline how data will be collected (where, when, and how) to ensure that the data collected will answer the question and test the hypothesis. Useful data must also be precise (repeatable), so measurements must be performed the same way each time.
5. **Assemble Data**: Following the investigation plan, take the measurements of data.
6. **Analyze Data**: Construct graphs or charts to help look for patterns and trends in the data. Data analysis often involves comparing data from different times and places and looking for patterns and different types of variations.
7. **Document Conclusions**: Carefully review what was performed during the investigation. Concentrate on any trends that may have been noticed when the data were analyzed. Look at any graphs that were made. Based on the data collected, make a statement about what was learned from the data collection. Was the hypothesis supported? Explain why or why not.

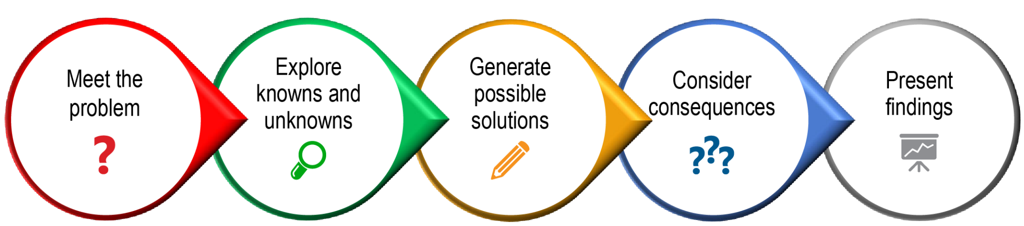
8. **Present Findings**: Share the research results with peers and the community. This is a very important step for scientists. This can take many forms, such as a science fair or a poster presentation.
9. **Pose New Questions**: Think about and record other questions that have been raised by this investigation and how to answer them. It is rare that a scientific question is answered by just one experiment or investigation.



Problem-Based Learning Framework

In the problem-based learning process, the roles and responsibilities of educators and learners are different than in a traditional classroom setting. The educator acts as a facilitator by providing students with problems to work, assisting them in identifying and accessing the materials or equipment to solve the problems, giving necessary feedback and support, and evaluating students' participation. Learn more about the problem-based learning process at https://www.cal.org/adultesl/pdfs/problem-based-learning-and-adult-english-language-learners.pdf.

1. **Meet the Problem**: Identify the problem, introduce new vocabulary, and discuss previous experiences with the problem.
2. **Explore Knowns and Unknowns**: Use resources to explore the knowns and unknowns.
3. **Generate Possible Solutions:** Brainstorm possible solutions based on resources and prior experience with the problem.
4. **Consider Consequences**: Examine the pros and cons of each solution to determine a viable solution.
5. **Present Findings**: Communicate and discuss the process and solutions as a team.



Teamwork

Student activities can be completed either as a team or individually, depending on time and preference. Grouping strategies during the design challenges can be used to efficiently break up student tasks, help promote student engagement, and appeal to a variety of learning styles and student strengths.

It is important that everyone on the team be able to participate and contribute throughout these activities. Everyone is a scientist and an engineer! If one student does all the building, the other students may be very bored during the building process. If one student is the leader, other students may not have a chance to share their ideas.

Tip: Create team role name tags for each member of the team. This strategy not only helps students visually identify peer roles, but also helps students feel individually accountable for team success.

Here are some possible roles that students can take:

Student Role	Description
Communications and Outreach	Takes notes of all team decisions and actions for use in a final presentation. If a camera is available, takes video and/or photos throughout the investigation or challenge for use in a final presentation.
Logistics	Makes sure that the team has all the resources they need, that resources are distributed fairly, and that the team knows when resources are running low.
Mission Assurance	Makes sure the team is following the plan. Keeps track of time and makes sure that everyone has a chance to have their voice heard.
Safety	Ensures all team members are wearing their safety goggles and following safety protocols.

Curriculum Connection

NASA's journeys have propelled technological breakthroughs, pushed the frontiers of scientific research, and expanded our understanding of the universe. These accomplishments, and those to come, share a common genesis: education in science, technology, engineering, and math, or STEM.

This educator guide will address the four disciplines within STEM.

Science: The science activity "Propelling the Payload With Electric Propulsion" (Activity Two) gives students the opportunity to discover Newton's second law of motion and learn about the relationship between force and mass.

Technology: "Navigate Your Zone" (Activity Three) provides an opportunity for students to practice coding. In this introductory lesson, students maneuver a spherical programmable robot (e.g., the Sphero® (Sphero, Inc.) robotic ball), which simulates an unmanned aerial vehicle (UAV) flying through or around obstacles to bring supplies to areas that can only be reached by unmanned vehicles.

Engineering: During the "Propeller Design Challenge" (Activity One), students will be fully engaged while they create and test their individual, unique designs on their hand-built propeller cars.

Math: "3, 2, 1… Lunch!" (Activity Four) will combine graphing, problem solving, creativity, and math skills in a captivating game that students are sure to enjoy.

Eagle Eyes in Treacherous Skies

Collecting data about tornadoes and volcanic eruptions is no simple task. A drone equipped with the relevant sensors can dramatically reduce risks for researchers. It also costs less than chartering a helicopter or plane and is more eco-friendly than a large aircraft. But a vehicle must be rugged to perform effectively under such extreme conditions. Black Swift Technologies worked with NASA to build the S–2 fixed-wing aircraft, a remotely piloted UAV capable of flying in extreme temperatures, altitudes, and windspeed. https://spinoff.nasa.gov/eagle-eyes-in-treacherous-skies

Volcano spewing ash cloud. (NASA)

Flying in the Fast Lane With Air Traffic Software

Think of the national airspace as a complex highway system, but with aircraft. They are all moving at different speeds and converging on relatively few airports, intent upon arriving safely and on time. Like the highway patrol, the Federal Aviation Administration (FAA) oversees the busy thoroughfares overhead. But unlike a patrol car with a flat tire, the systems used to manage all that air traffic cannot go down for repair or upgrades. NASA has spent 30 years researching, developing, and evaluating software tools for FAA air traffic management decision making. One recent outcome of that work is a software system called Airspace Technology Demonstration 2 (ATD–2). This software integrates arrivals, departures, and surface traffic management, using flight data to help air traffic managers improve the efficiency and predictability of these operations. https://spinoff.nasa.gov/page/flying-in-the-fast-lane-with-air-tr

Pilots depend on air traffic controllers, ground control, and other air traffic management professionals to provide up-to-date flight data. (NASA)

Introduction and Background

Overview

Due to issues such as weight limitations or dangerous conditions, it is not always safe or practical for there to be people on board everything in the sky. For over 40 years, NASA has expanded its research capabilities by incorporating technology that can fly without an onboard crew. While the term "drone" is commonly used to describe such devices, the technical term for the aircraft is "unmanned aerial vehicle" (UAV). UAVs in NASA's fleet range from tiny aircraft to those the size of more typical piloted aircraft and include both autonomous and remotely piloted vehicles. These vehicles may rely on solar energy or batteries to power their electric motors.

The UAV is just one piece of a much bigger unmanned aircraft system (UAS). A system is made up of many things working together. For example, the highway transportation system is not just made up of the highways; it also includes the many different types of vehicles as well as the users sharing the roadways. Likewise, the UAS includes everything that makes it possible to safely fly UAVs: the UAVs themselves, the software that lets the UAVs navigate and avoid collisions, the equipment used to track the UAVs (such as radar, cameras, or the global positioning system), the equipment used to communicate with the UAVs (such as radio towers), and the people who control all of the above.

One example of NASA's innovations in this field is the UAS Integration in the National Airspace System (UAS–NAS) project. Until UAS–NAS, little research had been done to find ways to reduce technical barriers that prevented UAVs from safely flying through the same airspace as more traditional commercial aircraft. The UAS–NAS project, which concluded in 2020, worked to make sure the UAV delivering a package to a house would not interfere with the helicopter delivering patients to the local hospital. The technology and procedures developed during this nearly decade-long program are now assisting the Federal Aviation Administration (FAA) in developing the rules for certification of unmanned aircraft to help ensure they can safely coexist with other air traffic.

NASA is also leading the nation in opening a new era of air transportation called advanced air mobility, or AAM. A new future for both rural and urban transport is in the works at NASA and in the aviation community at large—a future where commuters will take to the air and goods will be delivered by drone. Researchers have already studied, designed, and tested tools and technologies that could be used to manage the airspace for drones flying at low altitudes and even in complex urban landscapes.

Electric Propulsion

Engineers David North (middle) and Bill Fredricks (right) carry the GL–10 to one of its flight tests. (NASA/David C. Bowman)

Imagine a battery-powered aircraft that has 10 engines and can take off vertically like a helicopter and fly efficiently like an airplane. That concept is being tested by NASA researchers. The Greased Lightning (GL)–10 flight demonstrator is electrically powered, has vertical takeoff abilities, and operates autonomously. A flight demonstrator is a vehicle designed and built to prove a flight concept that can be used by future vehicles. The initial plan was to develop a 6-meter-wingspan (20 feet) aircraft powered by hybrid diesel/electric engines, but the team started with smaller versions for testing, built by rapid prototyping. Researchers have built more than 12 prototypes, and each prototype has helped answer specific technical questions while keeping costs down. The GL–10 has fostered concept models that could revolutionize the aviation industry, creating a cleaner and more sustainable mode of transportation. The focus has been on creating an all-electric aircraft for short-distance flights. Like electric cars, these short flights in electric-powered aircraft, through open skies, could make air transportation faster than driving, particularly in dense urban areas or in other areas where ground transportation can be challenging. These future aircraft could also potentially fly in rural areas where there may not be roads to transport people or goods.

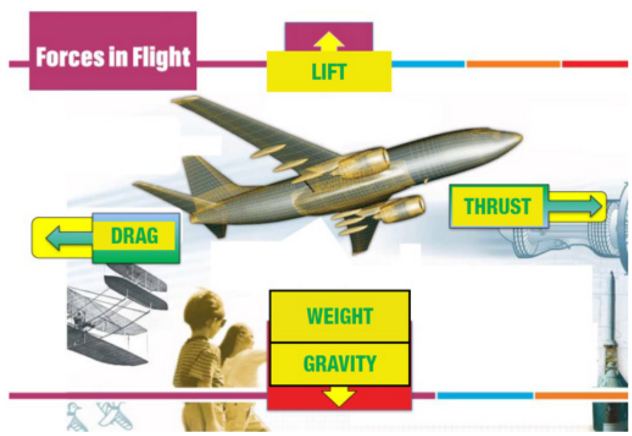
UAVs using electric propulsion have many benefits. One of the key benefits is that electric motors run more quietly, so there is less noise pollution. Electric motors are also very efficient at converting electrical energy into mechanical energy for motion, which means they consume less energy. One of the challenges with electric propulsion is that batteries have significantly lower energy density than gasoline. This means the batteries store less energy than gasoline for an equivalent weight or volume. Even with the more efficient motor, the result is limited flight time for electric aircraft. Adding more batteries would mean adding more weight. As Newton's second law tells us, there is a direct relationship between force and mass. The more massive an object, the more force it takes to move that object. Right now, the solution is to limit the distance the UAV can travel until battery technology advances or another solution is discovered. Some examples of possible solutions are solar-powered batteries, self-charging batteries, lighter batteries, or a combination of the three. Most of the UAVs in the near future that will be entering the skies below 400 feet will be powered by electric propulsion. These UAVs will be used as air taxis and package delivery vehicles; they will provide emergency response, perform rescue missions and medical drops, conduct aerial photography, and much more.

Advanced Air Mobility (AAM)


Air taxi: NASA's concept electric vertical takeoff and landing vehicle (eVTOL).

As UAV technology becomes more common in rural and urban communities, AAM researchers and engineers at NASA are exploring systems to map and monitor the skies. For mapping, it is important to have accurate and up-to-date information about all the obstacles (such as buildings, trees, and other aircraft) where UAVs could fly. One of the goals for AAM is to create a digital three-dimensional (3D) "roadmap" of the sky in order to improve navigation software and make it safer to fly. NASA has also developed Safeguard, an artificial intelligence "safety net" based on mathematical models and algorithms. This technology uses a geofence, which is like an invisible dog fence for drones, to ensure a UAV stays within an approved perimeter and avoids "no-fly zones" near hospitals, airports, or other restricted airspace. This new technology has many potential benefits and challenges, and NASA wants to ensure the market is sustainable, secure, and safe.

How Do Aircraft Fly?



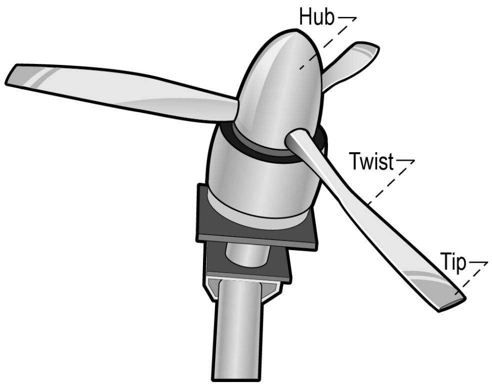
The four forces in flight that enable an aircraft to fly.

There are four main forces that determine whether and how any aircraft will fly: lift, weight, thrust, and drag. A force can be thought of as an invisible pushing or pulling in a specific direction. Each force occurs simultaneously and affects the performance of the aircraft.

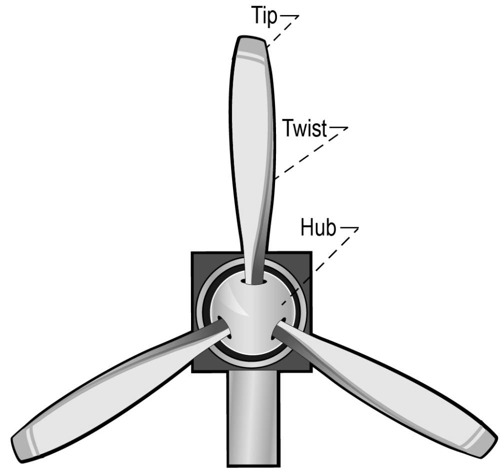
- **Lift** is a force that allows an aircraft to climb or stay in the air rather than fall to the ground.
- **Weight** is the measure of the force of gravity on the aircraft.
- **Thrust** is a force that moves the aircraft forward through the air.
- **Drag** is a force that opposes thrust. It is a type of friction and makes objects harder to move through the air.

Propeller Basics

Thrust is generated by the propulsion of the aircraft. Different propulsion systems develop thrust in different ways, but all thrust is generated through some application of Newton's third law of motion. Newton's third law of motion states that for every action, there is an equal and opposite reaction. UAVs commonly get their thrust and lift from propellers, though other factors such as blade shape can also play a part. For example, when a quadcopter's propellers spin, they push air downward. In the context of Newton's third law, this represents the action; the equal and opposite reaction is the upward force of lift that pushes the quadcopter up. In this particular example, each of the four propellers will create some lift, and the total lift for the quadcopter will be the sum of the four propellers' lift. When the total force of the lift from the four propellers exceeds the weight of the quadcopter, the quadcopter rises into the air. The amount of lift each propeller generates is based on a variety of factors.



The parts of a propeller (hub, twist, and tip), as viewed from below.



The parts of a propeller (hub, twist, and tip), as viewed from in front.

Each propeller consists of two or more blades spread evenly around a hub. The propellers shown above have three blades. The total number of blades, as well as the length, shape, and twist of each blade, all factor into the amount of force a propeller can generate. The positioning of the propeller determines whether that force is vertical lift, horizontal thrust, or some combination of the two.

On some aircraft, the propeller blades can provide both upward lift and forward thrust. The propeller blades rotate parallel to the ground to provide upward lift for takeoff, but the propellers can then pivot 90° so the blades are rotating perpendicular to the ground to provide forward thrust.

Number of Blades

Propellers commonly have from two to six blades. The number of blades a propeller has is a compromise that the designer makes between power (more blades) and efficiency (fewer blades). In other words, a propeller with two blades will use less energy than a propeller with six blades, but it will not produce as much thrust at the same speed.

Blade Length

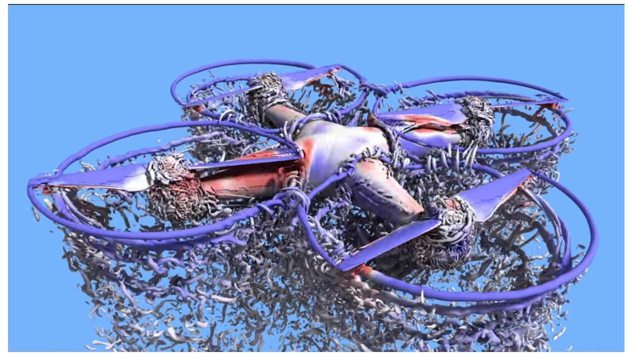
The length of a blade is measured from hub to tip. The length of a blade is essentially the radius of the imaginary circle formed by the spinning propeller; therefore, the total size of the propeller (the diameter of that imaginary circle) is twice the length of the blade. Longer blades (and, consequently, wider propellers) can generate more thrust at the same speed but require a stronger (higher torque) motor to turn the propeller. Typically, the propeller size varies according to the size and purpose of the aircraft. Small package-carrying drones only require small, relatively slow propellers, whereas larger air taxis would require bigger propellers.

Blade Shape

The shape of a blade has many possible factors. For this activity, the main consideration is the shape of its tip, which might be round, pointed, or blunt. Other shape factors include the width of a blade, its cross section, and the curves of the leading and trailing edge. The shape of a blade determines how efficiently it “cuts” through the air. The cross section of a propeller blade can be fairly flat, but shaping a propeller blade more like an airplane’s wing typically reduces drag and increases lift.

Blade Pitch and Twist

A propeller works by pushing air in the direction opposite that in which the aircraft is intended to travel. In order to force the air where it needs to go, the blades must have a pitch or twist to them. *Pitch* is when the entire blade is angled relative to the hub, and *twist* is when the tip of the blade has a different angle than the rest of the blade. A twist in the blade can help maximize the efficiency of the blade, because the tip of the blade has to pass through more air than the base of a blade in order to make a full revolution. Together, the pitch and twist of the blades determine the direction the air is pushed. Reversing the direction of a propeller's rotation reverses the direction the air is pushed. Think of it like a screw—if a screw is turned in one direction, it moves into the wood; and if it is turned the other way, it moves out of the wood. The speed at which the propellers rotate, along with the pitch of the blades, determines how much air is pushed.



This computer simulation shows the movement of air caused by the rotating of a quadcopter's propellers. Watch the simulation: https://youtu.be/hywBEaGiO4k

Blade Surface Area

The surface area of a blade is influenced by all the factors above and is, essentially, the amount of material that touches the air at any given time. The surface area of the propeller is the combined total of the surface areas of all blades. The more surface area a propeller has, the more air it can push, thereby creating more thrust. However, this comes at the cost of more power draw from the motor and increased drag.