National Aeronautics and Space Administration

In Thrust We Trust

A museum experiment for students

Four to Soar Aerodynamics Unit

Table of Contents

In Thrust We Trust

Grades: 5–8

Time: 45 minutes to 1 hour

In this lesson, the angle of a propeller's blades will be altered to see how the thrust generated by an electric propeller car is affected.

Objectives

Students will understand how the angle of a propeller blade affects thrust.

Main Concepts

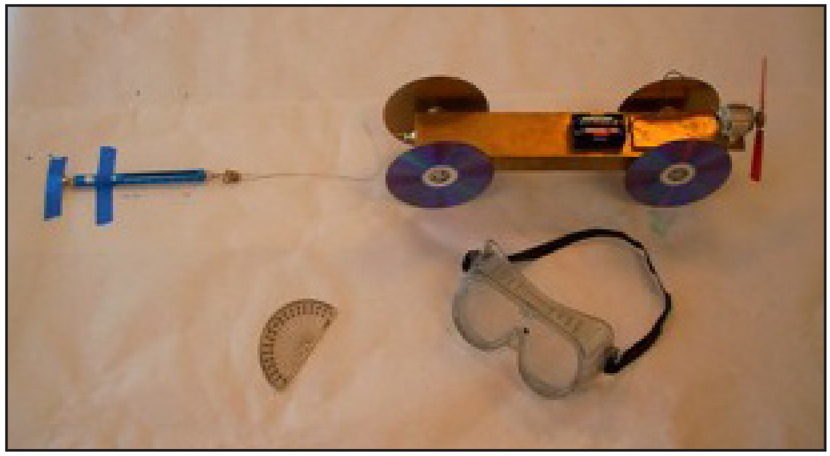
- Scientific progress is made by asking meaningful questions and conducting careful investigations.
- A force has both direction and magnitude.

Education Standards

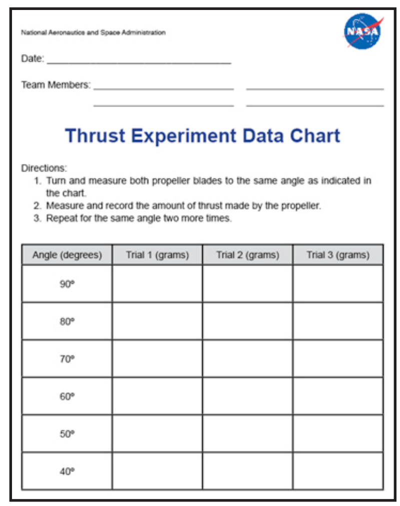
California Science Content Standards	*National Science Education Standards*
Grade 5 • Investigation and Experimentation: 6e, 6f, 6g, 6h Grade 6 • Investigation and Experimentation: 6b Grade 7 • Investigation and Experimentation: 7a Grade 8 • Forces: 2a, 2c, 2d, 2e • Investigation and Experimentation: 9a, 9b, 9c, 9e, 9f	Grades 5–8 Science and Technology, Content Standard E • Abilities of Technological Design: a, b, c, d, e • Understanding About Science and Technology: d, e Physical Science, Content Standard B • Motions and Forces: b, c

Materials List

Each team of 3–4 students will need:



- 18” string
- 1 pushpin
- 20-g or 30-g spring/pen scale
- 1 pre-made electric propeller car (motor shaft diameter 1/16”)
- Batteries (as required)
- 3 - 4 safety goggles (1 per child)
- Clear protractor
- 1 plastic propeller (balsa glider variety)
- 2 eye screws (1/4”)
- 1 dowel segment (5/8” x 3/16” with 1/16” hole)
- Hot glue gun
- Tape
- ***Thrust Experiment Data Chart*** (p.15)
- Pencil or pen for data recording



National Aeronautics and Space Administration

Date: ______________________

Team Members: ______________________ ______________________

______________________ ______________________

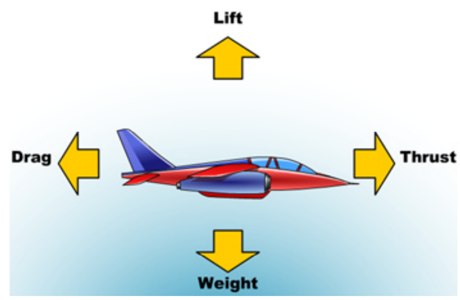
Thrust Experiment Data Chart

Directions:

1. Turn and measure both propeller blades to the same angle as indicated in the chart.
2. Measure and record the amount of thrust made by the propeller.
3. Repeat for the same angle two more times.

Angle (degrees)	Trial 1 (grams)	Trial 2 (grams)	Trial 3 (grams)
90°			
80°			
70°			
60°			
50°			
40°			

Background



~ Four Forces ~

There are four primary forces that act on an airplane in flight: thrust, weight, drag, and lift. It is the interplay between these four forces that result in an airplane's motion.

~ Thrust ~

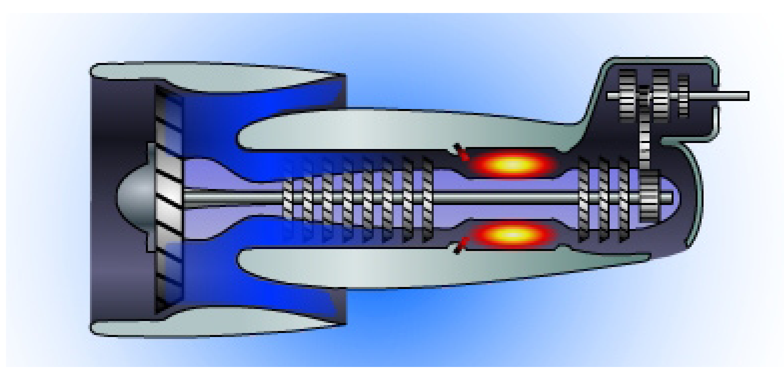
Thrust is a force that propels an object in a particular direction. Since the very first successful powered aircraft, airplanes have used motors attached to propellers to generate thrust. Today's smaller aircraft still generate thrust using propellers. A propeller has two or more blades that rotate around a central hub. Each propeller blade is positioned at a slight angle to deflect air towards the rear of the aircraft. Some propellers can have the pitch angle of their blades adjusted to help the propeller achieve peak thrust in different situations. Small propellers are more efficient and less expensive than small jets and are often used in private aircraft.

Modern jetliners such as the 747 or the A380 use jet engines. Like an engine attached to a propeller, a jet engine generates thrust by moving air with rotating blades. In a jet engine, the air is 1) moved through the engine and compressed, 2) heated, and 3) ignited to gain force as it passes out of the engine. First, as air flows through a jet engine, it passes through a series of rotating and stationary blades known as a compressor. As the air is forced into smaller and smaller volumes, the pressure is increased. Second, the air heats up as its volume is decreased. Next, fuel is added to the air in a combustion chamber and the mixture is ignited. This ignition causes the hot air to dramatically accelerate towards the back of the engine. Then, as the hot air leaves the combustion chamber, it passes over a turbine. The turbine has blades, and the hot air causes them to rotate a shaft that is connected to the compressor. The turbine removes a small amount of energy from the flow through the engine, but the majority of the energy is passed through. Finally, the job of the nozzle of a jet engine is to direct the hot airflow's energy into velocity–or movement in a direction. The nozzle allows the flow of hot gasses to leave the engine and produce thrust.

For a view of a jet engine go to:

- NASA Ames' Future Flight Design, Propulsion Lab, http://futureflight.arc.nasa.gov/prop.html
- NASA Glenn's Beginner's Guide to Propulsion, http://www.grc.nasa.gov/WWW/K-12/airplane/bgp.html

NASA Glenn Research Center played a leading role in the development of the original engine for the 747 aircraft. Today, NASA Glenn is one of the leading research centers in the world studying the field of propulsion and is currently studying ways to make aircraft engines quieter, cleaner, and safer.



Engage

1. Create excitement in the students.

Launch a rubber band powered airplane or fly a battery operated or radio controlled propeller plane, if available.

Draw on prior knowledge through these discussion questions:

- What happened here?
- How does an airplane fly?

2. Introduce and discuss the forces of flight.

Aerodynamics is the science of flight. In aerodynamics, we are interested in the motion and energy of an aircraft. We want to know about the forces at work on an aircraft and how that aircraft is controlled.

What is a force, anyway? In science we often work with forces, which are pushes or pulls on an object. Forces can be invisible, like gravity, or they can be completely visible, like someone pushing open a door with their hand. In the case of an airplane, there are always four forces at work any time the airplane is in flight. These forces are called lift, weight, thrust, and drag. We'll briefly discuss them, and then your team will have a chance to investigate one of these forces in the lab.

Lift is the upward force created by the wing of an airplane. It is a very important force because without it airplanes would simply be very expensive cars—they would be able to roll around on the ground but would never rise into the air. A wing creates lift in part by deflecting air downwards and in part due to the way air flows over its special shape.

Weight is the force of gravity acting on the mass of the airplane. It is what pulls an airplane down towards the ground. Weight is helpful in making sure that an airplane does not float around once it is parked; however, when an airplane flies it must overcome its weight to take to the air. Today, designers work with lightweight alloys and special plastics called polymers to build airplanes that are lightweight yet strong.

Drag is a force created by the friction of air against the skin of an airplane as it moves forward. Drag affects more than just airplanes—you can feel it pushing back on your hand if you hold it out the window of a moving car. In an airplane, drag increases as speed through the air increases. Faster airplanes will have ways of pulling up their landing gear, among other things, to reduce drag and increase speed.

Thrust is the force we are going to investigate in our group. Thrust is a forward push or pull that accelerates an airplane and keeps it in flight at a constant speed despite the slowing force of drag. Thrust comes from an airplane's engine, be it a small airplane with a propeller or a large airplane with a giant jet engine. Thrust is an important force since an airplane cannot fly without forward motion through the air.

Major concepts

- A force is simply a push or a pull.
- There are four forces of flight.
- Weight is the measure of the force of gravity on the mass of an object.
- Thrust is the force that moves an airplane forward and, in the case of an airplane, is usually generated by the airplane's engines and propellers.
- Drag is the force that resists the forward motion of an object, such as the resistance of air molecules that are pushed aside as an airplane travels through the air.
- Lift is the upward force that causes an object to rise or, in the case of an airplane, to fly. Lift is generated primarily by airflow over the wings of an airplane.
- In order for an aircraft to remain in flight, lift must be equal to or greater than weight and thrust must be equal to or greater than drag.

NOTE: For the following discussion, you may want to use the image of the airplane with the four force arrows on page 8 or one of the following NASA articles, videos, or animations:

- The Four Forces of Flight, NASA Explores
  http://www.nasaexplores.com/search_nav_5_8.php?id=01-083&gl=58
- Future Flight Design, NASA Quest
  http://futureflight.arc.nasa.gov/aero.html
- Virtual Skies, NASA Quest
  http://virtualskies.arc.nasa.gov/vsmenu/vsmenu.html
- Beginner's Guide to Aeronautics, NASA Glenn Research Center
  http://www.grc.nasa.gov/WWW/K-12/airplane/forces.html

Guidelines for a discussion to help bring out these concepts

An object has opposite forces acting on it at any given time. We see this with airplanes. When an airplane flies, it has a force pushing down on it, pushing up on it, pushing it backward, and pushing it forward.

- What is pulling the airplane downward to the ground?
  (Weight) ***Weight*** is the measure of the force of gravity on the mass of an airplane.

- What direction is the opposite of weight? (up)

- What must an airplane do to fly? (It must overcome weight.) This upward force is called ***lift***.

- How might lift be generated?
  (In an airplane or glider, lift is generated by air flowing over the wings.)

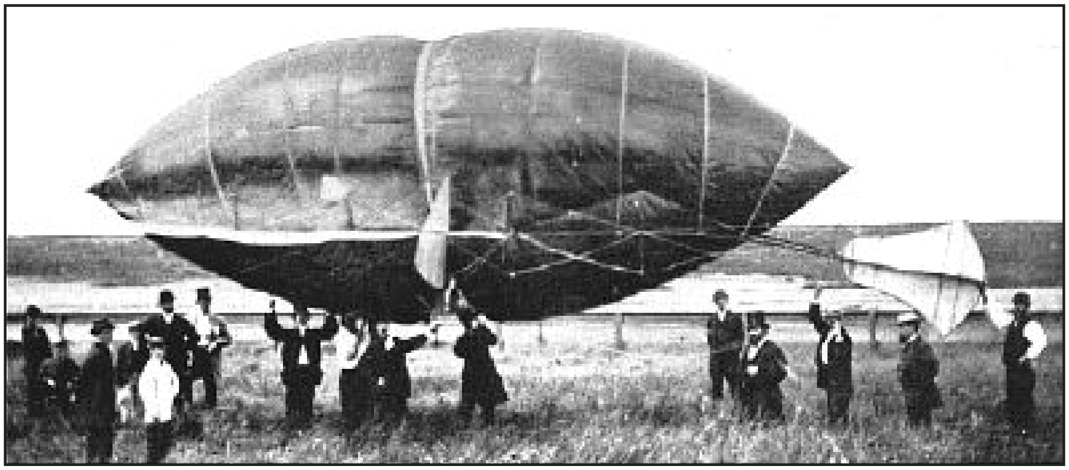


Photo of Frederick Marriott and the Avitor (courtesy of Dave Fowler)

- In what direction does your hand get pushed when you hold it out the window of a moving car and feel the air pushing against it? (Backward) We call this backward force ***drag***.
- What do airplanes need to overcome this backward force of drag? (A forward push.)
- What pushes an airplane forward? (The airplane's engines or propellers.) We call this forward force ***thrust***.
- When an airplane takes off, how would you describe its thrust compared to the drag? (Thrust must be greater than drag.)
- How would you describe the airplane's lift compared to its weight? (Lift must be greater than the airplane's weight.)
- Once in the air, if an airplane is maintaining the same height (or altitude) and speed (or velocity), how would you describe the four forces? (They would be balanced. Thrust would equal drag and lift would equal weight.)

3. Discuss the main focus of this lesson – the thrust force.
    - What is the job of a propeller on an airplane?
    - Holding up the airplane you have flown from step 1, point to the propeller and ask *"Does anyone notice anything unusual about the blades of this propeller?"* (The blades are twisted).

Four Forces of Flight

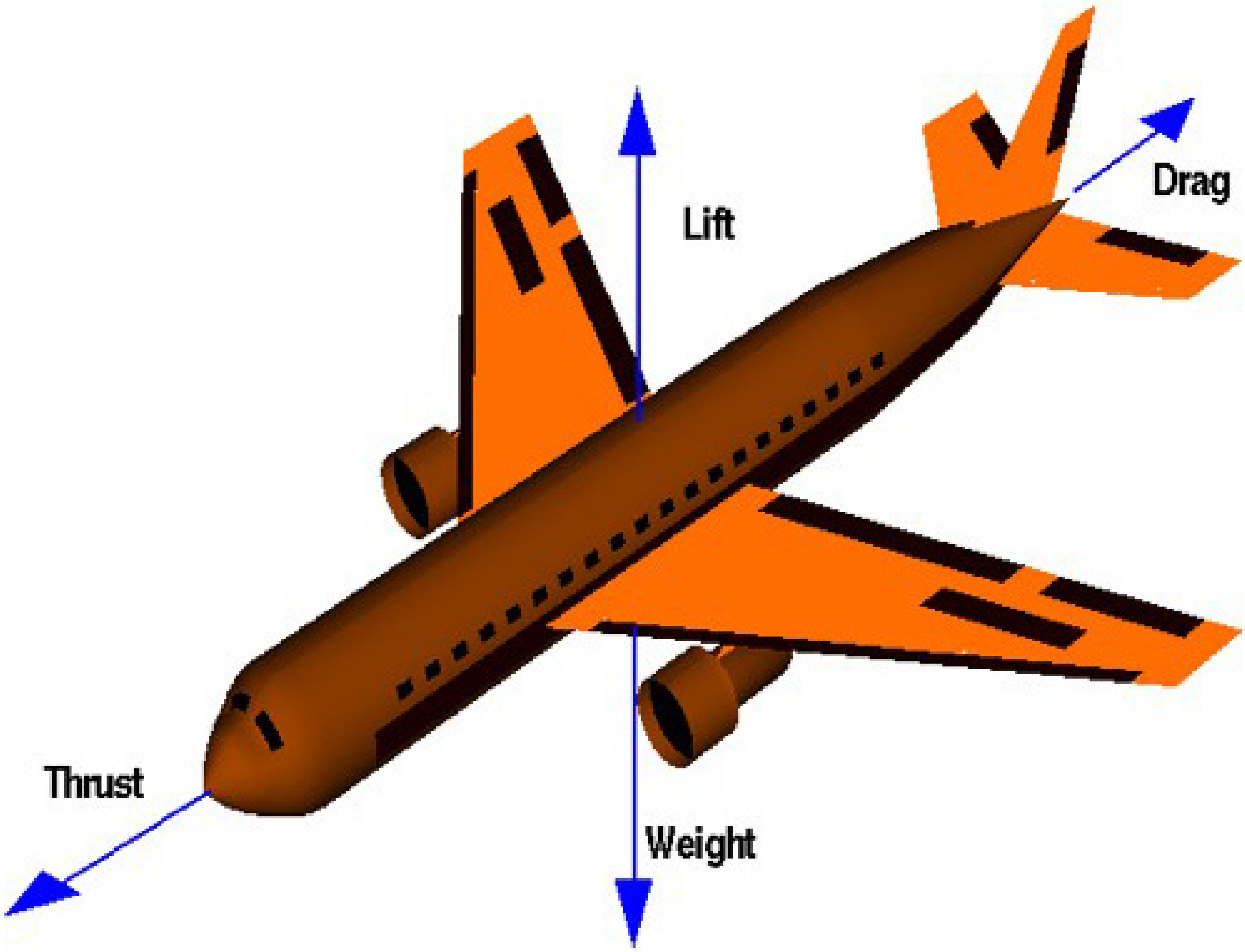
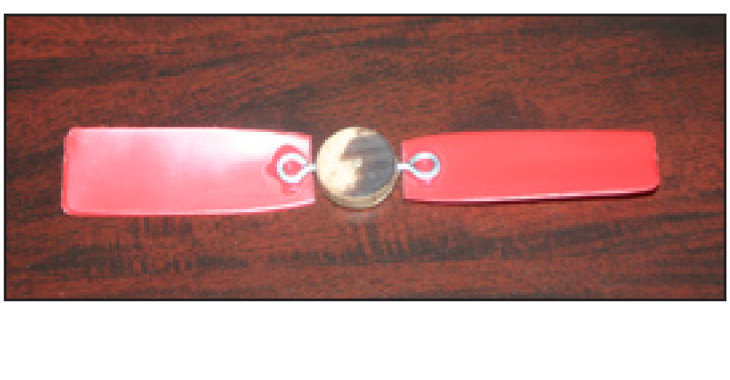


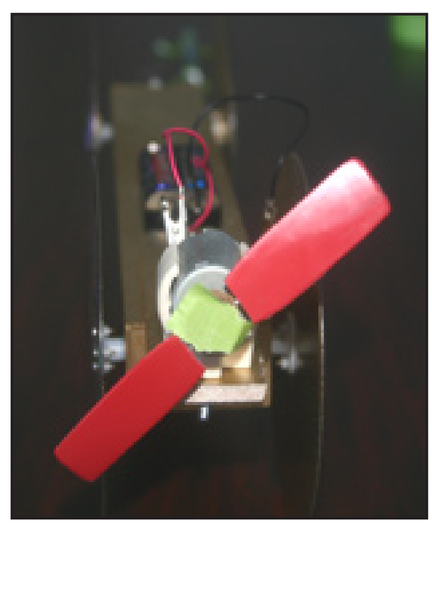
Image from NASA Glenn Research Center

Explore

1. Prepare the experimental apparatus prior to the activity.
   - Make a variable pitch propeller for each electric propeller car by cutting the flat portion of the blades off of the plastic propeller 1.75” from the propeller hub. Discard the hub and retain the blades.
   - Use a hot glue gun to attach the eye end of a 1/4” eye screw at the cut-off edge of each propeller blade.
   - Once glue has set, screw eye screws into opposite edges of the dowel segment. It should now be possible to turn the screw eyes slightly to adjust the pitch angle of the propeller blades.
   - With the blades securely attached to the edges of the dowel segment, press the motor shaft from the electric propeller car through the hole in the center of the dowel. Ensure that the motor shaft fits tightly in the hole so that the propeller will not separate from the electric motor during the activity.
   - Attach a push pin into the back end of the electric propeller car (the end opposite the propeller). Tie one end of the 18” string to the push pin. If the electric propeller car construction does not allow attachment of a push pin, use tape to secure the string to the back of the car.
   - Attach the remaining end of the string to the 30-g spring scale. During the experiment, the scale must be securely taped down to the experimental surface, with the car pulled gently away until the slack is removed from the string. Preparation of the experimental setup is now complete.
   - If the experiment is to be performed on an extremely smooth surface, it may be necessary to cover the surface with newspaper or butcher paper to reduce the car’s tendency to skitter sideways during the experiment.

Pictured below is a sample of the modified propeller for use in the experiment. The propeller consists of 1 plastic propeller, two 1/4” eye screws, and one 5/8” x 3/16” dowel segment with 1/16” hole. Each blade can be twisted to adjust the angle of deflection.





1. Explain the experiment guidelines.

   To conduct the experiment, students will work in groups of 3–4. The experimental sequence includes:

   - Use a protractor to set propeller pitch angle.
   - Gently pull the electric propeller car away from the scale to remove slack from the string.
   - Check that all team members have put on their safety goggles.
   - Call out "clear" before starting the electric motor to ensure that all students have their fingers well clear of the propeller.
   - Turn the switch or otherwise close the circuit to start the propeller blades turning.
   - If necessary, prevent the car from shaking or pulling sideways by positioning rulers or other small obstacles alongside the wheels—but well clear of the turning propeller!
   - Once the car has stabilized, record the grams of thrust indicated on the spring scale.
   - Turn the switch or otherwise open the circuit to stop the propeller.

Dryden Flight Research Center EC80-13848 Photographed 1980
XV-15 Tilt Rotor

   - Verify that the data is recorded; adjust propeller pitch to the next test angle and repeat.

During the experiment, students may think that the batteries on their car are running down as the motor noise will change as the propeller speed drops. Thrust will drop and eventually return to zero as the propeller blade angle reaches zero degrees, but when the experiment is repeated and the blade angle is returned to 90 degrees, the motor will return to its original speed.

2. Introduce the thrust experiment.

Following are samples of the types of things you may want to say to explain this experiment as you demonstrate with an actual model.

- "The force that we are going to investigate with these propeller-driven cars is ***thrust***. Who can remind me what thrust is? Thrust is a forward push or pull. Our test equipment is a car, not an airplane, but the rotating propeller will generate thrust just like an airplane's propeller."
- "You may have noticed that propeller blades are angled slightly. We call this small angle the ***pitch*** of the propeller. Why do you think propeller blades are pitched? Does a propeller's blade pitch have any effect on the aircraft?"
- "Look at your experimental setup. Your team has a car with a motor and a propeller on the front. You can adjust the blades on the propeller in either direction to increase or decrease blade pitch. You will also see that you can measure the force generated by the propeller with a spring scale located behind the car."
- "Try changing the angle of the propeller and measure how much force is generated at the new angle. You will need to use a protractor to help you set the new angle. Be sure to position both blades to the same angle."
- "You can use a protractor to find the measure of an angle. The usual unit of angle measure is called a ***degree***. When the propeller blades are pitched straight up and down (vertical), their pitch is 90 degrees. When they are flat (horizontal), their pitch is 0 degrees. It is important to make sure that both propeller blades are set to the same angle every time to keep the propeller balanced."
- "Record your data in the provided data chart."

NOTE: If the class has not done the ***Angles Everywhere*** lesson prior to their visit or if they are not familiar with using a protractor, you may want to have the **Sample Angles** worksheet (pp.8-9) from the ***Angles Everywhere*** lesson handy for chaperones to use to help students quickly learn how to use a protractor.

Explain

1. Students share their results with the class and discuss the questions below.

- Why do we do each experimental trial more than once?

> If a trial is done only once, it is difficult to know if the results are an outcome of the experiment or instead a fluke, accident, or mistake due to equipment failure, unusual conditions, or operator error. If a trial is repeated a number of times, then the chance that the results are due to some unexpected condition or mistake will be smaller. If the whole experiment can be repeated by many groups of people, in different places, and with different equipment, then the results are more believable. We call this ***reliability*** and ***reproducibility***.

- As the angle changed, what happened to the force measurement?

> As the angle changes, there should be a measurable difference in the force. Remember that in this case, grams are a measure of the amount of thrust generated by the propeller and do not measure the mass or weight of the system.

- What does the angle of the propeller have to do with how much thrust is generated by the propeller?

> As the angle of the propeller changes, the amount of thrust changes.
>
> At the highest angle (90 degrees), there is very little drag resisting the propeller's rotation. However, at such a blade angle, virtually no air is deflected to the rear of the propeller car. Little if any thrust will be produced, although the car may vibrate and skitter around at the end of its string. The car may even move backwards, toward the scale. If this happens, turn off the motor and record zero thrust for the blade angle.
>
> As the angle changes and the propeller begins to take a larger bite of air with each rotation, more air is displaced. Thrust will increase over the first several adjustments, peaking towards the middle of the spring scale's range.
>
> Beyond a critical angle, changing the propeller's pitch no longer increases thrust. Air flows over the propeller blades in a turbulent manner, and the drag on the blades increases significantly. The propeller's rotation slows down and thrust is greatly reduced. At zero degrees blade pitch, no thrust will be produced at all although vibration will continue. Pilots in an aircraft that has lost engine power will often intentionally turn the propeller of the disabled engine to zero degrees. This is called "feathering" and is done to stop the uncontrolled rotation of the propeller.

- Why do you think the propellers were already twisted in **Propeller Palooza**?

> The twist in the propeller gives the plane the correct propeller blade angle to generate maximum thrust.

2. Connect to NASA research.

NASA Glenn Research Center is the leader in research and design of aircraft. This field is called ***aeronautics***. NASA Glenn develops aircraft engine technologies to address the many critical issues facing the aeronautics industry, now and in the future. NASA Glenn's efforts support the nation's goals to develop quieter, cleaner, and safer airplanes. The technology is transferred to the aviation industry to help maintain U.S. leadership in the world's aviation market. Tomorrow's passenger aircraft will have better fuel efficiency.

3. Highlight aeronautics careers

If you enjoyed today's activity, then here are some resources to find out about careers in aeronautics.

- Future Flight Design Career Fact Sheets, NASA Quest:
  http://futureflight.arc.nasa.gov/cfs.html
- Astro Venture Career Fact Sheets and Trading Cards, NASA Quest:
  http://astroventure.arc.nasa.gov/
- Virtual Skies career information sections, NASA Quest:
  http://virtualskies.arc.nasa.gov/vsmenu/vsmenu.html

Extend / Apply

The following activities are for students once they return to the classroom.

- Make a graphic representation of the electric propeller car experiment results.
- Calculate the mean (average) force for each of the electric propeller car trials and graph this. *How different is the mean from each of the results?* Calculate this difference as a percentage.
- Research careers in aeronautics and aviation.

Resources

- Future Flight Design, NASA Quest: http:// futureflight.arc.nasa.gov
- Exploring Aeronautics, EP-2005-09-601-ARC, http://quest.arc.nasa.gov/projects/aero/ExploringAero
- What is Your Angle: http://www.nasaexplores.com/show_58_student_st.php?id=021231112817
- Four Forces on an Airplane, NASA Glenn Research Center: http://www.grc.nasa.gov/WWW/K-12/airplane/forces.html
- Future Flight Design career fact sheets, NASA Quest: http://futureflight.arc.nasa.gov/cfs.html
- Astro Venture career fact sheets and trading cards, NASA Quest: http://astroventure.arc.nasa.gov/
- Virtual Skies, each section has career information, NASA Quest: http://virtualskies.arc.nasa.gov/vsmenu/vsmenu.html
- NASA Quest, a great resource for careers and further technical information related to the lessons: http://quest.nasa.gov/

Date: ___________________________________

Team Members: __________________________ __________________________

__________________________ __________________________

Thrust Experiment Data Chart

Directions:

1. Turn and measure both propeller blades to the same angle as indicated in the chart.
2. Measure and record the amount of thrust made by the propeller.
3. Repeat for the same angle two more times.

Angle (degrees)	Trial 1 (grams)	Trial 2 (grams)	Trial 3 (grams)
90º			
80º			
70º			
60º			
50º			
40º			