National Aeronautics and Space Administration

The Wing's the Thing

A museum experiment for students

Four to Soar Aerodynamics Unit

Table of Contents

The Wing's the Thing

NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/gallery/photo/index.html
NASA Photo: EC00-0277-1 Date: September 15, 2000 Photo by: Jim Ross

A restored NACA P-51 Mustang in flight

Grades: **5–8**

Time: **45 minutes to 1 hour**

In this lesson, students change the angle of attack of an airfoil to see how it affects the amount of lift generated.

Objectives

Students will understand:

- how an airfoil generates lift.
- how the angle of attack of an airfoil affects lift.

Main Concepts

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

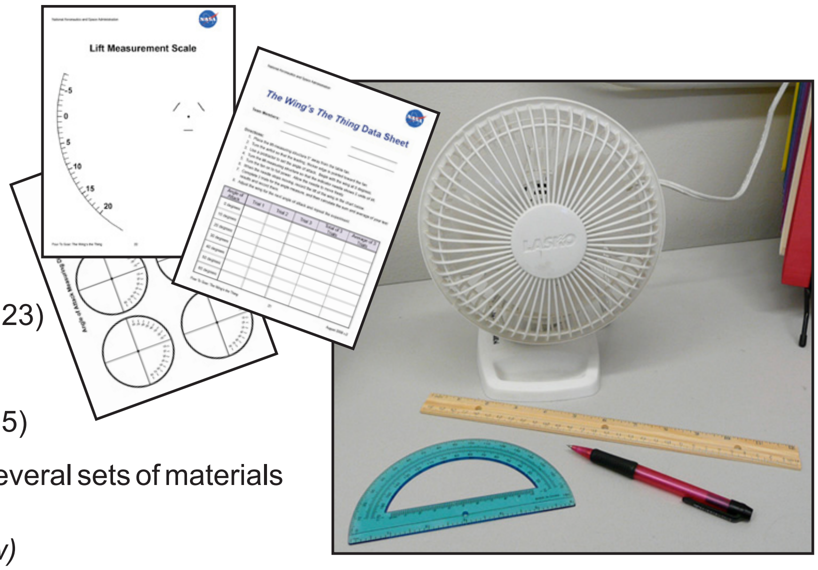
Education Standards

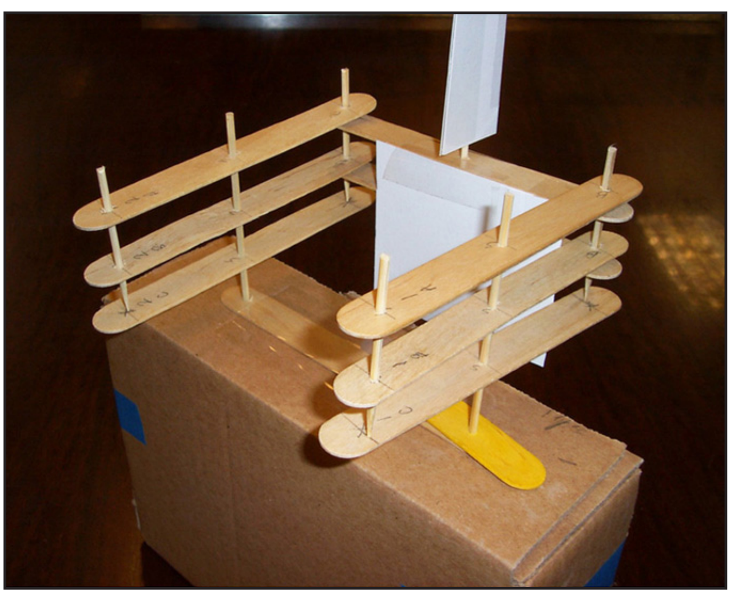
California Science Content Standards	*National Science Education Standards*
Grade 5 • Investigation and Experimentation: 6e, 6f, 6g, 6h Grade 6 • Investigation and Experimentation: 6b Grade 7 • Investigation and Experimentation: 7a Grade 8 • Forces: 2a, 2c, 2d, 2e • Investigation and Experimentation: 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

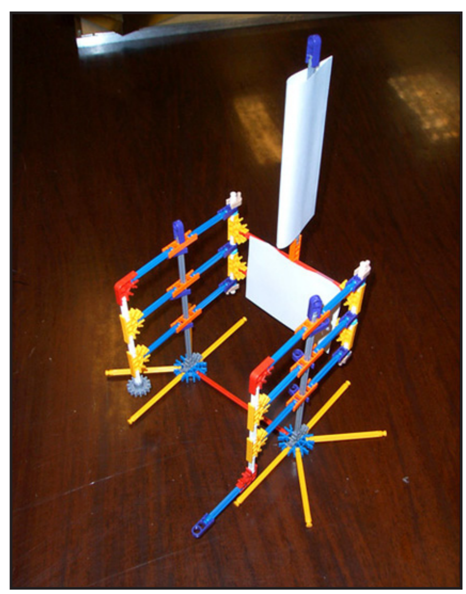
Each team of students will need:

- Table fan
- Protractor
- Ruler
- Pencil or pen for recording data
- ***The Wing's the Thing Data Sheet*** (p. 23)
- ***Lift Measurement Scale*** (p. 24)
- ***Angle of Attack Measuring Disk*** (p. 25)
- Pre-assembled lift device using one of several sets of materials (see instructions on pp. 5–8):
  - Cardboard Box version *(shown below)*
  - Construction Toy version *(shown below)*
- One wing section consisting of:
  - 1 center support (skewer or rod at least 7" long)
  - 2 pieces of cardstock (sized for test equipment)
  - Double-sided tape





Cardboard Box version



Construction Toy version

Two versions of the experimental setup are depicted in the images above. In both setups, there is a desk fan sitting on the floor 5 inches away from a device that has a vertically-mounted airfoil made from cardstock. The airfoil is mounted on an upright support that freely swings from side to side. The airfoil can pivot along its long axis so that the angle of attack can be adjusted.

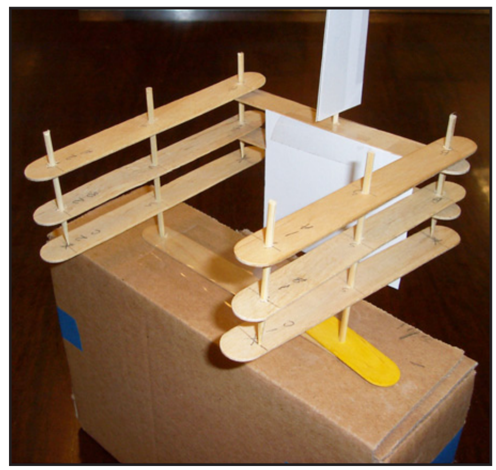
~ Lift Device Construction ~

The basic lift device is derived from the one used by Orville and Wilbur Wright during their initial wind tunnel tests in 1901–1902. In this device, the wing is tilted 90° and stands vertically instead of parallel to the ground. As the model wing is exposed to increasing air flow, the resulting lift pushes the wing to the side rather than upwards. The Wright brothers used this arrangement to eliminate gravity from their measurements. A flat plate, perpendicular to the flowing air, creates a drag force that forces the test device back towards a rest position. Lift created by the wing deflects the device in a consistently measurable way.

Two different means can be used to build the lift device. One approach relies on tongue depressors, skewers, cardstock, and a cardboard box. The other method makes use of commercially available construction toys. A recipe is given using K'NEX pieces, but a number of other construction toys can be used with comparable results.

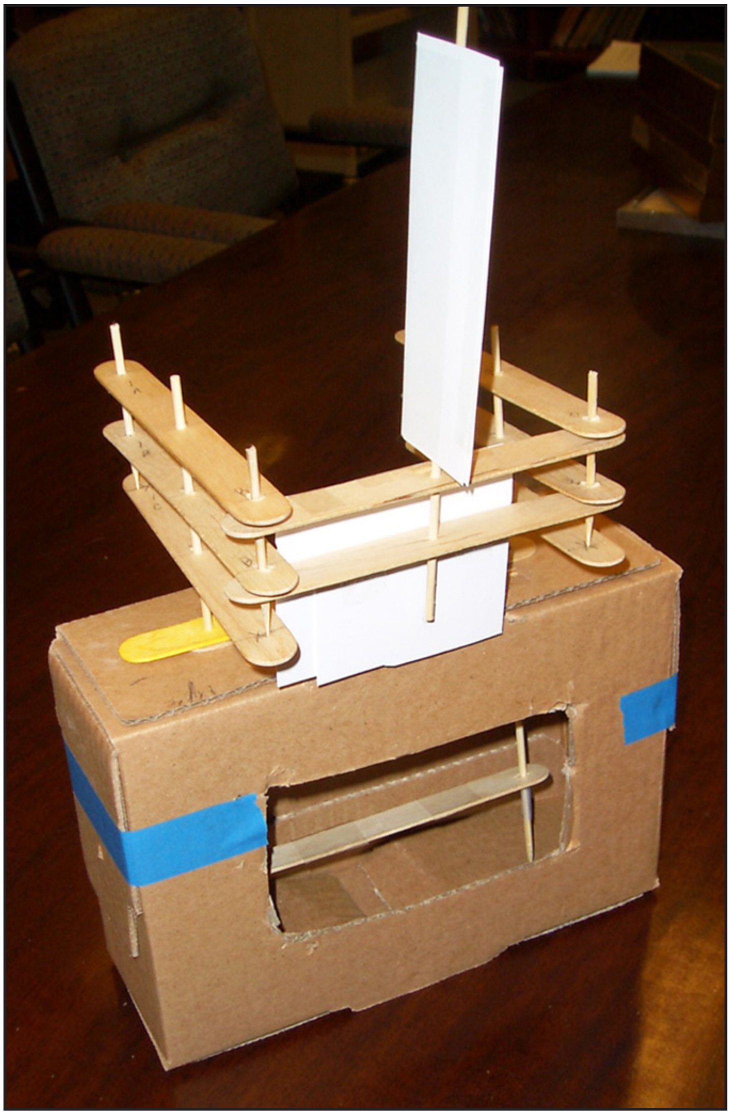
Materials List: Cardboard Box Version

- 1 wooden box (size variable, but 3" x 9" x 6" works well)
- 11 wooden tongue depressors/ jumbo craft sticks (¾" wide x 6" long)
- 5 wooden skewers (9" to 12" long)
- Cardstock piece (3" x 5")
- Cardstock piece (2.5" x 3.5")
- Angle of Attack Measuring Disk (p. 25)



Construction Procedure: Cardboard Box Version

- Drill 1/8" holes in the center of 8 of the wooden craft sticks.
- Drill two 1/8" holes centered ½" from each end of 6 of the craft sticks with center holes, leaving two craft sticks with no center holes.
- Place one craft stick with only two end holes on top of the longest side of the box. Tape the stick securely to the top of the box and extend the two holes through the box into its interior.
- Slide two full-length skewers through the two holes in the craft stick taped to the top of the box. The skewers should be free to rotate; do not glue to the craft stick.
- Push one craft stick with holes onto the ends of the two skewers inside the box. About half of the skewer should be inside the box, with the remaining half outside.
- Cut a 2" long piece of craft stick off to make a pointer. Drill a 1/8" hole in this craft stick segment and glue it to one of the two long skewers on the outside of the box, just above the box top.



- Mount three craft sticks parallel to each other on the top portion of each of the two skewers on the outside of the box. The bottom sticks should be about 1.5" above the box top, with 1" spaces between the bottom, middle and top sticks. Glue these in place so that the skewers will turn when the craft sticks rotate.

- Cut 4 skewer pieces 2" long. Push through the holes at one end of each triple craft stick assembly to provide stability.

- Position two transverse craft sticks between the triple craft sticks at the back end of the lift apparatus. Push 2" pieces of skewer through the combined five craft sticks. Use glue only between the two transverse sticks and the skewers. Do not glue these skewers to the triple sticks.

- Attach an upright skewer segment about 9" long through the two center holes in the transverse sticks. Do not use glue to attach the skewer, as it must be able to rotate in place.

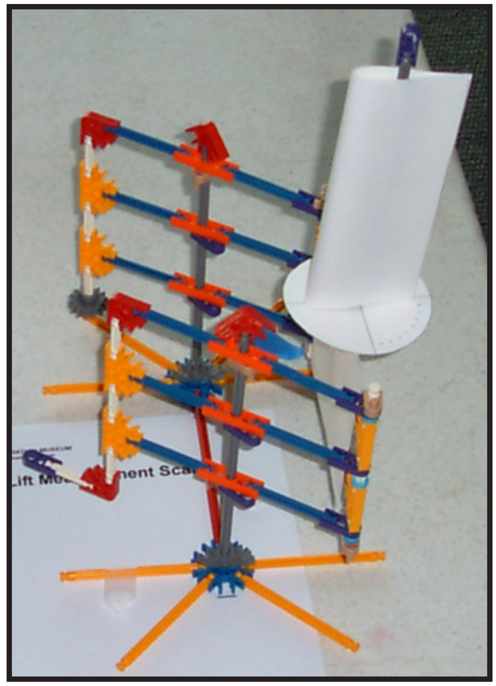
- Cut out the Angle of Attack Measuring Disk. Punch a hole in the center of the Disk and slide it down over the upright skewer until it touches the uppermost craft stick. Tape or glue the Disk to the craft stick with its 0-degree index line perpendicular to the craft stick and pointing in the opposite direction from the triple craft stick assemblies. The Disk should not be taped or glued to the upright skewer, which must be able to rotate.

- Cut a piece of cardstock about 3" x 5". Use glue and tape to wrap around the center skewer to form a vertically-oriented airfoil about 1.5" x 5".

- Cut a second piece of cardstock 2.5" x 3.5" for use as a drag plate. Attach this to the two transverse sticks, perpendicular to the orientation of the airfoil.

Materials List: Construction Toy Version

- 3 7" rods
- 3 5" rods
- 8 3" rods
- 13 2" rods
- 12 1" rods
- 2 7–hole connectors
- 8 5–hole connectors
- 2 4–hole connectors
- 3 3–hole connectors
- 7 2–hole connectors
- 19 1–hole connectors
- Cardstock piece (4.5" x 6.5")
- Cardstock piece (4" x 4.5")
- Angle of Attack Measuring Disk (p. 24)



Note: Materials may vary by manufacturer – a K'NEX 400–piece "Value Tub" contains sufficient materials to build 2 devices.

Construction Procedure: Construction Toy Version

- Build the base. Link two large 7–hole connectors with a 5" rod. Use smaller 3" rods to make four 'toes' for each connector.
- Build the uprights. Attach 4–hole connectors transverse to the base, and attach one long 7" rod vertically to each.
- Build the left and right linkages. Start with the front of each linkage: two 5–hole connectors linked with a short 1" rod, with additional 1" rods at either side. The three rods should line up along the flat edges of the connectors.
- Continue building the linkages. Attach 3–hole connectors to the ends of the 1" rods, top and bottom.
- Continue building the linkages. Attach a 2" rod to the top 3–hole connector and both 5–hole connectors in a direction perpendicular to the line formed by the 1" rods. Add a 2–hole connector to the end of each 2" rod, and add a second 2" rod to the opposite side of each 2–hole connector.
- Complete building the linkages. Add a 1–hole connector to the remaining end of each 2" rod.

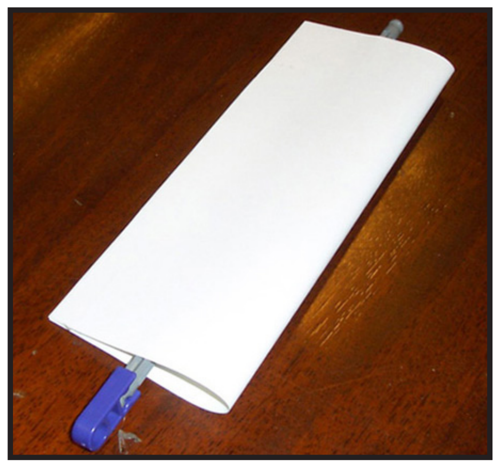
- Mount the linkages. Place 1–hole connectors on the two upright 7” rods as stops approximately 2.5” high. Slide one linkage assembly onto each 7” rod and drop down until stopped by the 1-hole connectors.

- Continue mounting the linkages. Add additional 1–hole stoppers to the 7” rod roughly 5” and 7” high so as to support the middle and upper arms of each linkage.

- Attach the two linkages. Form spacer bars by attaching each of two 5” rods to the center holes of two 5–hole connectors.

- Continue attaching the linkages. Slide a 1” rod through the 1–hole connector at the back end of one linkage. Attach the side holes of the 5–hole connectors used to form the spacer bars to the ends of the new 1” rod. The linkages are now loosely attached by the spacer bars.

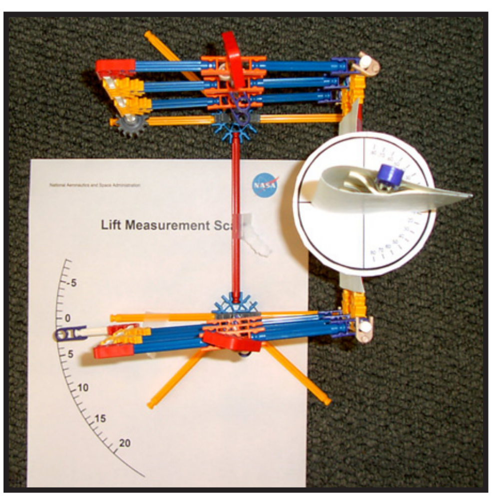
- Continue attaching the linkages. Attach an additional 1” rod to the top and bottom of the 5–hole connector assemblies and secure at the top and bottom using additional 1–hole connectors.



- Attach the wing. Cut a piece of cardstock roughly 4.5” x 6.5”. Fold without creasing into a 6.5” long airfoil shape, and use double-sided tape to hold the airfoil in shape and secure the remaining 7” rod inside.

- Cut out the Angle of Attack Measuring Disk. Punch a hole in the center of the Disk and slide it up onto the bottom of the 7” rod holding the airfoil shape.

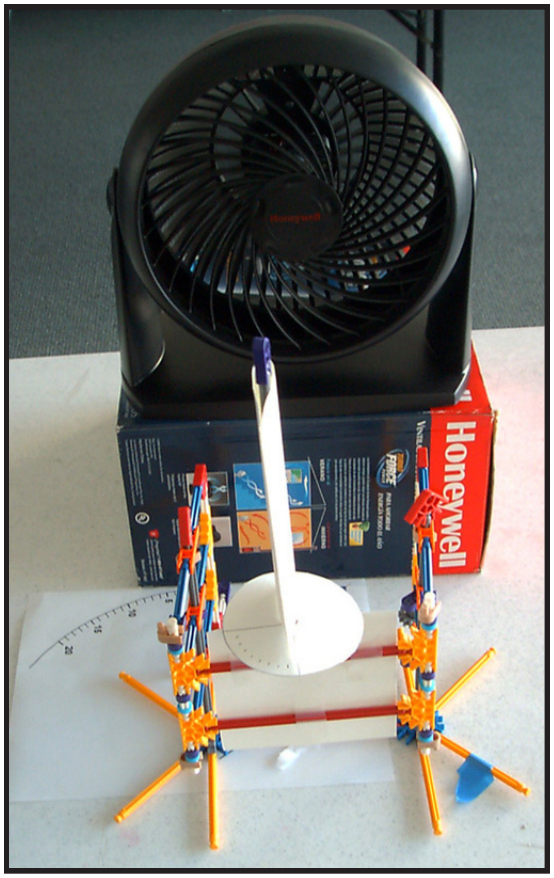
- Continue attaching the wing. Attach a 2–hole connector to the center of the upper spacer bar, pointed up. Attach one end of the 7” rod inside the wing to the remaining end of the 2–hole connector.

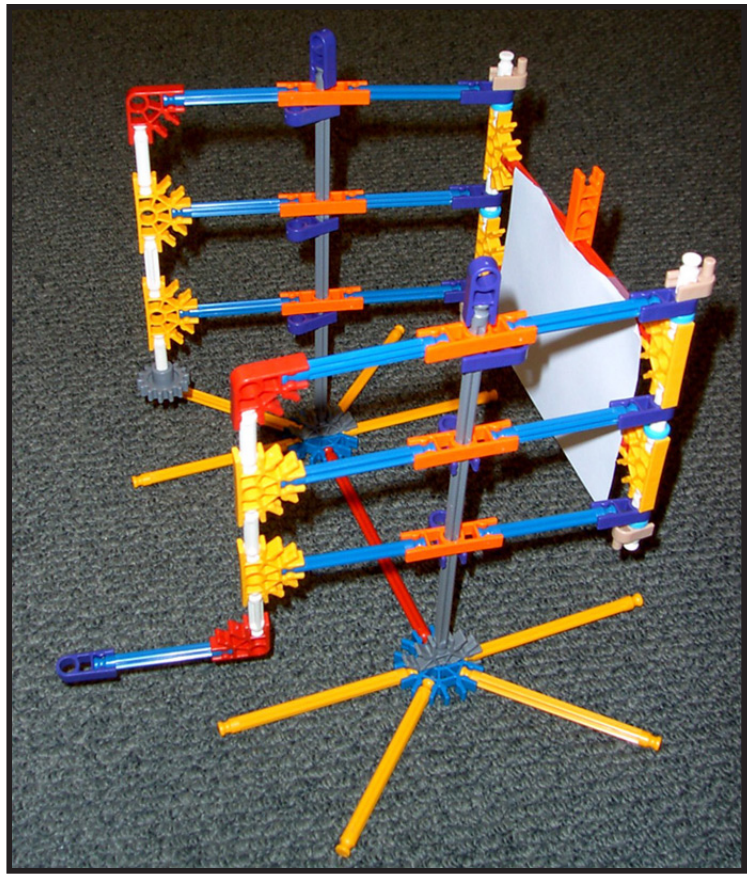


- Create the drag plate. Cut an additional piece of cardstock roughly 4” x 4.5”. Tape this to the platform created by the two spacer bars. The drag plate should face perpendicular to the wing and should not inhibit the free swing of the device.

- Rotate the Angle of Attack Measuring Disk so the 0-degree index line is perpendicular to the edge of the drag plate beneath. Use tape to secure the Disk in place so that it will not rotate as the wing rotates, but instead remains in a fixed position with respect to the drag plate.

- Create the indicator. Attach a 1” rod and a 1–hole connector to the free end of a 3–hole connector swinging at the front bottom of the device. This will create an indicator to measure the amount of lift generated.


Honeywell



Background

Have you ever heard the expression, "Can you give me a lift?" What does this mean? It means that someone needs to be picked up and taken someplace else, usually in their car. What does this have to do with an aircraft? In gliders and airplanes, the wings have the job of "picking up" the aircraft. In other words, the wings provide lift for the aircraft.

Lift is the force that directly opposes the weight of an airplane and holds the airplane in the air. The wings generate most of the lift on a normal airplane. Lift is a force produced by the motion of the airplane through the air. Because lift is a force, it has both a magnitude and a direction associated with it. Lift works roughly perpendicular to the wing.

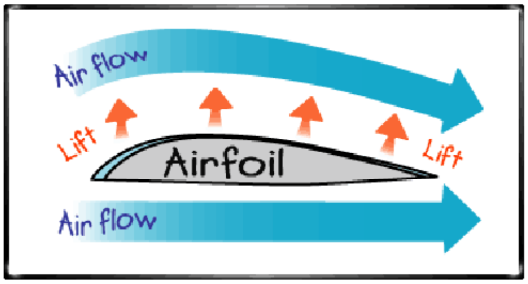


Image from NASA Ultra-Efficient Engine Technology, Dynamics of Flight

In an airplane, lift occurs when the wings deflect a moving flow of air. For most airplanes, the wings generate lift through two different means: 1) impact lift and 2) lift through the Bernoulli Effect.

Impact lift is the simplest to understand and is responsible for most lift generated by an airplane at low speeds. As a plane moves forward, its nose is pitched slightly upward into the oncoming airflow, forcing the wings to meet the air at an angle. The angle an airplane's wings make with the oncoming air is called the **angle of attack**. The angle of attack can be changed by pitching (moving) the airplane's nose up or down. As the airplane's wings strike the air at an angle, the airflow is turned downwards. Lift is generated in the opposite direction, in keeping with Newton's Third Law of Motion. This law states that for every action there is an equal and opposite reaction. For an aircraft wing, both the upper and the lower surfaces contribute to deflecting airflow.

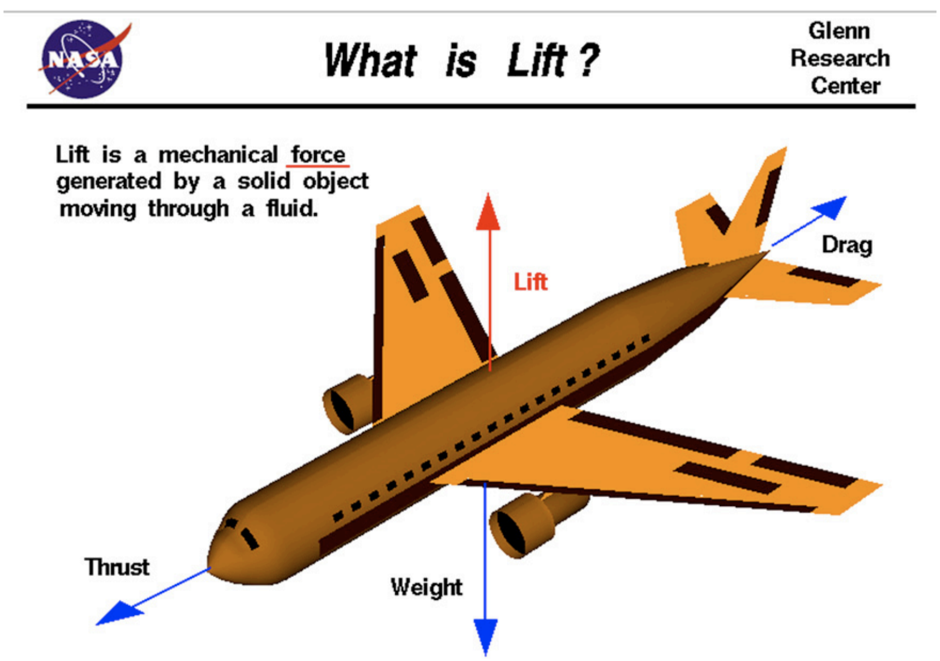
Bernoulli's Law states that fluids (such as air) exert less pressure at higher speeds than at lower speeds. Most airplanes have wing shapes (airfoils) that force air to move over their top surfaces more quickly than their bottom surfaces. When a wing is designed in this way, air presses on the bottom of the wing harder than on the top. This difference in pressure results in lift that helps keep the airplane in the air.

The Bernoulli Effect increases at higher airspeeds when the airplane is flying at a smaller angle of attack. When airspeed is low and the angle of attack is high, or in an airplane with airfoils that are not curved properly, or that may be curved the wrong way (as is the case when an airplane flies upside down), there may be little or no lift generated by Bernoulli's Law. This inquiry investigation will explore only lift and the relationship between angle of attack and the lifting force. It will *not* consider the Bernoulli Effect.

Lift is a mechanical force. It is generated by the contact of a solid body with a gas such as air. For lift to be generated, the solid body must be in contact with the air—no air, no lift. A spacecraft in Earth orbit like the Space Shuttle does not stay in space because of lift from its wings but because it is traveling at a velocity sufficient to keep it in orbit around the planet. Space is nearly a vacuum, and the shuttle's wings cannot generate lift until the shuttle re-enters Earth's atmosphere. Without air, there is no lift.

Lift is generated by the velocity difference between a solid object and the air. There must be some relative motion between the object and the air; without motion, there is no lift. It makes no difference whether the object moves through a calm air or wind moves past a stationary solid object. For example, airplane wings generate lift when they move forward, pushing their fixed wings through the air. A kite, on the other hand, is tied to the ground (or someone standing still on the ground), and on a windy day air is forced over the kite's structure to create lift. There must be some relative motion between the air and the object to be lifted for lift to be created.

The above information is adapted from NASA Glenn Research Center's Beginner's Guide to Aerodynamics, http://www.grc.nasa.gov/WWW/K-12/airplane/lift1.html



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.

   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 our airplanes do not float around once they are 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 your hand 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 to increase speed.

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 a very 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 object forward and, in the case of an airplane, is usually generated by the airplane's engines and propellers.
- Drag is a 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 use in the following discussion, you may want to use the image of the airplane with the four force arrows that is on page 8 of the ***In Thrust We Trust*** lesson. One of the following NASA articles, videos, or animations could add to the discussion as well.

- 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 especially 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.)

- 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 lift force.

- What part of the airplane do you think is responsible for lift?

Misconception Alert: Students may believe that the *engine* causes lift. This is a misconception. The engine provides thrust, not lift. The wings are the primary source of lift on an airplane.

Explore

1. Introduce the lift 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 wing of an airplane is responsible for providing lift. What do you think will happen to lift as we change the angle of the wing relative to the wind? (*Accept all answers.*)

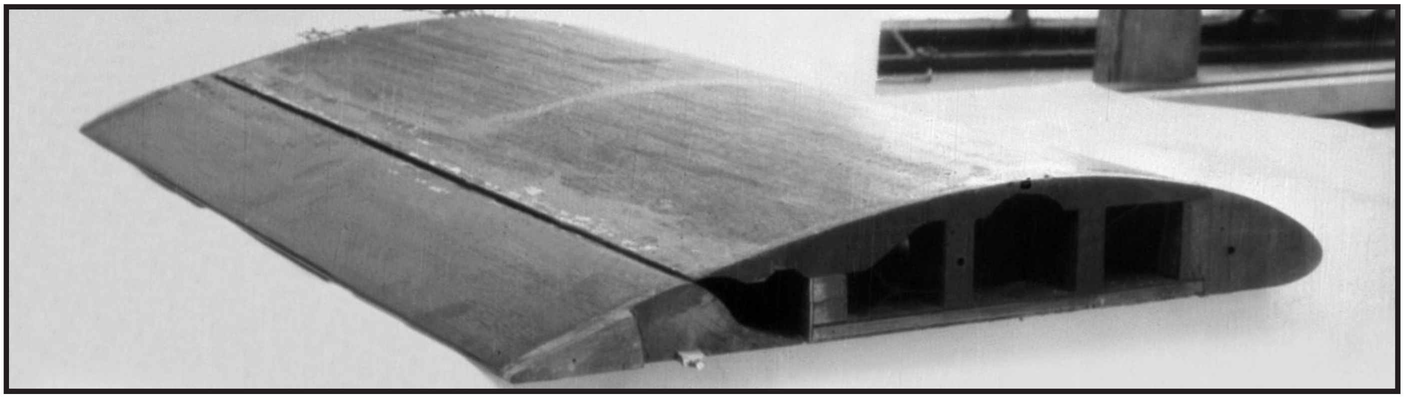
   • The angle of an airplane's wing relative to the oncoming air is called the **angle of attack**. An airplane pilot can change the angle of attack of his or her airplane simply by raising or lowering the nose of the airplane. Today we will see if the angle of attack makes a difference in how much lift can be generated by a wing.

   • Look at the experimental setup. Your team has a fan, a ruler, and a lift testing device that has an adjustable model of a wing attached vertically in front of the fan. We have rotated the wing 90 degrees to eliminate the force of gravity from our measurements.

   • It might seem odd to have our wing positioned straight up and down since a real airplane would not fly this way. However, that is exactly what the inventors of the first airplane had to do. Wilbur and Orville Wright were having a tough time understanding exactly how a wing creates lift. To help them learn more about it, they decided to build small model wings out of tin and test them in a device called a wind tunnel. The wind tunnel is a small fan contained inside a tube or tunnel that passes air over a test shape. The Wright brothers built about two hundred tin wings and tested them in their wind tunnel before deciding on a shape for their airplane.

   • We are going to do the same thing as the Wright brothers, but our wing will be made of stiff paper cardstock instead of tin. Just like the Wright brothers' experiment, our wing is mounted vertically. There is an indicator needle attached to the bottom of the lift measuring device, and underneath the needle is a measuring scale. This scale moves as the amount of lift changes. We can use this scale to measure how lift increases and decreases as the wing's angle through the air changes.

   • Look at the model wing carefully. Does this wing look like any airplane wing you have ever seen? (*The kids should say no. This is a cross-section of a wing. It may be helpful to show them the airfoil shape of a wing on an airplane or airplane model so they can see the shape of the airfoil in the wing and make the connection between the airfoil as a cross section of the wing.*) Wings on full-sized airplanes are very large, sometimes over 200 feet across!



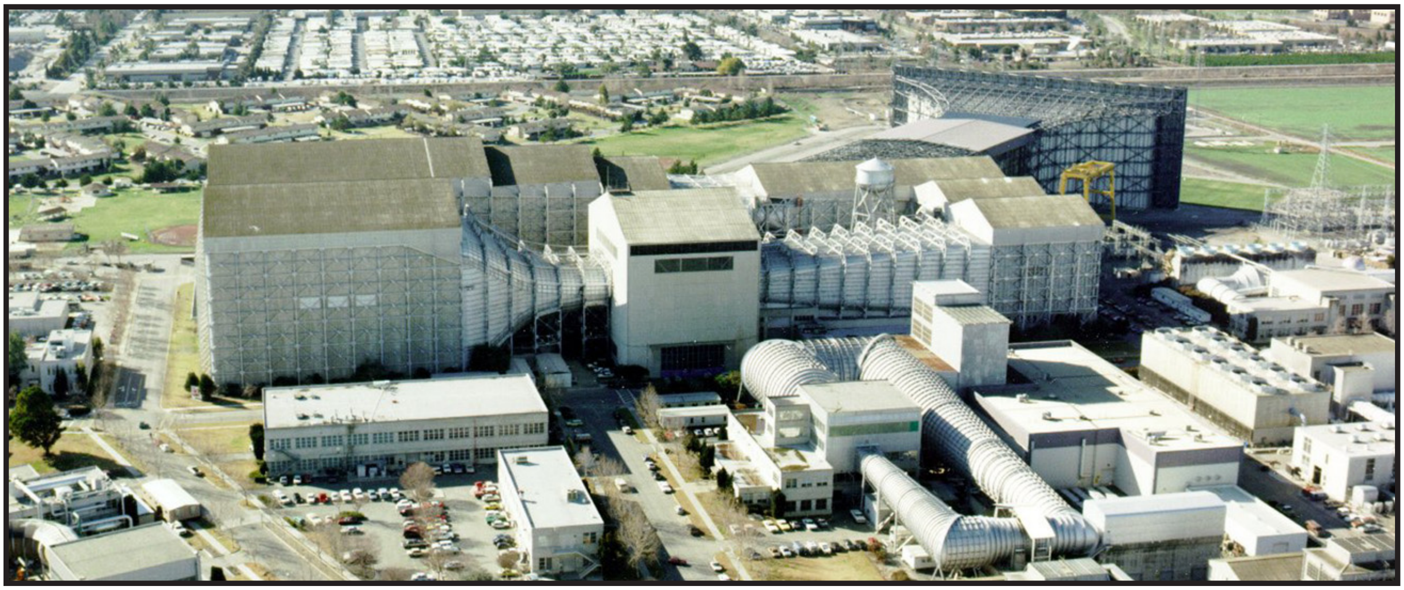
Dryden Flight Research Center ECN 30043 Photographed 1984
Rotor Systems Research Aircraft (RSRA)

Dryden Flight Research Center E55-2078 Photographed 1955
P-51 Mustang. NASA photo

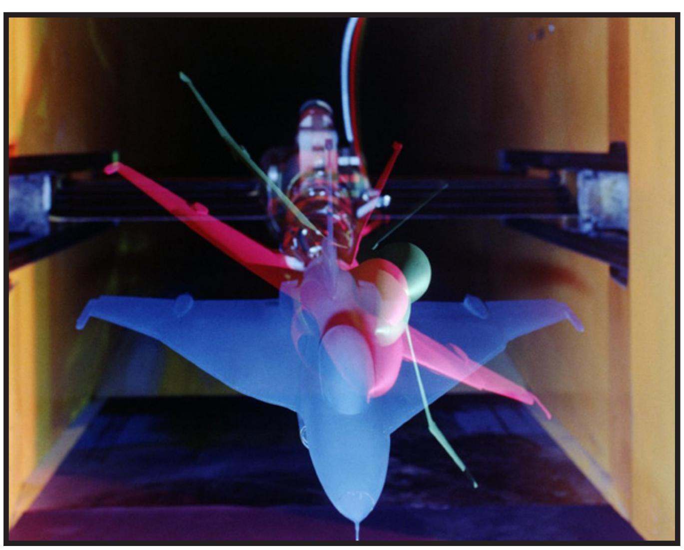
NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/gallery/photo/index.html
NASA Photo: E-2478 Date: 1950s Photo by: NASA photo (copy negative)

D-558-2 launch from Navy P2B-1S

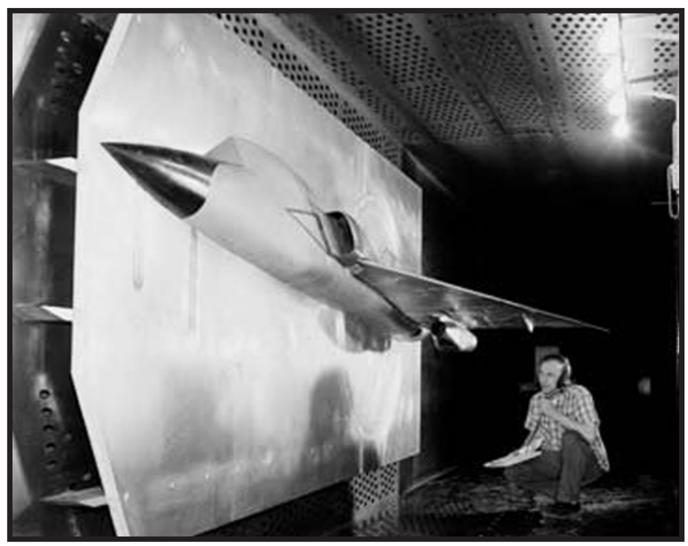
- There are only a few laboratories in the world big enough to blow air over full-sized wings, like the enormous National Full Scale Aerodynamics Complex at NASA Ames Research Center. The largest wind tunnel at NASA Ames has a test area of 80x100 feet; even it is not big enough to test full-sized wings for the largest airplanes. Even for smaller airplanes, the electricity needed to power a giant wind tunnel is about the same as the amount needed to power a small city!



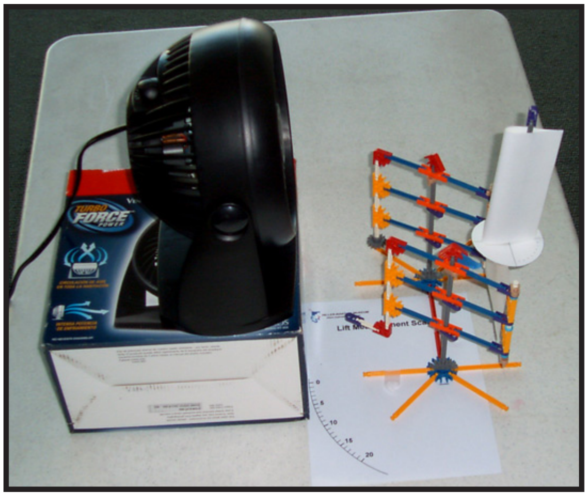
- It is very hard and very expensive for scientists and engineers at laboratories like NASA to test full-sized wings. Instead the test laboratories use a model airfoil. These airfoils are much smaller than a full sized wing, but have exactly the same shape. The model airfoil can be made very small, yet it still behaves the same way as a full-sized wing. A small airfoil, like the one you are using today, is perfect for experimenting with wing designs.



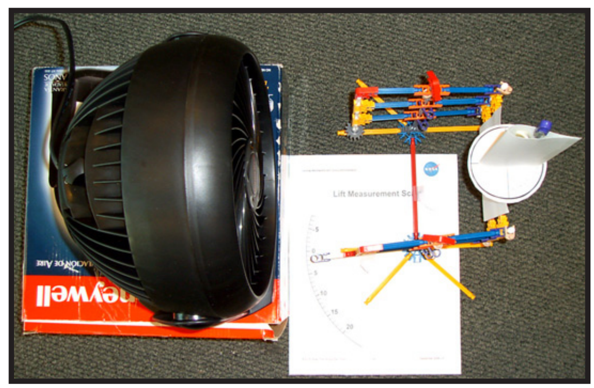

X-48B



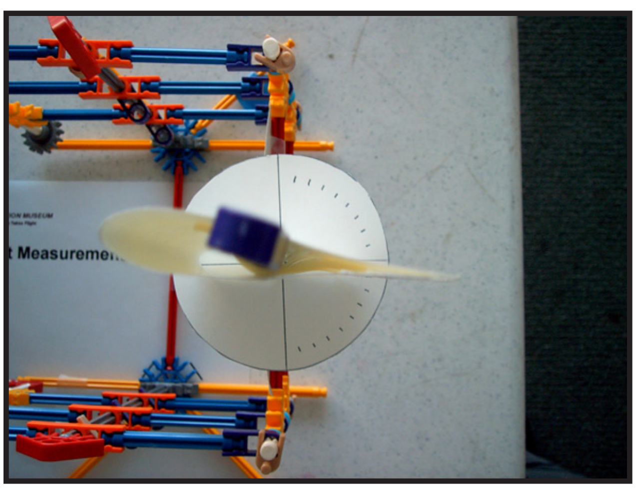
2. Explain the directions for the Lift Experiment and demonstrate using the model.



- Place the lift device 5” away from the table fan. Make sure that the table fan is pointed towards the middle of the airfoil and that the fan is perpendicular to the table. Place books or a box under the fan to ensure that both the fan and the airfoil are level with each other.

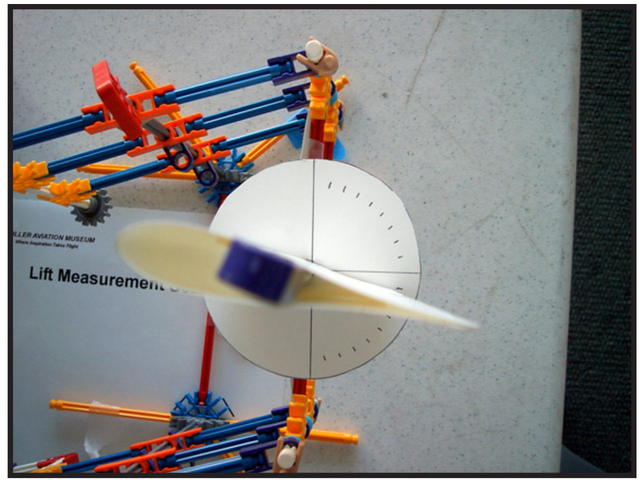


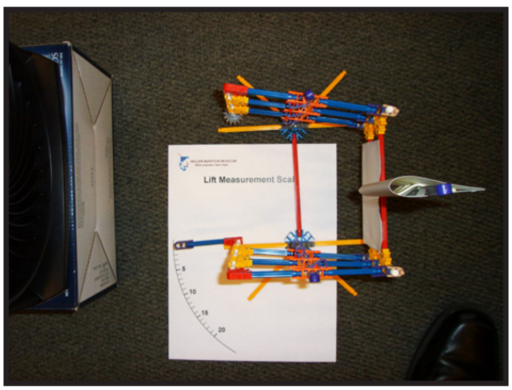
- Ensure that the Lift Measurement Scale (p.24) is properly positioned under the device so that the indicator needle follows the measurement arc as it moves.



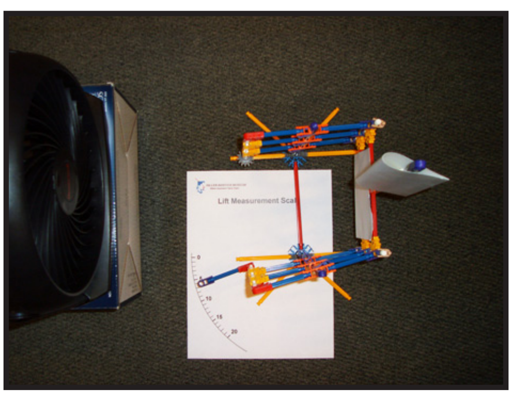
- Set the angle of attack of the airfoil as directed by the data sheet (p. 23). To set the angle, turn the trailing edge of the airfoil (the pointed edge) until it is over the desired angle on the Angle of Attack Measuring Disk (p.25). At zero degrees angle of attack, the airfoil’s leading edge (the blunt edge) is pointed parallel to the air flow from the fan. At ninety degrees, the airfoil’s leading edge is pointed perpendicular to the airflow from the fan.

- If the Angle of Attack Measuring Disk is not available, a protractor can be used to set the angle of attack of the airfoil. To set the angle, hold the protractor above the wing and turned so that zero degrees is the direction directly towards the fan. Imagine a line running from the front edge of the wing to the back edge of the wing, and turn the wing up (clockwise) until this line reaches the required angle.



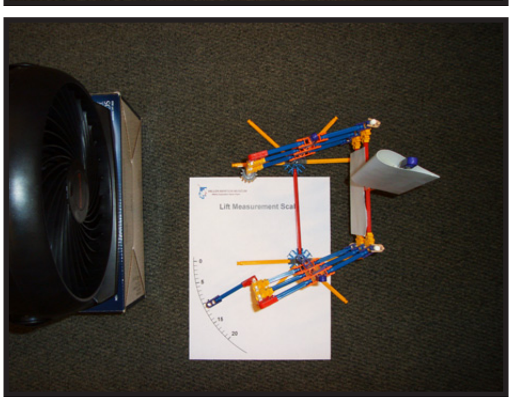


- Turn the structure so that the measurement needle begins at 0 units of lifting force.



- Turn on the fan and allow the device to move in response to the air flow. If the fan has several speed settings, use the highest speed for all experiments unless otherwise instructed.

- The indicator may move back and forth after the fan is turned on. Once the fan stops moving, measure the lifting force.



- Try making the angle adjustments suggested in the table on the data sheet and record your results to see how the relative lifting force changes as the angle of attack changes.

Explain / Evaluate

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***.

Did the angle of the wing affect lift?

As the angle increases, the lift should also increase. Students should note, however, that after a certain point, the lift decreases. There is a critical angle of attack at which the wing will generate the maximum possible lift. Beyond the critical angle of attack, the airflow over the wing becomes turbulent and lift decreases. If an airplane is pitched beyond its critical angle of attack (usually about 18 degrees), it is said to “stall” as lift drops dramatically. Airplane stalls are purely a function of angle of attack and are unrelated to the airplane’s engine.

In summary...

You learned in the design challenge that the shape of the propeller blade plays an important role in flight. Today, you have seen that the angle of the wings also plays an important role in flight. Engineers at NASA Langley Research Center, in conjunction with industry and the Federal Aviation Administration are working together to make lightweight, fuel efficient, easy-to-fly, and economical aircraft so that more people will be able to own their own aircraft and fly. You can learn more about this by visiting NASA Langley at www.nasa.gov/centers/langley/news/releases/1997/Aug97/97_95.html.

Extend / Apply (in the classroom)

- Make a graphic representation of the results. Grades 5 and 6 can make a plain bar graph. Grades 7 and 8 should pick and justify which type of graph they intend to use. (For example, grades 7 and 8 could make a bell curve.)

- Based on student results, draw conclusions about the angle that produced the maximum lift.

- Calculate the mean for each of the trials and graph the data. Older kids should justify their graphic selection (i.e. a bar graph versus a line graph).

- Research careers in aviation design and aeronautical engineering.

Resources

- Future Flight Design, NASA Quest: http://futureflight.arc.nasa.gov
- Beginner's Guide to Aerodynamics, NASA Glenn Research Center: http://www.grc.nasa.gov/WWW/K-12/airplane/index.html
- Case of the Wright Invention, NASA Sci Files: http://scifiles.larc.nasa.gov/text/educators/episodes/2001_2002/wright_invention.html
- Exploring Aeronautics, EP-2005-09-601-ARC, NASA Quest: http://quest.arc.nasa.gov/projects/aero/ExploringAero
- Dynamics of Flight, NASA Glenn Research Center: http://ueet.grc.nasa.gov/StudentSite/dynamicsofflight.html
- Aerodynamics Index, Wing Geometry Definitions, NASA Glenn Research Center: http://www.grc.nasa.gov/WWW/K-12/airplane/short.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/teachers/fact_sheets.html
- 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/

The Wing's The Thing Data Sheet

Team Members: ______________________ ______________________

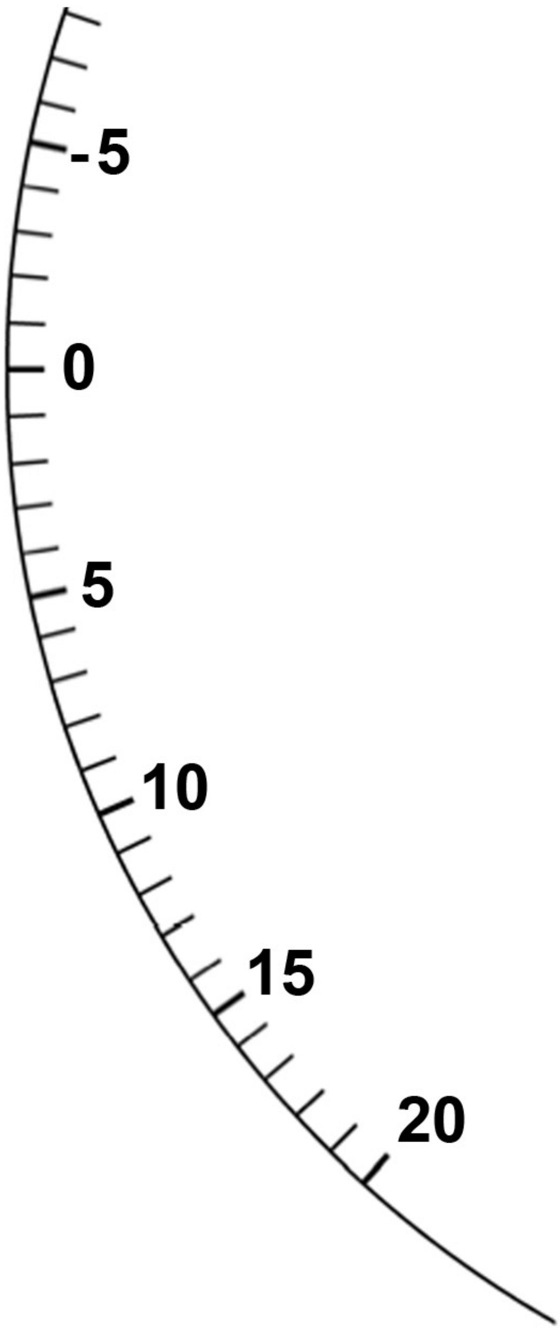
______________________ ______________________

Directions:

1. Place the lift-measuring structure 5" away from the table fan.
2. Turn the airfoil so that the leading, thicker edge is pointed toward the fan.
3. Use a protractor to set the angle of attack. Begin with the wing at 0 degrees.
4. Turn the lift-measuring structure so that the indicator needle shows 0 units of lift.
5. Turn the fan on to full power. Allow the needle to move freely.
6. When the needle stops moving, record the lift of the wing in the chart below.
7. Complete 3 trials for the angle measure, and then calculate the sum and average of your test results and record them.
8. Adjust the wing for the next angle of attack and repeat the experiment.

Angle of Attack	Trial 1	Trial 2	Trial 3	Total of 3 Trials	Average of 3 Trials
0 degrees					
10 degrees					
20 degrees					
30 degrees					
40 degrees					
50 degrees					
60 degrees					

Lift Measurement Scale



Angle of Attack Measuring Disks