

WIND TUNNEL LESSON MATERIALS

LAUNCHING INTO AVIATION: THE WRIGHT APPROACH
9TH GRADE

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LESSON 2

BUILD AND TEST A WIND TUNNEL

Lesson Prep

GRADE 9: Launching Into Aviation

UNIT 2 Taking Flight—Early Aviation Innovations

SECTION D Powered, Controlled Flight



Build and Test a Wind Tunnel

Session Time: Six, 50-minute sessions

DESIRED RESULTS

ESSENTIAL UNDERSTANDINGS

Appreciate the rich, global history of aviation/aerospace and the historical factors that necessitated rapid industry development and expansion. (EU1)

Aspire to the highest level of technical proficiency as it relates to flight operations and engineering practices. (EU5)

ESSENTIAL QUESTIONS

1. What contributions did the Wright brothers make to aviation?
2. What was the role of engineering practices in the development of the Wright brothers' flying machines?
3. How does the shape of an airfoil determine how much lift it creates?

LEARNING GOALS

Students Will Know

- How the Wright Brothers improved their designs through the use of a wind tunnel
- Key terms related to airfoils
- Which airfoil shape and characteristics create more lift by conducting tests, making observations, and analyzing data.

Students Will Be Able To

- *Describe* the scientific process the Wright Brothers used to solve the power, control, and lift problems they encountered. (DOK-L2)
- *Differentiate* between airfoils designs and *identify* their strengths and weaknesses. (DOK-L1, L2)
- *Analyze* data from wind tunnel tests to determine which airfoil designs created the greatest lift. (DOK-L4)
- *Synthesize* the results of the wind tunnel test. (DOK-L4)

ASSESSMENT EVIDENCE

Warm-up

Students will view a video of Boeing winglets during a wing tunnel test and answer questions related to wind tunnels.

Formative Assessment

Students will write a summary to explain which type of aircraft would be better suited for a symmetrical airfoil and an asymmetrical airfoil.

Summative Assessment

In small groups, students will present the findings of their wind tunnel and airfoil tests.

LESSON PREPARATION

MATERIALS/RESOURCES

- [Build and Test a Wind Tunnel Presentation](#)
- [Build and Test a Wind Tunnel Teaching Aid](#)
- [Build and Test a Wind Tunnel Student Activity](#)
- [Build and Test a Wind Tunnel Teacher Notes](#)

Wind Tunnel Build (per wind tunnel)

- Large pieces of cardboard cut into the following dimensions
 - Four (4) 21" x 25" x 8"
 - Four (4) 40" x 8"
 - Four (4) 10" x 7"
- Box fan (highest powered fan available)
- Box knife
- Metal straight edge
- Measuring tape/ruler
- Drinking straws (recommend using jumbo size straws)
- One (1) 8" x 10" piece Lexan/Plexiglass (can be purchased pre-cut at a major hardware store)
- Duct tape
- Hot glue gun and glue sticks
- Digital scale (measures to 0.1g, at a minimum)
- Safety glasses

Airfoil Build (per group)

- Airfoil Mount (assume each group builds one airfoil mount to test both airfoils)
 - Foam board pieces (recommend using standard white foam board from Dollar Tree)
 - One (1) 6" x 6"
 - Eight (8) 1" x 3"
 - Wire (can be from a wire hanger)
 - Three (3) 7 12" pieces of wire

- Symmetrical Airfoil
 - Foam board pieces
 - One (1) 16" x 5 14"
 - Three (3) 5 14" x 1"
- Asymmetrical Airfoil
 - Foam board pieces
 - One (1) 16" x 5 14"
 - Three (3) 5 14" x 1"
- Airfoil of Student's Own Design
 - Foam board pieces
 - One (1) 16" x 5 14"
 - Three (3) 5 14" x 1"
- Box knife
- Metal straight edge
- Measuring tape/ruler
- Hot glue gun and glue sticks
- Pliers/wire cutter
- Protractor
- Safety glasses

SAFETY

- Actively supervise students during the activity. Be ready to offer guidance in situations where safety could be compromised.
- Make sure students use eye protection. Have insulated gloves available for handling hot objects and pads for setting down objects with heated surfaces.
- Explain how to safely store sharp objects on an active workspace when they are not in use. Students should not be holding sharp objects or tools when they are not in use.
- Sharp tools should be stored in their protective cases when not in use.

LESSON SUMMARY

Lesson 1: The "Wright" Approach

Lesson 2: Build and Test a Wind Tunnel

Lesson 3: The "Wright" Attitude

In this multi-session lesson, the class will watch a video about a very precise wind tunnel used today. The students will explore the reasons why the Wright brothers built a wind tunnel and the process they used to test airfoils.

Students will build a wind tunnel as a class, learn about airfoils, then build their own in small groups to test in the wind

tunnel. It will take two sessions to build the wind tunnel and an additional two sessions to build the airfoils. One final session is needed to test the airfoils, summarize findings, and allow groups to present their findings to the class.

BACKGROUND

The students have been learning about the Wright brothers and their decision to measure the lift and drag on their various airfoils using a simple wind tunnel. In the early 1900s, the Wright brothers realized their gliders were only producing a fraction of the lift predicted by Otto Lilienthal's previous experiments. They decided to do their own aerodynamic research in order to produce more accurate lift data. They built airfoils, tested them, identified areas for improvement, and then re-tested the designs. They were the first to use this process to systematically test their theories and design their gliders and airplanes.

Airfoil: is a wing shape that when moved through a fluid (air) produces an aerodynamic force

Angle of attack: the angle formed by the chord of the airfoil and the direction of the relative wind

Asymmetrical airfoil: two sides of the airfoil are shaped differently

Camber: the curve of the wing

Chord: straight line that connects the leading edge to the trailing edge

Leading edge: the first place air makes contact with the airfoil

Max camber: maximum distance between the mean camber and the chord line

Mean camber: a line drawn between the leading edge and trailing edge so that the distances between the upper and lower surfaces of the airfoil are equal

Planform: shape of the entire wing when viewed from above

Span: the entire length of the wing from wingtip to wingtip

Symmetrical airfoil: is shaped so that its upper and lower surfaces are identical

Trailing edge: the last place air has contact with the airfoil

Thickness: maximum distance between the upper and lower wing surfaces

DIFFERENTIATION

To promote reflective thinking and guided inquiry in the activities outlined in the **EXPLAIN/EXTEND** sections of the lesson plan, circulate around the classroom and assist students who might have trouble completing the steps of the activity. Ask questions that provoke their own ideas for possible solutions to the challenges they are experiencing.

LEARNING PLAN

ENGAGE

Teacher Material: [Build and Test a Wind Tunnel Presentation](#)

Slides 1-3: Introduce the topic and learning objectives for this lesson.

Slide 4: Conduct the **Warm-Up** using a video of Boeing 737 MAX winglets in a wind tunnel.

- “Boeing 737 MAX Winglets in the Wind” (Length 2:08)
<http://safeYouTube.net/w/oKJd>

Take no more than 10 minutes of class time to complete the warm-up. Collect student papers for grading when they are completed and ask students to share their answers.

Warm-Up

Show students the precision and scale of today's wind tunnels by viewing a video of Boeing's 737 MAX winglets in a wind tunnel. Ask students to individually write 2-3 sentence answers for each of the following questions:

Why are wind tunnels used to design aircraft?

What are wind tunnels used to measure?

What other industries besides aviation use wind tunnels to test designs?

Possible answers:

Why are wind tunnels used to design aircraft?

A wind tunnel provides a means to test aircraft and their components in order to determine their performance and behavior in the air. Wind tunnels provide a way to test objects in a much more cost effective and safe manner.

What are wind tunnels used to measure?

Wind tunnels allow for the measurement of aerodynamic forces and airflow around an object. The objects tested can be entire aircraft models, airfoils, engines, rockets, and more.

What other industries besides aviation use wind tunnels to test designs?

The automobile, boating, and motorsports industries all use wind tunnels. The sporting goods industry uses them to test things like helmets and golf balls.

EXPLORE

Teacher Materials: [Build and Test a Wind Tunnel Presentation](#), [Build and Test a Wind Tunnel Teaching Aid](#)

Slide 5: In the early 1900s, the Wright brothers realized their gliders were only producing a fraction of the lift predicted by Otto Lilienthal's previous experiments. The Wrights examined all the terms in the lift and drag equations. Some values—weight of the glider, wind speed, and wing surface area—could be directly measured, so the Wrights were confident of their accuracy. But the coefficients of lift and drag were drawn from the work of others. The brothers focused on these as the possible source of their gliders' poor lift performance. They decided to do their own aerodynamic research in order to produce more accurate lift data. The lift equation is $L = (C_L \times \rho \times V^2 \times S) / 2$.

Slide 6: In order to improve on their designs, the Wright brothers built a wind tunnel and were the first to use a series of engineering practices in order to test, analyze, and improve their airfoil designs.

Wind tunnels are used to manage airflow around a stationary object. This helps control variables that may impact results of testing.

The wind tunnel was a wooden box with a square glass window on top for viewing during testing. A fan belted to a one-horsepower engine, which ran the machinery in their bicycle shop, provided airflow of about 30 miles per hour.

What made the Wrights' wind tunnel unique were the instruments they designed and built to measure lift and drag. Called balances, after the force-balancing concept, these instruments measured the forces of lift and drag acting on a wing in terms that could be used in the equations. The balances are made from old hacksaw blades and bicycle spokes.

Slide 7: Explain to students that they are going to participate in the construction of a wind tunnel and test airfoils. The focus at this point of the lesson should be on actually constructing the wind tunnel per the specifications in the [Build and Test a Wind Tunnel Teaching Aid](#).

It is important that the wind tunnel be constructed correctly so that the airfoil testing is possible. It will take about two sessions to build the wind tunnel.



Teaching Tips

A class only has to build one wind tunnel and keep it. Students should design and test their own airfoils after experimenting with the two samples. To save time, pre-cut cardboard pieces per the measurements provided. Divide students into smaller teams and have them work on separate tasks (e.g., the feet, the tunnel, etc.).

EXPLAIN

Teacher Materials: [Build and Test a Wind Tunnel Presentation](#), [Build and Test a Wind Tunnel Teacher Notes](#)

Student Material: [Build and Test a Wind Tunnel Student Activity](#)

After the wind tunnel is built, use slides 8-17 to lead a class discussion on airfoils using information presented in the slides. The presentation covers important terminology and factors that influence the performance of an airfoil. Students should write definitions for the airfoil terms presented in their own copies of **Build and Test a Wind Tunnel Student Activity**.

Slide 8: An airfoil is a wing shape that when moved through a fluid (air) produces an aerodynamic force. It is a structure with curved surfaces designed to give the most favorable ratio of lift to drag in flight.

Slide 9: The leading edge of the airfoil is the first place air makes contact with the airfoil. The trailing edge is the last place air has contact with the airfoil.

Slide 10: The chord is a straight line that connects the leading edge to the trailing edge. The angle of attack is the angle between the chord line and the relative wind flow. If the leading edge of the airfoil is higher than the trailing edge, then the airfoil has a positive angle of attack. If the leading edge is lower than the trailing edge, the airfoil has a negative angle of attack.

Slide 11: The thickness of an airfoil is the maximum distance between the upper and lower wing surfaces.

Slide 12: Camber is the curve of the wing. The mean camber is a line drawn between the leading edge and trailing edge so that the distances between the upper and lower surfaces are equal. Max camber is the where there is maximum distance between the mean camber and the chord line.

Slide 13: Airfoil shapes can be symmetrical or asymmetrical. If an airfoil is shaped so that its upper and lower surfaces are identical, it is a symmetrical airfoil. Some airfoils are curved differently on the top side than on the bottom. Those airfoils are asymmetrical, because their two sides are differently shaped.

Slide 14: Ask students what kind of airplane would most benefit from a symmetrical wing. The answer is on the next slide.

Slide 15: The answer is aerobatic airplanes. Given the same flying conditions such as the angle of attack, the same airspeed, or the same density of air, both symmetrical wings and asymmetrical wings can produce lift; however, the asymmetrical wing is designed to create more lift and less drag. Symmetrical wings are best used for aerobatic aircraft. Aerobatic aircraft need to generate lift even while spinning and going inverted or upside down. Underscore this concept, because students will revisit it in the Formative Assessment.

Slide 16: Planform is the shape of the entire wing when viewed from above. The span is the entire length of the wing from wingtip to wingtip. Students should recall that the chord is the distance between the trailing edge and the leading edge.

Slide 17: Wilbur and Orville conducted preliminary tests on as many as 200 different model wing shapes as they perfected the operation of their wind tunnel. They made formal tests and recorded data on nearly 50 of these. They learned many important factors that impacted the designs of their wings.

Slide 18: The angle of attack is the angle at which relative wind meets an airfoil. It is the angle formed by the chord of the airfoil and the direction of the relative wind, or the vector representing the relative motion between the aircraft and the atmosphere.

The critical angle of attack is the angle of attack which produces maximum lift coefficient. This is also called the "stall angle of attack." Below the critical angle of attack, as the angle of attack increases, the coefficient of lift (Cl) increases. Conversely, above the critical angle of attack, as angle of attack increases, the air begins to flow less smoothly over the upper surface of the airfoil and begins to separate from the upper surface. On most airfoil shapes, as the angle of attack increases, the upper surface separation point of the flow moves from the trailing edge towards the leading edge. At the critical angle of attack, upper surface flow is more separated and the airfoil or wing is producing its maximum coefficient of lift. As angle of attack increases further, the upper surface flow becomes more and more fully separated and the airfoil/wing produces less coefficient of lift.

EXTEND

Teacher Materials: [Build and Test a Wind Tunnel Presentation](#), [Build and Test a Wind Tunnel Teacher Notes](#)

Student Material: [Build and Test a Wind Tunnel Student Activity](#)

Slide 19: Guide students through the process of building airfoils using directions from [Build and Test a Wind Tunnel Student Activity](#). In small groups, the students will build airfoils out of foam board. They will build a symmetrical airfoil of a given chord and span, an asymmetrical airfoil of the same chord and span, and an airfoil of their own design. They will test the airfoils at various angles of attack to determine which creates more lift.

To measure the lift of the airfoils, students will note the weight the airfoil assembly exerts on a digital scale before the wind tunnel is turned on and while the wind tunnel is running.



Questions

Students will be asked to answer the following question before they begin testing their airfoils. The question is found in [Build and Test a Wind Tunnel Student Activity](#).

Before you test the airfoils, hypothesize which airfoil will create more lift. How will the angle of attack influence the lift created? Explain your reasoning.

Students should take the following steps to measure the lift on their airfoils:

1. Place the digital scale inside the wind tunnel.
2. Ensure the digital scale has been "zeroed" out.
3. Place the airfoil mount and the symmetrical airfoil on the scale.
4. Looking through the viewing window, take note of the weight in grams (to the tenth or hundredth) before the wind tunnel is turned on.
5. Turn on the wind tunnel (ensure the fan is at the highest power setting).
6. After a few moments, take note of the new weight in grams (to the tenth of hundredth).

7. Subtract the weight found in step 6 from the weight found in step 4 to determine the amount of lift generated.
8. Repeat these steps for both airfoils and the different angles of attack.



Questions

Students will be asked to answer the following questions based on their observations. The questions are found in **Build and Test a Wind Tunnel Student Activity**.

Which airfoil produced the most lift? Explain why.

If done correctly, the symmetrical airfoil will create more lift. The Wright brothers proved through the wind tunnel tests that cambered airfoils produced greater lift.

Which airfoil produced the most lift for a given angle of attack? Why?

If done correctly, the most lift will be created by the asymmetrical airfoil at 30 degrees angle of attack. This will be easier to determine if students are using a higher quality digital scale that measures to the hundredth of a gram.

Next, have the students go back to their wind tunnel with their asymmetric airfoil. Have the students mount the airfoil upside down so that the cambered side of the airfoil is facing the scale. Place the entire airfoil mount on the scale with the leading edge pointed toward the fan. Have students note the weight again before turning on the fan.



Questions

Students will be asked to answer the following questions based on their observations. The questions are found in **Build and Test a Wind Tunnel Student Activity**.

What happens to the weight once the wind tunnel is turned on? Why?

The air doesn't know the airfoil is upside down, and the air moves around the airfoil just as it did before. The air on the cambered side of the airfoil is still lower pressure air than on the flat side. Just as before, this creates a force, but now that force is downward and places more pressure on the scale. The scale should indicate a weight greater than the no-wind weight.

What would you expect if we did the same exercise with the symmetrical airfoil?

A symmetrical airfoil will create the exact same amount of lift whether right side up or inverted. This is why aerobatic airplanes generally use symmetrical airfoils.



Teaching Tips

If the teacher desires and time allows, the students can use the engineering practices to design and test their own airfoil.

Slide 20: Conduct the Formative Assessment.

Take no more than 5 minutes of class time to complete the assessment. Collect student papers for grading when they are completed.

Formative Assessment

In groups of two to three students, students will explain which type of aircraft would be better suited for:

- symmetrical airfoil
- asymmetrical airfoil

Ask students to write a short summary for each type of airfoil.

Possible answers include:

Most airfoils are asymmetrical, meaning that one surface of the wing has more curve than the other. Usually the top of the wing has more curve, causing it to produce lift in level flight. This makes a wing more efficient, which is why transport planes, airliners, and even normal category general aviation airplanes generally have asymmetrical wings.

This is a disadvantage in aircraft that must be able to fly inverted, such as fighters and aerobatic aircraft. These airplanes often have symmetrical airfoils, with the top and bottom of the wing having the same curve. Such a wing will produce no lift at zero angle of attack, but will be able to fly inverted more easily.

EVALUATE

Teacher Material: [Build and Test a Wind Tunnel Presentation](#)

Slide 21: Conduct the Summative Assessment.

Summative Assessment

An important aspect of engineering design is presenting findings. In their small groups, ask students to prepare a 5-minute presentation to include the following regarding their airfoil tests:

- Performance of their airfoils
- Limitations encountered
- Errors made
- Ideas for improving the design of their airfoils
- Ideas for improving the testing methods

Encourage students to use their data to support their statements on the topics above.

Summative Assessment Scoring Rubric

- Follows assignment instructions
- Presentation shows evidence of one or more of the following:

- Knowledge of the various types airfoils tested and how they performed
- Usage of airfoil terminology
- Responds to questions of audience and instructor
- Shows understanding of concepts covered in the lesson.

Points	Performance Levels
9-10	Consistently demonstrates criteria
7-8	Usually demonstrates criteria
5-6	Sometimes demonstrates criteria
0-4	Rarely to never demonstrates criteria

GOING FURTHER

If time allows, have students use the engineering design process to design and test their own airfoils. They could also set the airfoils to negative angles of attack and measure the decreases in lift.

STANDARDS ALIGNMENT

NGSS STANDARDS

NGSS STANDARDS

Three-dimensional Learning

- **HS-ETS1-1** - Analyze a major global challenge to specify qualitative and quantitative criteria and constraints for solutions that account for societal needs and wants.
 - Science and Engineering Practices
 - Asking Questions and Defining Problems
 - Constructing Explanations and Designing Solutions
 - Disciplinary Core Ideas
 - ETS1.A: Defining and Delimiting Engineering Problems
 - Crosscutting Concepts
 - Systems and System Models
 - Influence of Science, Engineering, and Technology on Society and the Natural World
- **HS-ETS1-2** - Design a solution to a complex real-world problem by breaking it down into smaller, more manageable problems that can be solved through engineering.
 - Science and Engineering Practices
 - Constructing Explanations and Designing Solutions
 - Disciplinary Core Ideas
 - ETS1.C: Optimizing the Design Solution
 - Crosscutting Concepts

- none
- **HS-ETS1-3** - Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.
 - Science and Engineering Practices
 - Constructing Explanations and Designing Solutions
 - Disciplinary Core Ideas
 - ETS1.B: Developing Possible Solutions
 - Crosscutting Concepts
 - Influence of Science, Engineering, and Technology on Society and the Natural World
- **HS-PS2-2** - Use mathematical representations to support the claim that the total momentum of a system of objects is conserved when there is no net force on the system. (NOTE: This standard is not explicitly used as math is not required to complete the exercise).
 - Science and Engineering Practices
 - Using Mathematics and Computational Thinking
 - Disciplinary Core Ideas
 - PS2.A: Forces and Motion
 - PS2.B: Types of Interactions
 - Crosscutting Concepts
 - System and System Models
- **HS-ETS1-4** - Use a computer simulation to model the impact of proposed solutions to a complex real-world problem with numerous criteria and constraints on interactions within and between systems relevant to the problem.
 - Science and Engineering Practices
 - Using Mathematics and Computational Thinking
 - Disciplinary Core Ideas
 - ETS1.B: Developing Possible Solutions
 - Crosscutting Concepts
 - Systems and System Models

COMMON CORE STATE STANDARDS

- **HSN-Q.A.2-3** - Reason quantitatively and use units to solve problems.
- **HSS-ID.B.5** - Summarize, represent, and interpret data on two categorical and quantitative variables.
- **HSN-Q.A.2-3** - Reason quantitatively and use units to solve problems.
- **HSS-ID.B.5** - Summarize, represent, and interpret data on two categorical and quantitative variables.

- **RST.9-10.1** - Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.
- **RST.9-10.2** - Determine the central ideas or conclusions of a text; trace the text’s explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.
- **RST.9-10.4** - Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.
- **SL.9-10.1.C** - Propel conversations by posing and responding to questions that relate the current discussion to broader themes or larger ideas; actively incorporate others into the discussion; and clarify, verify, or challenge ideas and conclusions.
- **WHST.9-10.2** - Write informative/explanatory texts, including the narration of historical events, scientific procedures/ experiments, or technical processes.
- **WHST.9-10.4** - Produce clear and coherent writing in which the development, organization, and style are appropriate to task, purpose, and audience.
- **WHST.9-10.6** - Use technology, including the Internet, to produce, publish, and update individual or shared writing products, taking advantage of technology’s capacity to link to other information and to display information flexibly and dynamically.
- **WHST.9-10.8** - Gather relevant information from multiple authoritative print and digital sources, using advanced searches effectively; assess the usefulness of each source in answering the research question; integrate information into the text selectively to maintain the flow of ideas, avoiding plagiarism and following a standard format for citation.
- **WHST.9-10.9** - Draw evidence from informational texts to support analysis, reflection, and research.
- **HSN-Q.A.3** - Choose a level of accuracy appropriate to limitations on measurement when reporting quantities.

REFERENCES

<https://www.fi.edu/history-resources/wind-tunnel>
<https://wright.nasa.gov/airplane/tunnel.html>
<http://www.dynamicflight.com/aerodynamics/airfoils/>
<https://www.grc.nasa.gov/www/k-12/airplane/incline.html>

LESSON 2

BUILD AND TEST A WIND TUNNEL

Teaching Aid

GRADE 9: Launching Into Aviation
UNIT 2 Taking Flight—Early Aviation Innovations
SECTION D Powered, Controlled Flight

BUILD AND TEST A WIND TUNNEL**BUILD A WIND TUNNEL****MATERIALS (Per Wind Tunnel)**

- Large pieces of cardboard cut into the following pieces
 - Four (4) 21" x 25" x 8" (these are for the intake)

These pieces will be in the shape of a trapezoid. Your dimensions might vary based on the size of your fan. In this case, a 21" square frame fan was used. Adjust the longer parallel side of the trapezoid to fit your fan. The shorter parallel side should always be 8", the size of your tunnel. The angled sides of the trapezoid panel will be shorter or longer based on the size of your fan. Have the students calculate that distance as a geometry exercise, if you wish.
 - Four (4) 40" x 8" (these are for the tunnel)
 - Four (4) 10" x 7" (these are to provide support under the tunnel)
- Box fan (highest powered fan available)
- Box knife
- Metal straight edge
- Measuring tape/ruler
- Drinking straws (recommend using jumbo size)
- One (1) 8" x 10" piece Lexan/Plexiglass (can be purchased pre-cut at a major hardware store)
- Duct tape
- Hot glue gun and glue sticks
- Digital scale (measures to 0.1g, at a minimum)
- Safety glasses

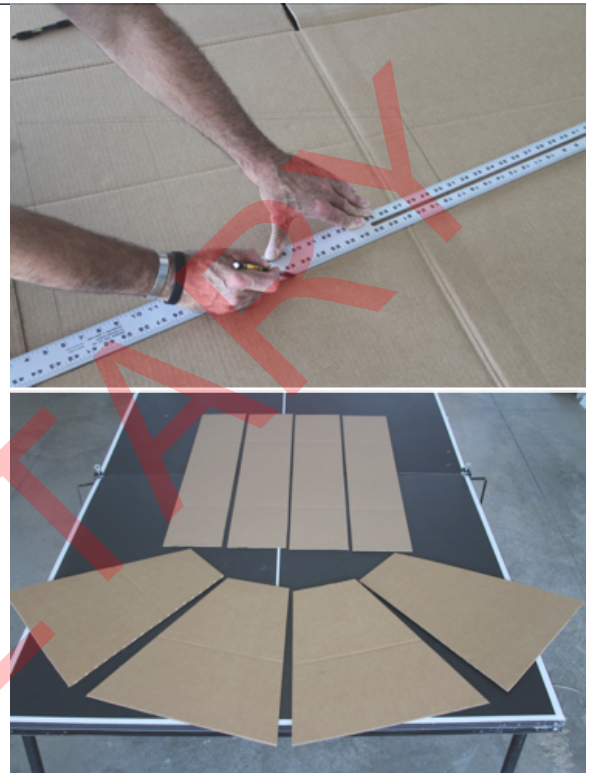
SAFETY

- Actively supervise students during the activity. Be ready to offer guidance in situations where safety could be compromised.
- Make sure students use eye protection. Have insulated gloves available for handling hot objects, and pads for setting down objects with heated surfaces.
- Explain how to safely store sharp objects on an active workspace when they are not in use. Students should not be holding sharp objects or tools when they are not in use.
- Sharp tools should be stored in their protective cases as soon as you finish using them.



1

Measure and cut the pieces of cardboard.



2

Duct tape three of the four 40" x 8" tunnel pieces together on the long edges. Leave one edge untaped.



3

On one end of the 40" x 8" tunnel, glue the straws down using hot glue. The straws will straighten the turbulent airflow coming from the fan. Using jumbo straws will reduce the time needed to complete this step and produce the same results.





4

On the top (untaped) 40" x 8" tunnel flap, cut a hole for the sheet of Lexan. Ensure the hole is smaller than the area of the Lexan so it can be taped in place from the outside and not fall through the hole (e.g., 8" x 10" Lexan = 7-1/2" x 9-1/2" hole).



5

Tape the last 40" x 8" tunnel piece into place to make a square tube. Tape the Lexan onto the tunnel from the outside.





6

Tape the four trapezoid-shaped cardboard pieces for the intake together, and then tape them around the fan. Ensure that you seal the area around the fan with duct tape as best you can.



7

Make two support stands to hold up the tunnel using the four 10" x 7" pieces of cardboard. Cut a slit halfway down each piece and slide them together to make an "X".



8

Duct tape or hot glue the stands to the bottom of the tunnel.



9

Duct tape the tunnel to the intake.



LESSON 2

BUILD AND TEST A WIND TUNNEL

Student Activity

GRADE 9: Launching Into Aviation
UNIT 2 Taking Flight—Early Aviation Innovations
SECTION D Powered, Controlled Flight

BUILD AND TEST A WIND TUNNEL



BUILD AND TEST AIRFOILS

Name _____

Class _____

You have been learning about the Wright Brothers and their decision to measure the lift and drag on their various airfoils using a simple wind tunnel. They built airfoils, tested them, recognized areas for improvement, and then re-tested the designs. They were the first to use this process to systematically test their theories and design their gliders and airplanes.

WHAT IS AN AIRFOIL?

An airfoil is a wing shape that when moved through a fluid (air) produces an aerodynamic force. Airfoils are used as the basic form of the wings, fins, and horizontal stabilizers of most aircraft.

1. Write the definition of the following:

1a. Trailing Edge _____

1b. Leading Edge _____

1c. Chord _____

1d. Angle of Attack _____

1e. Thickness _____

1f. Mean Camber _____

1g. Max Camber _____

1h. Symmetrical Airfoil _____

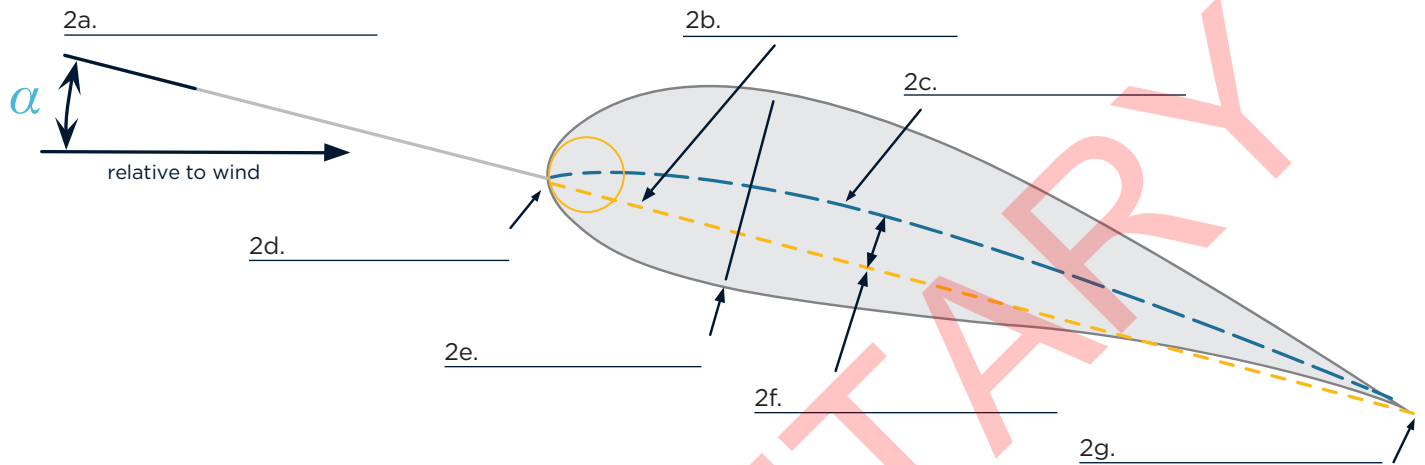
1i. Asymmetrical Airfoil _____

1j. Planform _____

1k. Span _____



2. Label the parts of the airfoil.



Characteristics of an airfoil that influence lift

3. Curved surfaces produce more lift than _____ surfaces.
4. Curved surfaces also produce more drag. They learned that a curved surface with a _____ is ideal.
5. Airfoils with the curve closer to the _____ produce more lift.
6. Airfoils that are _____ and _____ create more lift.
7. _____ airfoils create lift at zero angle of attack.

BUILD AND TEST

In small groups, you will build two airfoils out of foam board. Each group will build one symmetrical airfoil of a given chord and span, and one asymmetrical airfoil of a given chord and span. You will test the airfoils in your new wind tunnel to determine which airfoil creates more lift.

Both of your airfoils will have a chord of 6" and a span of 5-1/4".

Finally, you will summarize the results of your airfoil test and present your findings to the class.

MATERIALS (per group)

- Airfoil Mount (assume each group builds one airfoil mount to test both airfoils)
 - Foam board pieces (recommend using standard white foam board from Dollar Tree)
 - One (1) 6" x 6"
 - Eight (8) 1" x 3"
 - Wire (can be from a wire hanger)
 - Three (3) 7-1/2" pieces of wire



- Symmetrical Airfoil
 - Foam board pieces
 - One (1) 16" x 5-1/4"
 - Three (3) 5-1/4" x 1"
- Asymmetrical Airfoil
 - Foam board pieces
 - One (1) 16" x 5-1/4"
 - Three (3) 5-1/4" x 1"
- Airfoil of Student's Own Design
 - Foam board pieces
 - One (1) 16" x 5-1/4"
 - Three (3) 5-1/4" x 1"
- Box knife
- Metal straight edge
- Measuring tape/ruler
- Hot glue gun and glue sticks
- Pliers/wire cutter
- Protractor
- Safety glasses

SAFETY

- Use eye protection.
- Have insulated gloves available for handling hot objects, and pads for setting down objects with heated surfaces.
- Do not hold sharp objects or tools when they are not in use.
- Sharp tools should be stored in their protective cases as soon as you finish using them.

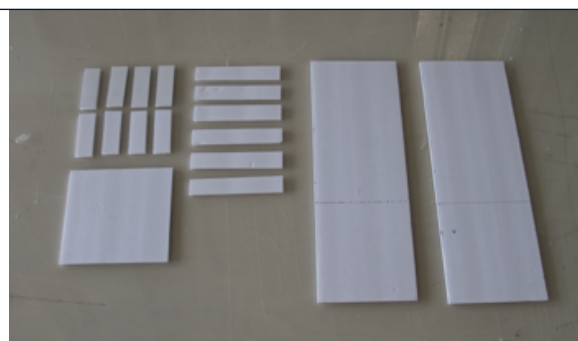
1

Gather all materials.



2

Measure and cut the foam board pieces needed for the airfoil mount and both airfoils.



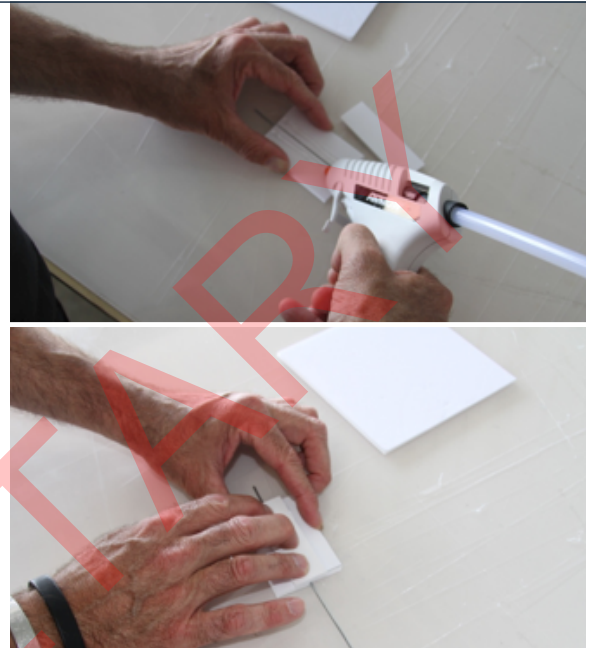


3

AIRFOIL MOUNTBuild the two side structures for the airfoil mount.

Put one of the pieces of wire between two of the 1" x 3" pieces of foam. You are not gluing the wire to the pieces; it is just providing a spacer. You will pull the wire out once the side structure is assembled.

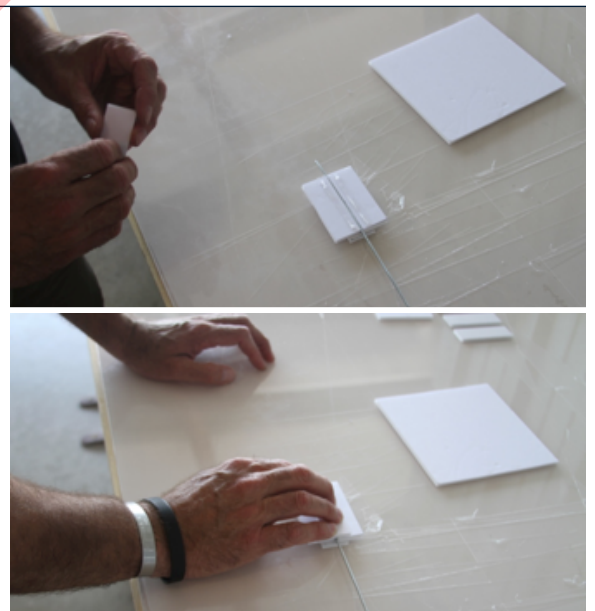
Apply hot glue to the inside of both foam pieces and center another 1" x 3" piece of foam on top. Press down and let the glue cool.



4

AIRFOIL MOUNTBuild the side structures for the airfoil mount.

Flip the side structure over and repeat the process on the other side. Ensure the hot glue is allowed to cool.



5

AIRFOIL MOUNTBuild the side structures for the airfoil mount.

Once all four pieces are glued together, pull the wire out.





6

AIRFOIL MOUNT

Build the side structures for the airfoil mount.

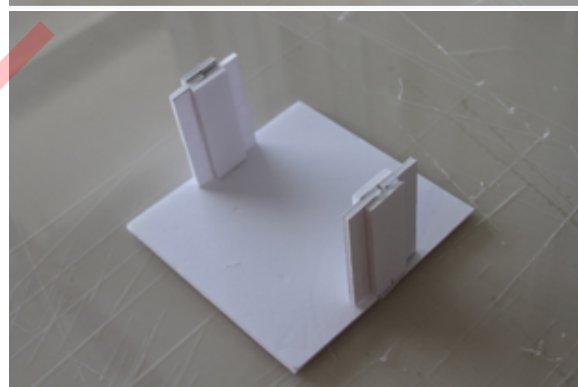
Repeat steps 3 through 5 to build a second side structure.

7

AIRFOIL MOUNT

Mount the side structures to the base.

Find the midpoint of one side of the 6" x 6" foam base and glue one of the side structures to the base vertically. Repeat this process on the opposite side of the base.



8

AIRFOIL MOUNT

Prepare the support wires.

Use the pliers to bend two of the 7-1/2" wires at a 90 degree angle. The angle should be made 2-1/2" from one end, leaving 5" remaining for the longer side of the "L" shaped result.





9

SYMMETRICAL AIRFOIL

Locate one of the 16" x 5-1/4" pieces of foam board. From one end of the board, draw three lines at the following measurements:

5-5/8"

6"

6-3/8"



10

SYMMETRICAL AIRFOIL

Use the metal straight edge and the box knife to SCORE the three lines. Scoring a line means that you just cut a very shallow line in the paper which guides the fold. DO NOT cut all the way through the foam board. Use minimal pressure to cut a very shallow line.

Score all three lines that you just drew.



11

SYMMETRICAL AIRFOIL

Very carefully and slowly, peel off the top layer of paper from the foam board. DO NOT peel the paper between the lines you just scored. Only peel the paper from the top and bottom portions of the board.





12

SYMMETRICAL AIRFOIL

Use the metal straight edge to help you bend the airfoil around the lines you scored. Complete this task gently and remember the design of a symmetrical airfoil is that both the upper and lower surfaces are identical.



13

SYMMETRICAL AIRFOIL

Continue to work and fold the airfoil evenly using your hands.

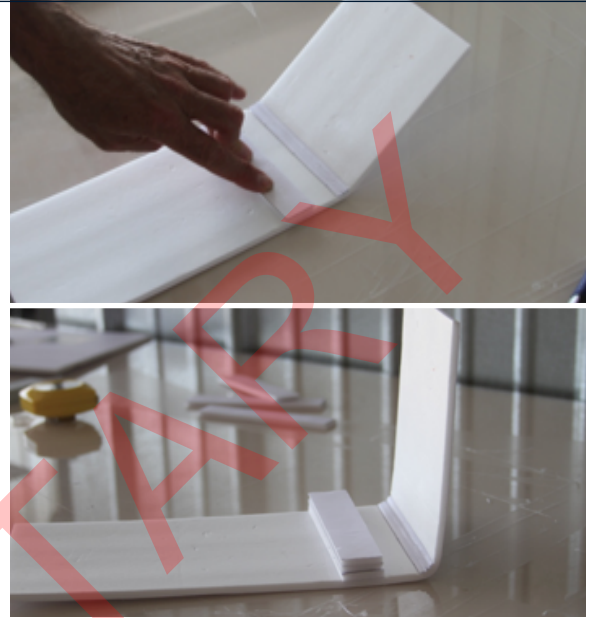




14

SYMMETRICAL AIRFOIL

Glue the three pieces of 5-1/4" x 1" foam board to the LONG piece of your board. Glue the pieces 1" below the scored line.



15

SYMMETRICAL AIRFOIL

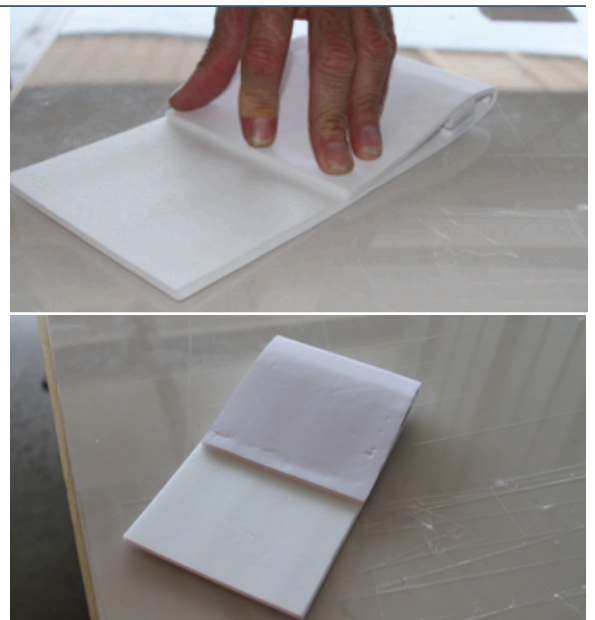
Once all three 5-1/4" x 1" pieces of foam board are stacked and glued together, apply glue to the top piece and fold the end over. Hold pressure until the glue has cooled.



16

SYMMETRICAL AIRFOIL

Apply glue just under the trailing edge of your airfoil and apply pressure until the glue has cooled.





17

SYMMETRICAL AIRFOIL

Using the straight edge, cut to remove the excess material behind the trailing edge.



18

SYMMETRICAL AIRFOIL

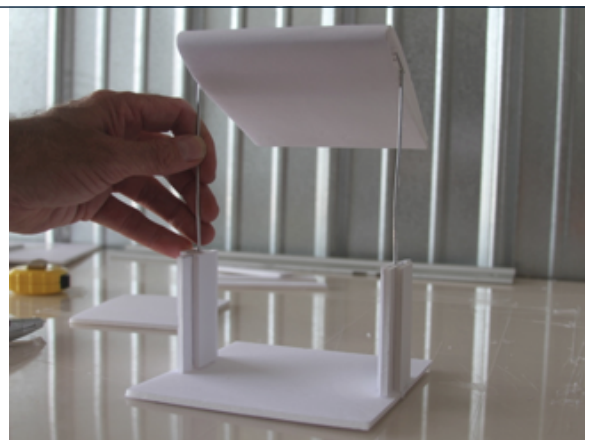
Insert the support wires into each end of the airfoil as shown. Insert the end of the wire that is 2-1/2" long into the center of the middle piece of 5-1/4" x 1" foam.



19

SYMMETRICAL AIRFOIL

Insert both wires down the middle of the side support structures of your airfoil mount.



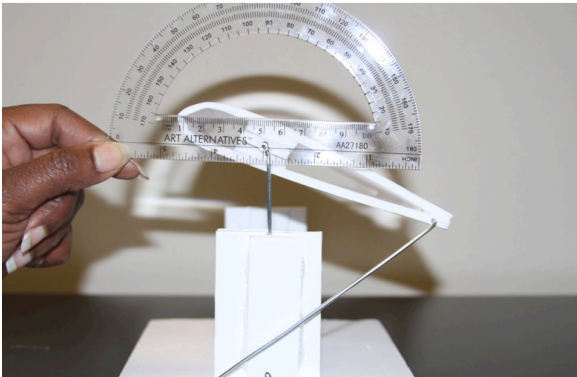
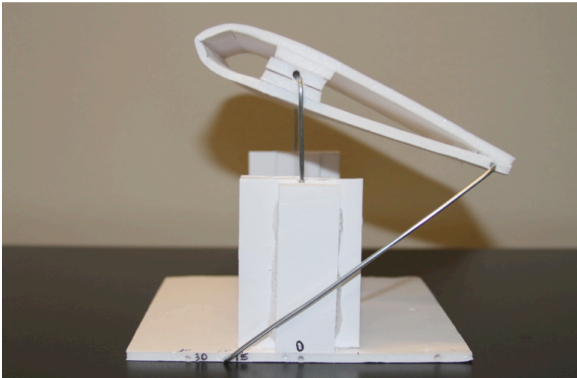
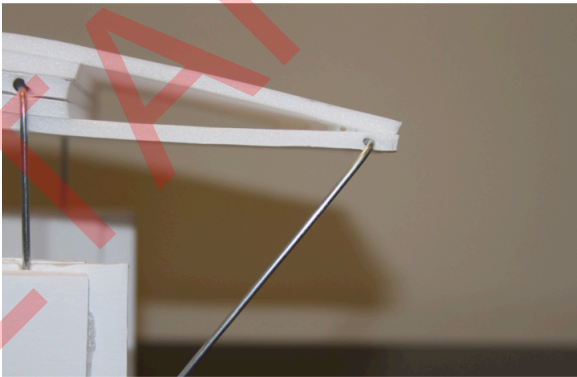


20

SYMMETRICAL AIRFOIL

Bend the third 7-1/2" piece of wire at both ends. Insert one end of the wire into the trailing edge of your airfoil.

Using the protractor, measure 0, 15, and 30 degrees angle of attack. Insert the wire into the base of the airfoil mount that corresponds with the 3 different angles of attack.



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21

ASYMMETRICAL AIRFOIL

Using the second 16" x 5-1/4" board, draw one line 6" from one end of the board.

Score that line and peel off the paper on just the smaller end of the airfoil piece as shown. Once again, be sure to not score the line too deeply.



22

ASYMMETRICAL AIRFOIL

Using the metal straight edge, bend JUST THE SMALLER END OF THE airfoil up. Bend it all the way over the straight edge.



23

ASYMMETRICAL AIRFOIL

Continue to work the fold with your hands.





24

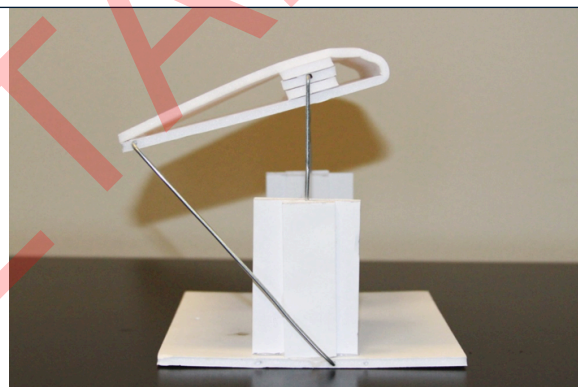
ASYMMETRICAL AIRFOIL

As in step 14, glue the three 5-1/4" x 1" pieces of foam board to the longer section, 1" from your scored line.

25

ASYMMETRICAL AIRFOIL

As in step 20, set the airfoil to 0, 15, and 30 degrees angle of attack.





TEST YOUR AIRFOILS

8. Before you test the airfoils, hypothesize which airfoil will create more lift. How will angle of attack influence the lift created? Explain your reasoning.

To measure the lift of the airfoils, you will note the weight the airfoil assembly exerts on a digital scale before the wind tunnel is on and while the wind tunnel is on.

Take the following steps to measure lift:

1. Place the digital scale inside the wind tunnel.
2. Ensure the digital scale has been “zeroed” out.
3. Place the airfoil mount and the symmetrical airfoil on the scale.
4. Looking through the viewing window, take note of the weight in grams (to the tenth or hundredth) before the wind tunnel is turned on.
5. Turn on the wind tunnel (ensure the fan is at the highest power setting).
6. After a few moments, take note of the new weight in grams (to the tenth or hundredth).
7. Subtract the weight found in step 6 from the weight found in step 4 to determine the amount of lift generated.
8. Repeat these steps for both airfoils and the different angle of attacks.

	ANGLE OF ATTACK	WEIGHT IN GRAMS BEFORE	WEIGHT IN GRAMS DURING THE TEST	LIFT GENERATED (G)
SYMMETRICAL AIRFOIL	0 degrees			
	15 degrees			
	30 degrees			
ASYMMETRICAL AIRFOIL	0 degrees			
	15 degrees			
	30 degrees			



9. Which airfoil produced the most lift? Explain why.

10. Which airfoil produced the most lift for a given angle of attack? Why?

11. Go back to your wind tunnel with your asymmetrical airfoil. Mount the airfoil upside down so that the cambered side of the airfoil is facing the scale. Place the entire airfoil mount on the scale with the leading edge pointed towards the fan. Note the weight again before turning on the fan. What happens to the weight once the wind tunnel is turned on? Why?

12. What would you expect if we did the same exercise with the symmetrical airfoil?

Share your findings

13. An important aspect of engineering design is presenting your findings. Put together your results to share with the rest of the class. Be prepared to describe what limitations you encountered, errors you made, and ideas you have for improving the design of your airfoils and improving the testing methods.

LESSON 2

BUILD AND TEST A WIND TUNNEL

Power Point Presentation

GRADE 9: Launching Into Aviation
UNIT 2 Taking Flight—Early Aviation Innovations
SECTION D Powered, Controlled Flight



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PROPRIETARY

UNIT 2 | SECTION D | LESSON 2 | PRESENTATION

BUILD AND TEST A WIND TUNNEL

LEARNING OBJECTIVES

By the end of this lesson, students will be able to:

- Describe the scientific process the Wright Brothers used to solve the power, control, and lift problems they encountered.
- Differentiate between airfoil designs and identify their strengths and weaknesses.
- Analyze data from wind tunnel tests to determine which airfoil designs created the greatest lift.
- Synthesize the results of the wind tunnel test.



WARM-UP

Watch a video of Boeing's 737 MAX winglets in a wind tunnel.



VIDEO

Write 2-3 sentence answers for each of the following questions:

Why are wind tunnels used to design aircraft?

What are wind tunnels used to measure?

What other industries besides aviation use wind tunnels to test designs?



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CHECKING THE DATA

- In their quest to build the flyer, the Wright brothers had been using the aerodynamic data of Otto Lilienthal and other early glider pioneers.
- The brothers realized their gliders were only producing a fraction of the lift predicted by Otto Lilienthal's previous experiments.
- They decided it was time to do their own aerodynamic research.

$$\text{Lift} = C_L \times \frac{1}{2} \rho v^2 S$$

Diagram illustrating the lift equation with labels:

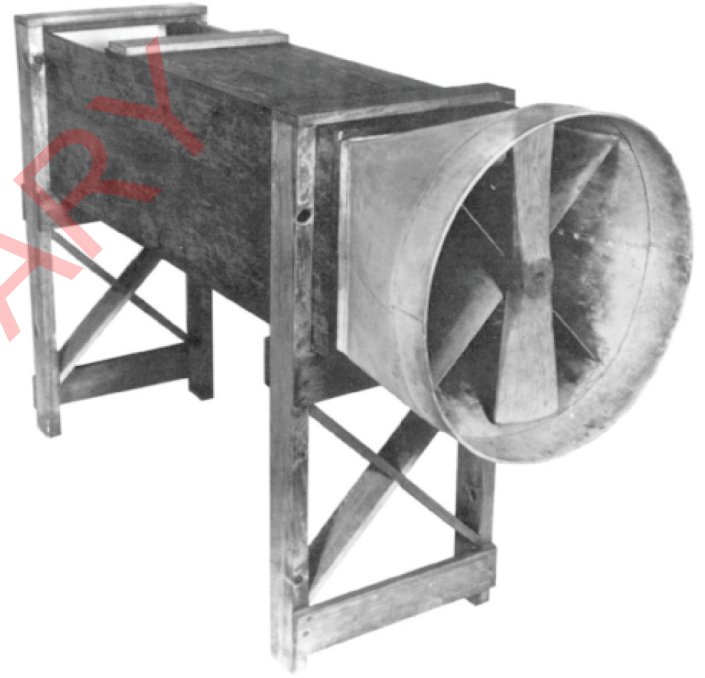
- C_L : Angle of Attack (red line)
- C_L : wing shape (purple line)
- ρ : density (green line)
- v : speed (red line)
- S : wing surface area (blue line)



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FIRST WIND TUNNEL

- In order to improve on their designs, the Wright brothers built a wind tunnel and were the first to use a series of engineering practices to test, analyze, and improve their airfoil designs.
 - manages airflow around stationary object
 - helps control variables that may impact results of testing
- The wind tunnel consisted of a simple wooden box with a square glass window on top for viewing during testing. A fan, belted to a one-horsepower engine, provided airflow of about 30 miles per hour.



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BUILD YOUR OWN WIND TUNNEL!

You and your classmates are going to build your own wind tunnel.

Later in the lesson you will also build your own airfoils to test in the tunnel.

Be sure to construct the wind tunnel correctly so that the airfoil testing is possible.

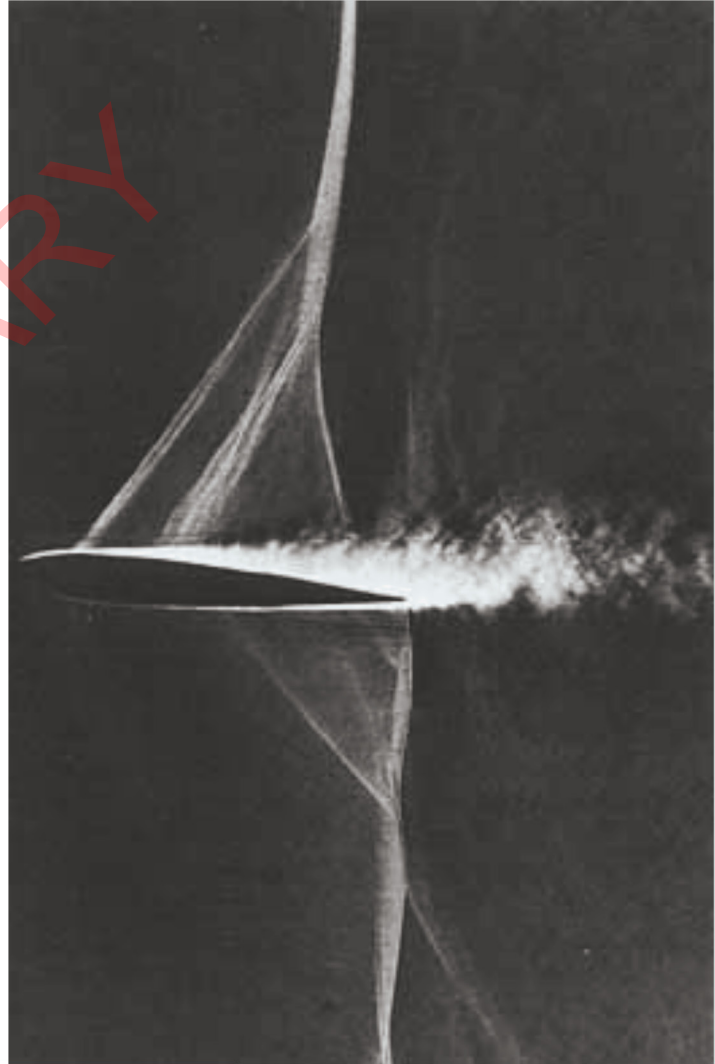


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WHAT IS AN AIRFOIL?

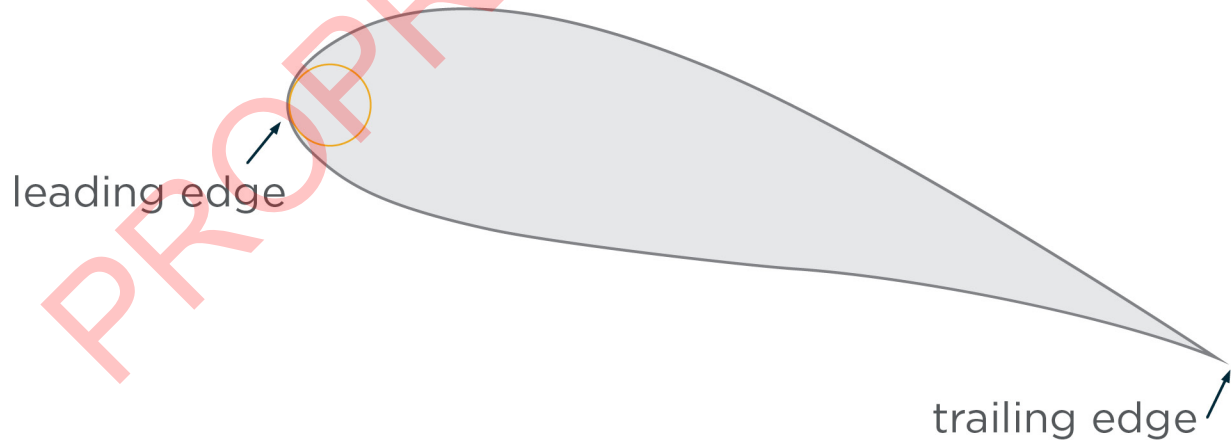
- **A wing shape that when moved through a fluid (air) produces an aerodynamic force**
- **Airfoils are used as the basic form of the wings, fins, and horizontal stabilizers of most aircraft**

PROPRIETARY



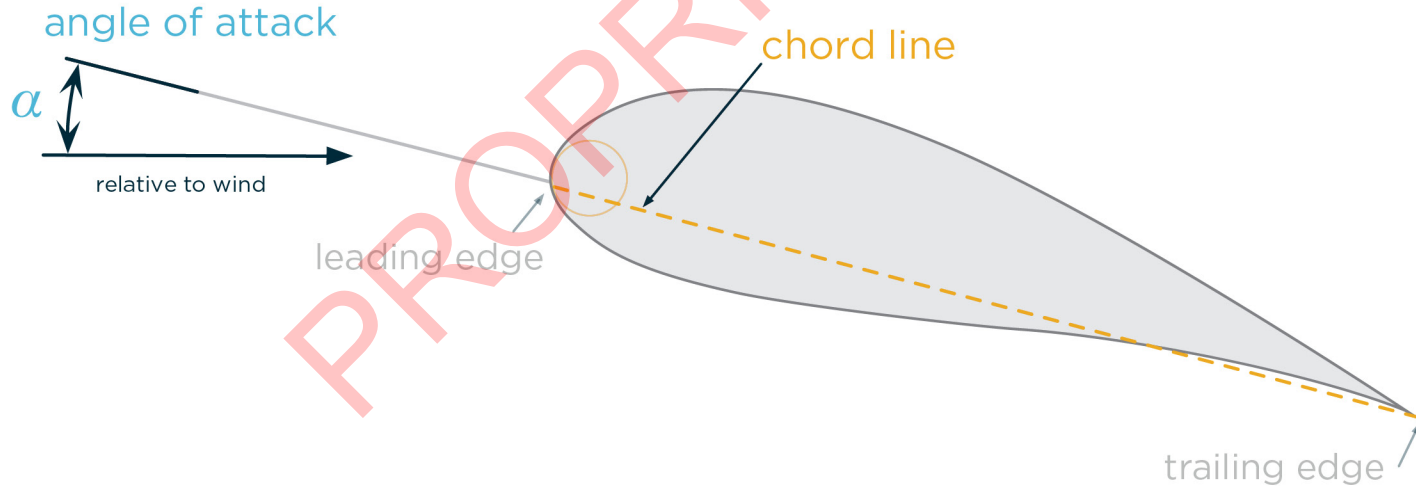
AIRFOIL TERMINOLOGY

- **Leading Edge** - first place air makes contact with the airfoil
- **Trailing Edge** - last place air makes contact with the airfoil



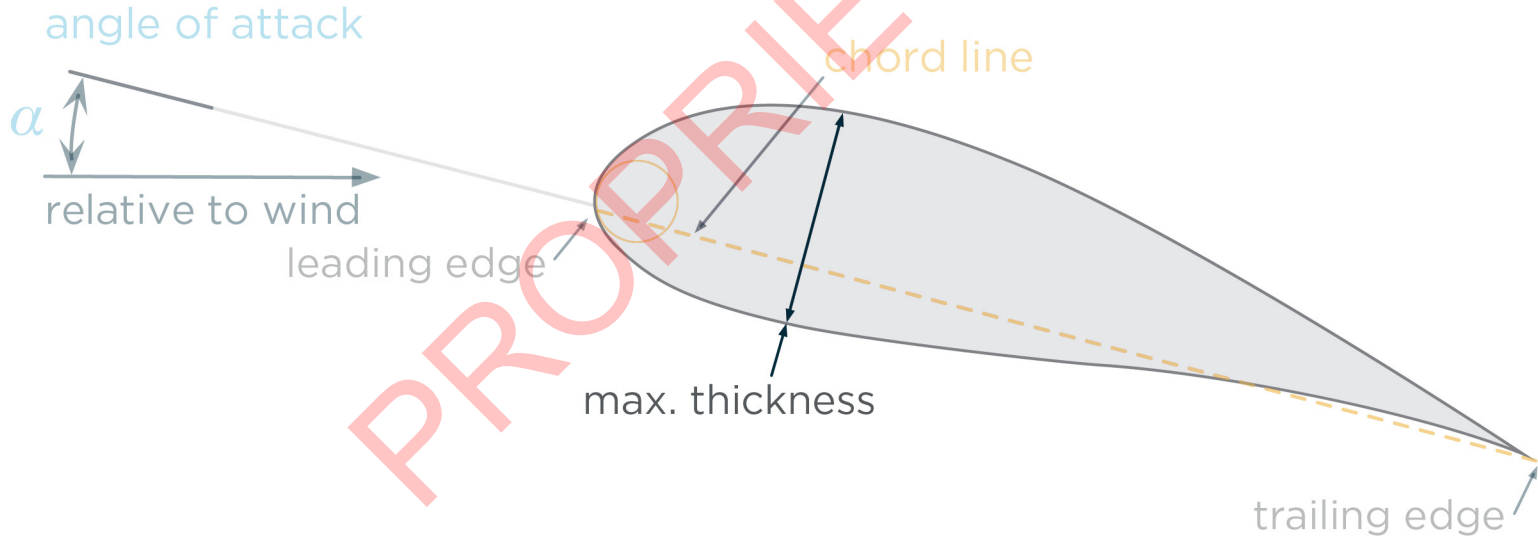
AIRFOIL TERMINOLOGY

- **Chord** - straight line that connects the leading edge to the trailing edge.
- **Angle of Attack** - angle between the chord line and the relative wind flow. If the leading edge of the airfoil is higher than the trailing edge, then the airfoil has a positive angle attack



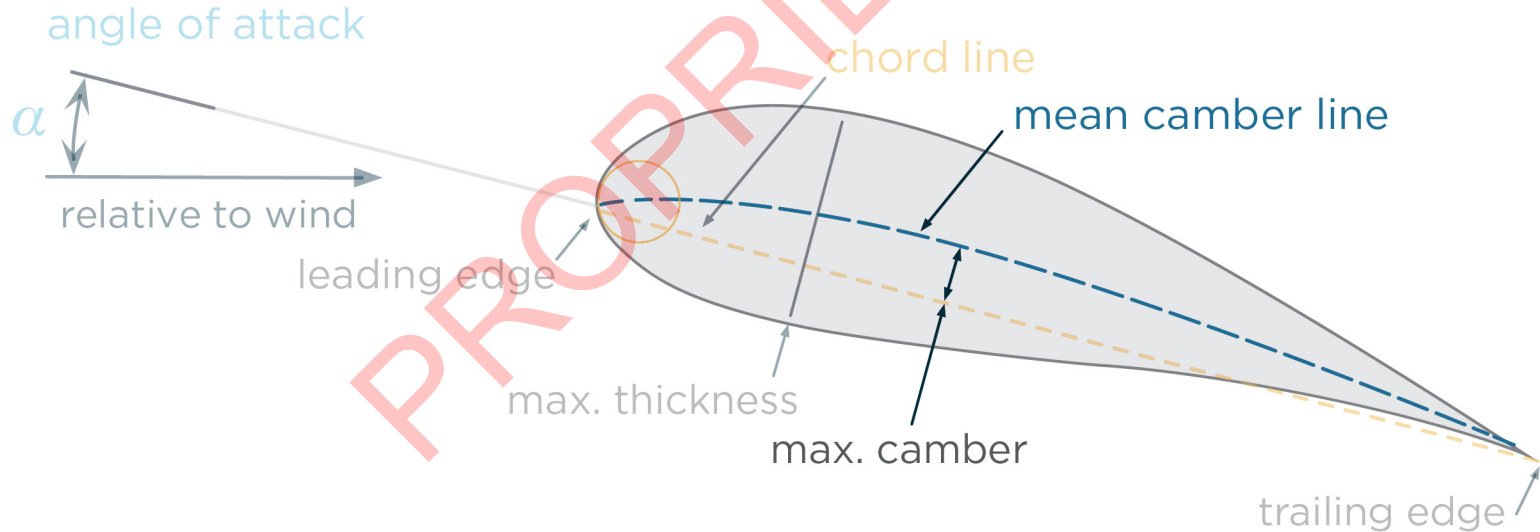
AIRFOIL TERMINOLOGY

Thickness - maximum distance between the upper and lower wing surfaces



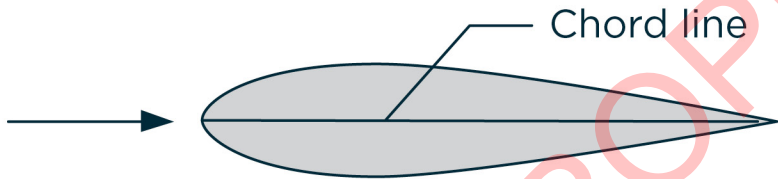
AIRFOIL CURVATURE

- **Camber** – the curve of the wing
 - The mean camber is a line drawn between the leading and trailing edge so that the distance between the upper and lower surfaces is equal
- **Max Camber** – measured where there is maximum distance between the chord line and the mean camber line



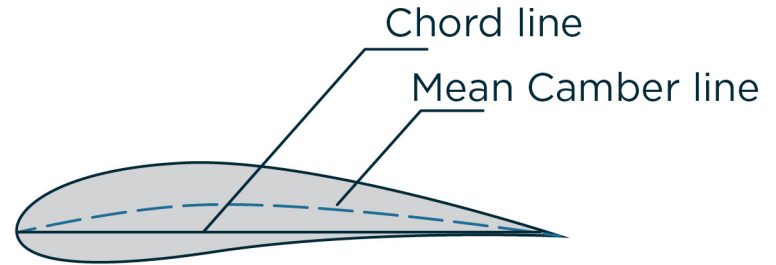
AIRFOIL SHAPES

Symmetrical Airfoil - the upper and lower surfaces of the airfoil are identical. The chord line and the mean camber line directly overlap one another.



Symmetric airfoil
Camber line = chord line

Asymmetrical Airfoil - the upper surface is more curved. The mean camber line is above the chord line.



Asymmetric airfoil
Camber line above chord line

CLASS DISCUSSION

**ASYMMETRICAL OR CAMBERED AIRFOILS
GENERALLY PRODUCE MORE LIFT.
BUT WHAT KIND OF AIRPLANE WOULD BENEFIT
FROM A SYMMETRICAL WING?**



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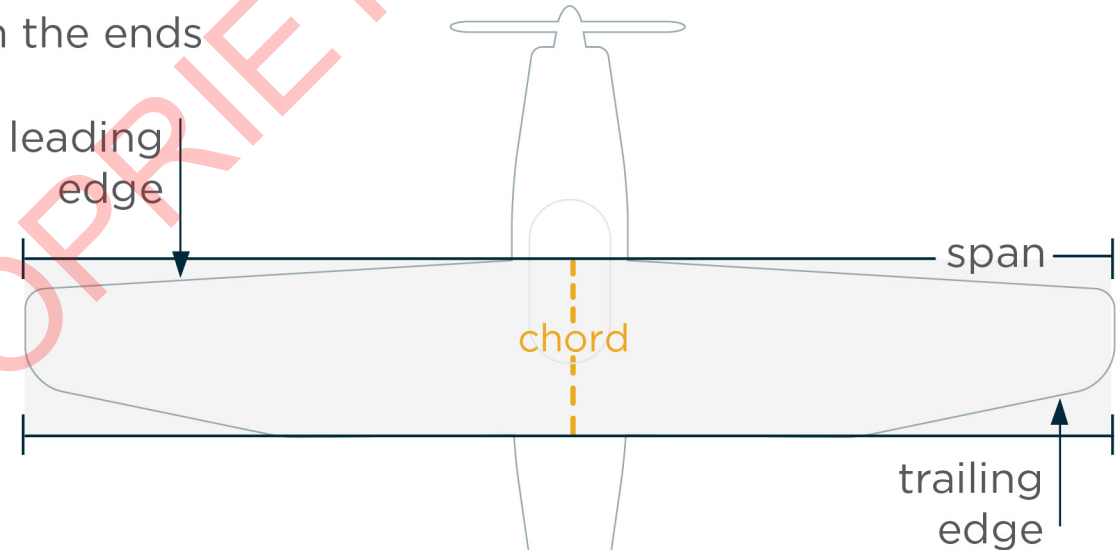


AIRFOIL TERMINOLOGY

Planform - the shape of the airfoil when viewing from above

Chord - the length from the trailing edge to the leading edge

Span - the length between the ends of the wingtips



WHAT THE WRIGHT BROTHERS LEARNED

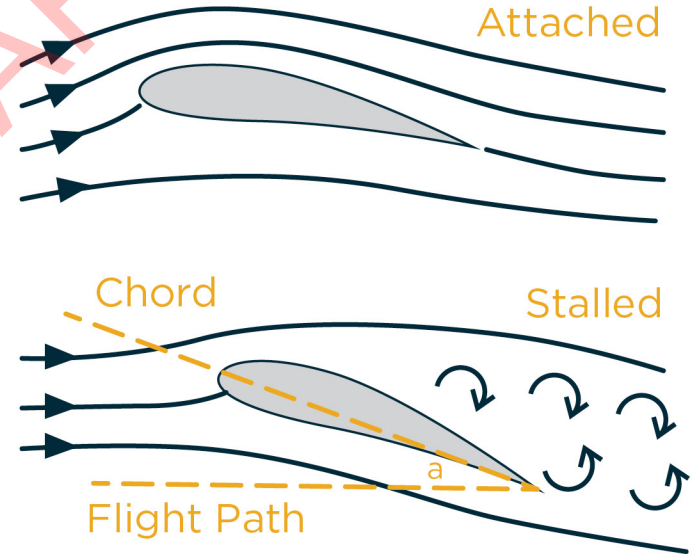
- **By testing more than 200 airfoils, the brothers learned very important factors that influence lift.**
 - Curved surfaces produce more lift than flat surfaces.
 - Curved surfaces also produce more drag; they learned that a curved surface with a small camber was ideal for maximizing lift.
 - Airfoils with the curve closer to the leading edge produce more lift.
 - Airfoils that are thin and long create more lift.
 - Cambered airfoils will create lift at zero angle of attack.



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HOW DOES ANGLE OF ATTACK AFFECT LIFT?

- **Lift is directly affected by angle of attack.**
 - As the angle of attack increases, so too does the lift produced by the airfoil.
 - This is true until the critical angle of attack is reached.
- **At the critical angle of attack, the boundary layer of air separates from the airfoil and creates drag.**
 - This is called an “aerodynamic stall”.



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BUILD YOUR OWN AIRFOILS

- **Working in small groups, you will build two airfoils of a predetermined span and chord.**
 - One symmetrical airfoil
 - One asymmetrical airfoil
- **Then you will test your airfoils to determine which produces more lift.**
 - If time allows, you can use engineering practices to design and test your own airfoil design.

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FORMATIVE ASSESSMENT

In groups of two to three students, explain which type of aircraft would be better suited for:

- symmetrical airfoil
- asymmetrical airfoil

Submit a short summary for each type of airfoil.

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SUMMATIVE ASSESSMENT

An important aspect of engineering design is presenting findings.

In your small groups, prepare a five minute presentation to include the following regarding your airfoil tests:

- **Performance of your airfoils**
- **Limitations encountered**
- **Errors made**
- **Ideas for improving the design of your airfoils**
- **Ideas for improving the testing methods**



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UNIT 2 | SECTION D | LESSON 2 | PRESENTATION

BUILD AND TEST A WIND TUNNEL