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 generated 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

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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