National Aeronautics and Space Administration

STEM LEARNING:

Explore Flight: Wind Tunnels Educator Guide (6-8)

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EXPLORE FLIGHT: WIND TUNNELS (6-8)

In this lesson, students use what they know about the four forces of flight to participate in an engineering design challenge to design, build, and test a model plane in a simple wind tunnel made from a long cardboard box and fan. They will be asked to evaluate their final design and that the designs of their classmates, and then present their final design to the class.

Objective

Students will be able to:

- Describe how a wind tunnel helps aeronautics engineers test aircraft designs
- Work in teams using the engineering design process to design, build, and test a model aircraft
- Propose a final design and support their proposal with evidence and reasoning

Student Prerequisite Knowledge

Before beginning this lesson, students should be familiar with:

- The four forces of flight
- A basic understanding of aerodynamics
- The engineering design process

Standards

Disciplinary Core Ideas

- MS-PS2-2: Motion and Stability: Forces and Interactions

Croscutting Concepts

- Systems and System Models
- Structure and Function
- Stability and Change

Science & Engineering Practices

- Developing and Using Models
- Analyzing and Interpreting Data
- Constructing Explanations and Designing Solutions
- Engaging in Argument from Evidence
- Obtaining, Evaluating, and Communicating Information

Materials

For the Wind Tunnel:

- Long rectangular cardboard box with the ends removed
- Small portable fan
- Tape
- Ruler
- Box cutter (optional)
- Saran wrap or other clear plastic (optional)

For the Aircraft Models:

- Tape
- Cardstock/cardboard
- Paperclips
- Scissors
- Cardboard tube (from toilet paper roll or paper towel roll)
- Popsicle sticks
- Foil
- Toothpicks

During the Activity

- Student handout(s)
- Scrap paper (optional)
- Timer/watch/smartphone

Preparation

- Print one handout for each student or student group.
- If using any of the "Supplemental Materials," print one per student or student group.
- Attach a ruler or meter stick to the inside of the cardboard box to measure how far the models move, or make markings on the inside of the box.

- Use tape to affix the long cardboard box to the floor or a flat surface.
- Place the fan in front of one end of the box and make a mark for where the fan will go for each student test.
- Create model kits for each group with the same amount of materials in each.
- If using the X-59 QueSST video as a warmup or engagement piece, link to or embed the "Low-Boom Flight Demonstration" video here: https://youtu.be/DPd0OHrmCBc
- If watching the background video together, link to, embed, or download the NASA eClips "Our World: Wind Tunnels in Action" video here: https://nasaeclips.arc.nasa.gov/video/ourworld/our-world-wind-tunnels-in-action or on YouTube: https://youtu.be/MksHQpIzui4

Other Considerations

Depending on the size and shape of your box, consider cutting out a viewing window so that students can see how far the model moves. To do this, use a box cutter to remove a square or rectangular portion of the box, then use saran wrap or another type of clear plastic (old overhead transparences work well) to cover the window and secure it with tape.

The "Supplemental Materials" give you the flexibility to personalize the activity to your classroom needs. The "Explore Flight: Wind Tunnel" reading is provided in student-friendly language and can be placed in plastic sheet protectors to distribute to each student for silent reading and marking up the text with dry erase markers, for example. You can use this reading to supplement or replace students doing their own research online, depending on your needs.

The "Quality Assurance" peer-review sheet can build in an extra layer of cooperative learning as students pair up with another group to give feedback at any point in the "create" phase of the design process. For example, before initial testing, before the final test after students have made improvements, or even after the final test when they are decided on what their final design proposal will be.

When making the model kits for students, the provided list is just a suggestion. There is no right amount of or variety of materials—use whatever you have on hand. The most important detail is that students use ALL of the materials to build their prototypes so that each aircraft model weighs the same when placed into the wind tunnel for testing. You can have an interesting discussion with students about why this is an important part of the competition.

Grouping Students

This activity guide can be completed either as a team or individually, as time and preference allows. Grouping strategies during the engineering design challenge can be used to efficiently break up tasks, help promote student engagement, and appeal to a variety of learning styles and student strengths. Here are some recommended group roles for this activity:

Project Manager – keeps the team on task, asks clarifying questions of the teacher, and is the team's spokesperson for class discussions.

Drafter/Sketch Artist – makes technical drawings of the proposed, built, and final design.

Technical Writer – records the answers to written questions, writes down test data, takes notes, and writes the final evidence and reasoning portions of the assignment (with input from the rest of the team).

Engineer – collects materials, coordinates the building of the initial and subsequent design(s), and consults earlier assignments/activities as needed to inform the design process.

Steps

1. Engage: Use a warm-up or other method to engage students in a discussion about the four forces of flight. Alternatively, show the "Low-Boom Flight Demonstration" video to engage students in thinking about what types of tools engineers use to test future aircraft designs.

2. Use page 1 of the Student Guide to guide students in learning about wind tunnels. Show the video, “Our World: Wind Tunnels in Action,” or have students watch it on their own.

3. Invite students to conduct internet research to find out more about wind tunnels and/or use the supplemental reading, “Explore Flight: Wind Tunnels.”

4. Host a class discussion to report out research results, and to ensure that every student has an understanding of what wind tunnels are and when they are used.

5. Introduce the design challenge to students, including criteria and constraints. Describe and assign group roles, if applicable.

6. Show students the wind tunnel and the materials they will have in their design kits.

7. Ask: Ask teams/students to generate questions. Have a brief discussion to answer them.

8. Imagine/Plan: Have students brainstorm and write about what airplanes look like and what makes something aerodynamic. Discuss their ideas with the class.

9. Optional: If students are having a hard time coming up with designs, you can pass out the “X-59 Specifications” diagram and have a brief discussion about what features make this design aerodynamic.
10. Give students only a few minutes to quick sketch some ideas for a design – the point is to get ideas

    flowing. If students are submitting one student packet, distribute additional scratch paper so that every student can sketch.

11. Have the group examine the designs, discuss the pros and cons of each, and pick one that they want to build and why.

12. Create/Test: Give students about 40 minutes to build, sketch, and test their first prototype.

13. Optional: during the create and test phase, you can also use the supplementary “Quality Assurance Check” handout to have student groups evaluate other groups’ designs.

14. After the first test, students can refine their designs if they have time in preparation for the final class test.

15. Have students present their models, then test one at a time and record their final results.

16. Improve: After the final test, give students time to answer questions about their own models and evaluate what features from the other models worked well. Inevitably, there will be groups that will want to modify and test another iteration. You can choose whether or not you have time for this.

17. Share: Have a final class discussion about what worked well and didn’t work well to make the planes as aerodynamic as possible.

18. Have students work on their final evaluation. Students should draw a final version of their proposed model, and use evidence from their individual and final tests and class discussion to explain why the features of the aircraft will work best as the solution. Evidence should be linked to reasoning about the four forces of flight, and how their designs work to overcome drag, provide lift, and explain any strengths or weaknesses of their design.

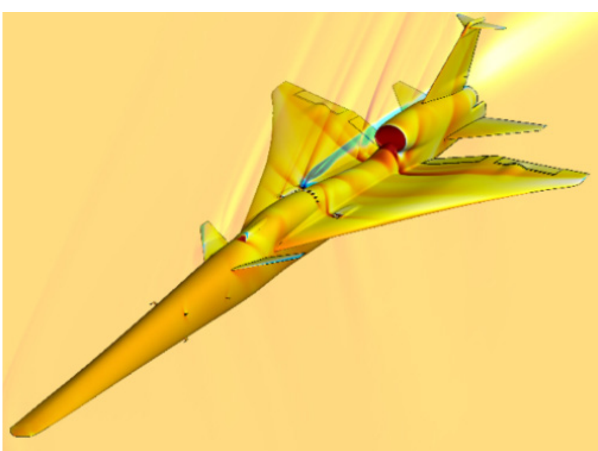
TEACHER BACKGROUND

The X-59 QueSST

For decades, NASA has been researching ways to make aircraft quieter—including reducing the noise associated with sonic booms. This body of research has led to NASA's newest X-plane—the X-59 Quiet Supersonic Transport, or QueSST. This aircraft is an engineering marvel (with innovative features that have been tested in wind tunnels and through computer modeling) that will reduce the sound of disruptive sonic booms to quieter "sonic thumps."

Starting in 2023, after rigorous flight testing, the X-59 will fly over communities in the United States to collect public opinion on the quieter sonic thumps. NASA hopes that sound data from the airplane's flights along with public survey data will help the FAA change the existing regulations that prohibit supersonic flight over land and will usher in a new era of commercial supersonic flight.

However, as chevron technology has matured, some newer designs have a less symmetrical shape. Figure C shows chevrons on the engine casing and the nozzle; the chevrons on the top of the casing are deeper than those on the bottom.



More About the X-59 QueSST

Low Boom Flight Demonstrator Mission:
https://www.nasa.gov/mission_pages/lowboom/index.html

How Wind Tunnels Work

Wind tunnels are machines for "flying" aircraft on the ground. They are tube-like structures or passages in which wind is produced, usually by a large fan, to flow over objects such as aircraft, engines, wings, rockets, or models of these objects. A stationary object is placed in the test section of a tunnel and connected to instruments that measure and record airflow around the object and the aerodynamic forces that act upon it. From information gathered in these observations, engineers can determine the behavior of an aircraft or its components at takeoff, while cruising, and during descent and landing.

Wind tunnels also help engineers determine the performance of, and eliminate "bugs" in, new designs of civil and military aircraft without risk to a pilot or costly aircraft. Responses to flight conditions of new materials and shapes for wings, ailerons, tails, fuselages, landing gear, power systems, and engine cowlings can be assessed before these designs are incorporated into aircraft.

Today, no aircraft, spacecraft, space launch, or reentry vehicle is built or committed to flight

Figure 1. *Computer modeling showing how the features of the X-59 QueSST aircraft reduce drag and therefore aircraft noise.*

until after its design and components have been thoroughly tested in wind tunnels. Every modern aircraft and space rocket has made its maiden flight in a wind tunnel. Wind tunnels have been among the key tools which have made U.S. aircraft and aeronautical equipment the most desired and most widely used in the world.

The National Aeronautics and Space Administration maintains the largest number and variety of wind tunnels ever operated by any single agency or company. NASA's 42 major wind tunnels vary in size from those large enough to test a full-size airplane to those with a test section only a few inches square where models as small as a match are tested.

Types of Wind Tunnels

According to NASA's official "Aeronautical Facilities Catalogue," which lists prime installations, 23 major wind tunnels are at the Langley Research Center in Hampton, Virginia, and 12 are at the Ames Research Center in Mountain View, California. Six others are at the Glenn Research Center in Cleveland, Ohio, and one is at the Marshall Space Flight Center in Huntsville, Alabama. In addition, there are a number of other wind tunnels located at these centers that provide additional test time, alleviate the load on the major wind tunnels, and provide precursor tests for the larger facilities.

Some of these tunnels are designed for the study of wing and fuselage shapes. Other wind tunnels are devoted either to testing propulsion systems or testing at various speeds. Airflow in a wind tunnel is produced and conditioned in several ways to simulate flight at the speeds, altitudes, and temperatures that would be encountered by particular kinds of aircraft. The speed of air flowing through a tunnel is usually expressed in terms of the speed of sound (760 mph at sea level). The ratio between the speed of airflow and the speed of sound is called a Mach number. At Mach 2, for example, the speed of a vehicle is twice the speed of sound (1,520 mph at sea level).

Some tunnels specialize in accelerating air only to subsonic speeds, which are slower than the speed of sound. Others reach transonic air speeds (slightly below, at, and above the speed of sound), supersonic speeds (much faster than the speed of sound), and hypersonic speeds (more than five times the speed of sound).

Some of NASA's wind tunnels are equipped with lasers for a technique called laser Doppler velocimetry. This is one of several new non-intrusive techniques that make possible precise determination of velocities with light beams. The light beams do not interfere with the airflow, as happens with measuring instruments that require a physical presence in the test chamber.

More About NASA's Wind Tunnels

NASA Langley Research Center Wind Tunnels:
https://www.nasa.gov/centers/langley/news/factsheets/WindTunnel.html

NASA Ames Research Center Wind Tunnels:
https://www.nasa.gov/centers/ames/orgs/aeronautics/windtunnels/index.html

The History of NASA's Wind Tunnels:
https://history.nasa.gov/SP-440/contents.htm

Free e-book, "Cave of the Winds," about NASA's Wind Tunnels:
https://www.nasa.gov/connect/ebooks/cave_of_the_winds_detail.html

Other Resources

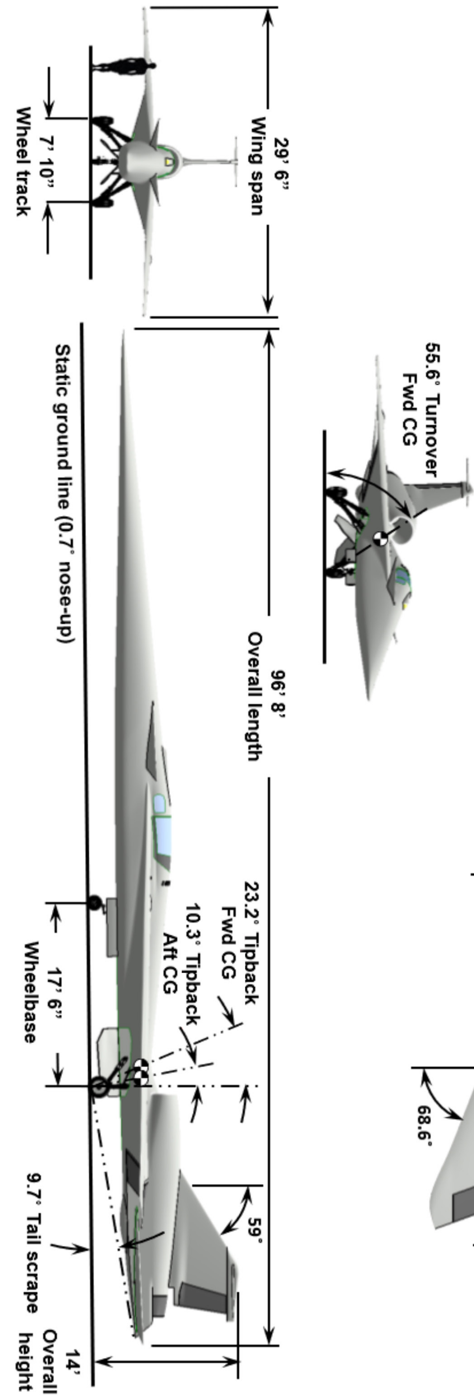
For more about NASA's BEST (beginning engineering science and technology) program, including teacher professional development resources and other engineering challenges, visit:
https://www.nasa.gov/audience/foreducators/best/index.html

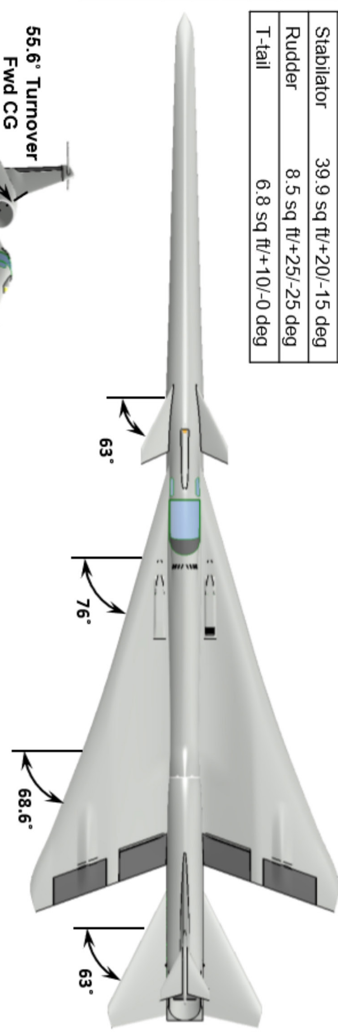
APPENDIX: SUPPLEMENTAL MATERIALS

X-59 SPECIFICATIONS

Configuration C611	
MDGW	24,300 lbs
ZFW	16,300 lbs
OEW	15,700 lbs
EW	14,990 lbs
Fuel	8,000 lbs
Payload	600 lbs
Design Mach	1.4
Loudness	<75 PLdB
Engine	1xF414-GE-100
Landing Gear	F-16 Blk25 NLG F-16 Blk25 MLG

Control Surfaces	
Aileron	12.8 sq ft/+35/-25 deg
Flap	13.1 sq ft/+30/-3 deg
Stabilator	39.9 sq ft/+20/-15 deg
Rudder	8.5 sq ft/+25/-25 deg
T-tail	6.8 sq ft/+10/-0 deg





EXPLORE FLIGHT: WIND TUNNELS

WHAT ARE WIND TUNNELS AND WHY DOES NASA USE THEM?

Sometimes scientists create a model to help them explain how or why something works the way it does. You may have seen model airplanes. These model airplanes are smaller than the real thing, and while the outside might look like the real thing, the inside does not. Many models are scale models. This means that every part of the airplane is made smaller by the same amount. Thus, a scale model is an exact copy of the real thing – only smaller.

A scale model can be used to test a researcher's hypothesis in a safe and controlled way. In aeronautics, researchers and engineers use models to design and modify airplanes.

Aeronautical researchers can make a scale model and mount it in a wind tunnel. A wind tunnel is a tube or tunnel through which air is blown. So, instead of an airplane flying through the air, a scale model of the airplane is mounted in a wind tunnel and air is blown around it.

Some wind tunnels are very large and can hold models that are the size of the real airplane. Some wind tunnels are very small and can only hold very tiny scale models of the airplane, or maybe a scale model of a part of the airplane. Some very small wind tunnels can blow air only at very high speeds (over 3,000 miles per hour), while some of the largest tunnels blow air at less than 150 miles per hour. This may sound slow, but this is near takeoff and landing speeds for many airplanes. So, these big wind tunnels are quite useful.

Keep Exploring

Watch this short video to see how engineers put together a small-scale model of NASA's newest X-plane, the X-59 QueSST, and placed it inside the 8- by 6-foot supersonic wind tunnel at Glenn Research Center in Cleveland, Ohio.
https://youtu.be/zwquWz4OrCw

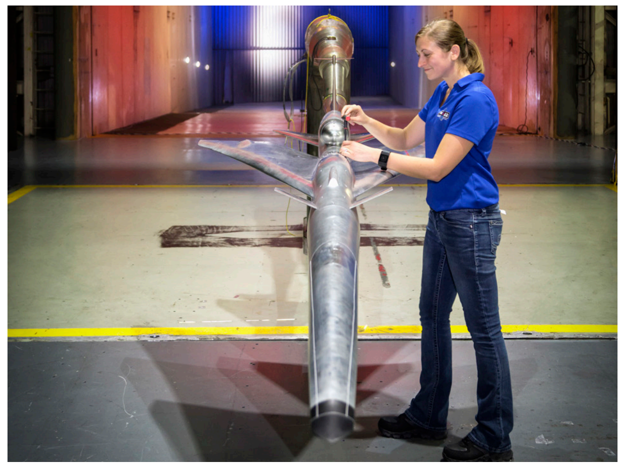


Figure 2. *Test Engineer Samantha O'Flaherty finalizes the set-up of the Quiet Supersonic Technology (QueSST) Preliminary Design Model inside the 14- by 22-foot subsonic wind tunnel at the NASA Langley Research Center.*

Figure 3. *An F/A-18 fighter aircraft in the giant 80- by 120-foot wind tunnel at the NASA Ames Research Center.*

QUALITY ASSURANCE CHECK

Collaborate with one other design team. Take turns reviewing the other team's design. Have **the other team** fill out the following design review.

Constraint	Yes	No
Did the team use **ALL** of the materials?		
Did the team use any additional materials?		
Are the model's wings less wide than the wind tunnel?		

What are the specific strengths of the design?

What are the specific weaknesses of the design?

What would you do to improve the design?

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