Hypersonics STEM Curriculum

Wind Tunnel Testing

Grade	Time	Subject Area	Key Concepts
6-8	75-90 min	Physical Science	Speed/velocity Atmosphere Ionization

Lesson Overview

In this lesson, students are presented a problem to solve. They are asked by the Navy to build a model aircraft body and test it in a wind tunnel. This lesson is designed to follow the Go with the Flow lesson but can also be done as a standalone lesson.

Depending on the set up of the class and available materials, each group could build their own wind tunnel (directions are included in the Wind Tunnel Testing handout) or a set of wind tunnels could be set up as stations around the classroom for groups to use as they are ready to test their prototypes. It may take longer to do the lesson if groups are sharing wind tunnels.

NGSS & CCSS Standards

MS-PS2-2 Plan an investigation to provide evidence that the change in an object's motion depends on the sum of the forces on the object and the mass of the object.

MS-ETS1-2 Evaluate competing design solutions using a systematic process to determine how well they meet the criteria and constraints of the problem.

MS-ETS1-4 Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved.

Learning Objectives

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

- Design, build, and evaluate an aircraft body model.
- Modify their original aircraft body prototype based on data they collected.
- Explain how the size of the net force, caused by different sizes of flow, effects their aircraft body prototypes motion.

Essential/Overarching Question

How can we better design the body shape of an aircraft that travels at hypersonic speeds?

Key Vocabulary

Speed – the rate at which an object is moving. Speed is calculated by dividing the distance travelled by the time it took to travel that distance.

Speed of Sound – the rate at which sound moves through a medium. The speed of sound depends on both the density and the temperature of the medium. The speed of sound through air at 20° C (68° F) at sea level is 343 m/s (767 mph).

Mach – the ratio of the speed of an object to the speed of sound or how many times the speed of sound an object is moving. It is often followed by a number indicating the ratio; for example: Mach 1 is the speed of sound, Mach 2 is twice the speed of sound, Mach 5 is five times the speed of sound.

Sonic – speeds equal to the speed of sound (Mach 1).

Subsonic – speeds smaller than the speed of sound (less than Mach 1).

Transonic – speeds near (Mach 0.8-1.2) the speed of sound where drag is highest (e.g. sound barrier).

Supersonic – speeds greater than the speed of sound (Mach 1 and greater).

Hypersonic – speeds greater than five times the speed of sound (Mach 5 and greater).

Fluid – a substance with no fixed shape; a liquid, gas, or plasma. A substance that flows when an external force is applied to it.

Flow – the motion of a fluid (liquid, gas, or plasma) when it experiences unbalanced forces.

Force – a push or a pull on an object or system.

Net Force – the vector sum of all forces acting on an object or system.

Wind Tunnel – a large tube with air moving inside. Wind tunnels are used to investigate air flow around an object placed in the passage.

Science Concepts Overview

When an object moves, at any speed, it moves through a fluid. A fluid can be any liquid or gas. In most cases, the object is moving through the air. As the object moves through the fluid, the fluid moves around the object. (This is also the case when the object is stationary, and the fluid is moving.) The motion of the fluid is called the flow.

As speeds increase, the flow becomes more of a factor in the movement of the object. For example, we typically do not notice the air moving around us as we walk, but we do when we are riding a bicycle or a skateboard. As objects move into supersonic and hypersonic speeds, understanding the flow becomes more important and largely factors into the design of the objects.

Wind tunnel testing is used to investigate how objects interact with flow. It can be used to simulate objects moving through a fluid, such as an aircraft moving though air, or a fluid moving around an object, such as wind moving around a building. Wind tunnel testing can be done on a smaller scale model, as we are doing, or with full size objects if the wind tunnel is large enough.

Materials List

- ☐ Cardboard (enough to make one wind tunnel per group)
- ☐ Clear plastic (overheads, sheet protectors, acrylic sheet, etc. – one per wind tunnel)
- ☐ Small fan with different speed settings (one per wind tunnel)
- ☐ Scissors
- ☐ Box Cutter (for teacher use)
- ☐ Tape (duct tape is best)
- ☐ Rulers (one per group)
- ☐ Goggles or other eye protection (one per student)
- ☐ An assortment of materials to build an aircraft body model (aluminum foil, cardstock, glue, tape, cardboard, popsicle sticks, balsa wood, foam, toothpicks, modeling clay, etc.)
- ☐ An assortment of materials to build an aircraft stand (small blocks, popsicle sticks, modeling clay, balsa wood, etc.)
- ☐ Wind Tunnel Testing handout (one per student)

Lesson Preparation

Prior to the lesson, the instructor should gather materials for the wind tunnel and model aircraft body builds, as well as make copies of the Wind Tunnel Testing handout.

As different fans will provide different amounts of flow, it is suggested that the fans are tested with a model aircraft body ahead of time to make sure the fans are strong enough to create a noticeable interaction with the model aircraft body.

If the instructor does not plan to have each group of students make their own wind tunnel, they should have the wind tunnel stations built and set up ahead of time.

Safety

Due to the nature of this lesson, it is recommended that the class take the following safety precautions:

- Participants should wear eye protection.
- Participants should be reminded to not place objects, including fingers, in the fans.

- Wind tunnels should be placed so the fans blow away from other groups in case of flying objects.
- Participants should be reminded to be mindful of where they walk in the classroom, so they do not walk in the path of a wind tunnel in case of flying objects.
- Instructors should cut the observation window for students.

Procedure

Engage (5 minutes)

1. If students did the Go with the Flow lesson prior, pose the following questions to the class:
    - Last class, we used a simulation to investigate how different shapes interact with flow and you used that information to test a prototype in the simulation. What were your big take aways from that research?
    - What are things that you still have questions about and would like to investigate further?
2. If students did not do the Go with the Flow lesson, pose the following questions to the class:
    - Most of us have seen different types of aircrafts, either in pictures or on television or in real life. What do you notice about the shape of the bodies of those aircrafts?
    - What do these aircrafts have in common?
    - What are differences between these aircrafts?

Explore (30 minutes)

3. Instructions for the explore, explain, and elaborate sections of this lesson are provided on the Wind Tunnel Testing handout. Groups of 2-4 are ideal for this lesson.
4. Share with students:
    - Today we are going to (continue) to study aircraft bodies and how they interact with flow by building model aircraft bodies to evaluate. In doing so, you will build a wind tunnel to do the testing. Start by reading the Project Briefing and let me know if you have any questions.
5. If groups are building their own wind tunnel, they should do that first, before building their aircraft body prototype, because the prototype and stand needs to fit inside of the wind tunnel. To build a wind tunnel:

    - Gather your materials: cardboard box, clear plastic, tape, fan.
    - Take a medium sized cardboard box and open/cut the box so that it is open at opposite ends. You may want to make sure any flaps are taped down.
    - On one side of the box, draw an observation window. The window should be slightly smaller than the clear plastic you will use as your window.
    - Ask an adult to cut out the window for you.

- Tape the clear plastic on the inside of your box. Trim the clear plastic if it is too large to fit in your box. Make sure all sides of the plastic are completely taped down.
- Place the fan at one open end of the wind tunnel so that it is blowing in the box. Make sure to set up your wind tunnel so that it blows away from other groups.

6. Students will need to design and build a model of their aircraft body using materials supplied by the instructor. In addition, students should build a stand for their model so that the model is "flying" in the wind tunnel. To test their model, the students will need to be able to place their model on top of a stand and place both inside of the wind tunnel with room to spare.

7. Students will test their model at different flow speeds. Students should place their model in the wind tunnel. They should turn the fan onto its lowest setting. They should observe the model in the wind tunnel for a couple minutes and record their data on the Wind Tunnel Testing handout.
8. Students should repeat their testing/data collection at each setting of the fan.

Explain (10 minutes)

9. Students will be asked to use evidence from their data to evaluate their aircraft body design. As part of this evaluation, in the Prototype Analysis questions, students will need to propose features of the design that worked well and features that need to be improved:
    - What happened to your prototype as the force of the flow increased?
    - Based on your data, which direction do you think the net (total) force is acting on your prototype? What data do you have to support your claim?
    - Based on your data, do you think your prototype was successful? What makes you say that?
    - What would you do to improve your prototype? ("Nothing" is not an acceptable answer here.)

Elaborate (15 minutes)

10. Students will now be asked to modify their design and repeat the test. Students will need to justify their re-design based on evidence from their data.
11. After students complete the testing of their re-design, they will further elaborate their understanding by answering the Final Analysis questions:

- What happened to your second prototype as the force of the flow increased?
- Based on your data, which direction do you think the net (total) force is acting on your second prototype? What data do you have to support your claim?
- Based on your data, do you think your second prototype was successful? What makes you say that? Why or why not?
- Do you think your second prototype was an improvement over your first? What makes you say that?
- In addition to the body, the wings are another important part of the aircraft design. In the space below, what shape wings would you use for your aircraft body prototype. What data do you have that supports that design?

Evaluate (15-30 minutes)

12. Ask students to work with their group to report their findings. This could be done in a variety of ways: verbal debrief, presentation slide, memo, email, etc. Give students the following prompt:
    - As scientists, it is important to share, compare, and review our results with other scientists. You are to work with your group to create a (insert reporting style) that highlights your key takeaways and big ideas from your data collection. This should be a clear, concise (insert reporting style), so it should be no longer than (insert size limit).
13. Students can either report their findings to the entire class or turn it in to the instructor.

STEM Career Connections

- Aerospace engineering
- Military aircraft design
- Car racing industry
- Materials scientist
- Architect

Extensions

As an additional lesson, students could add wings to their aircraft body to study how the wings change the aircrafts interaction with the flow and how different shaped wings change the direction and size of the lift force on the aircraft.

References & Resources

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Wind Tunnel Testing

Project Briefing

The Navy is working on a new hypersonic aircraft. Their current prototype is struggling with stability and maneuverability through different flows. ***Flow*** is the motion of a ***fluid*** (a liquid or a gas). The Navy is asking us to design and test a new prototype for the body of their aircraft. The aircraft will eventually be tested at ***supersonic*** (faster than the speed of sound) and ***hypersonic*** (greater than five times the speed of sound) speeds. We will start the testing process by observing how your prototypes interact with different ***subsonic*** (slower than the speed of sound) air flows.

Wind Tunnel Testing Set-Up

Instructions to build the wind tunnel:

- ☐ Gather your materials: cardboard box, clear plastic, tape, fan.
- ☐ Take a medium sized cardboard box and open/cut the box so that it is open at opposite ends. You may want to make sure any flaps are taped down.
- ☐ On one side of the box, draw an observation window. The window should be slightly smaller than the clear plastic you will use as your window.
- ☐ Ask an adult to cut out the window for you.
- ☐ Tape the clear plastic on the inside of your box. Trim the clear plastic if it is too large to fit in your box. Make sure all sides of the plastic are completely taped down.
- ☐ Place the fan at one open end of the wind tunnel so that it is blowing in the box. Make sure to set up your wind tunnel so that it blows away from other groups.

Prototype Design

Based on your prior research, sketch your aircraft body design in the box below. We are just focusing on the body of the aircraft, not the wings. Beside the box, note which materials you plan to use to build your prototype.

Build a small model of your prototype and a stand for your prototype. Your model needs to fit inside of your wind tunnel while sitting on top of a stand, with room to spare as shown in the picture. The purpose of the stand is to let the flow go around all sides of the prototype to simulate flying.

Prototype Testing

Place your prototype, on its stand, inside of your wind tunnel with the nose facing the fan. Turn the fan on the lowest setting. From the observation window, watch how your prototype interacts with the flow. Record your data (observations and measurements) in the table below. An observation can be a sketch or description of what you notice about your prototype's motion. A measurement may be how far your prototype moves because of the flow. Repeat for each speed setting on the fan.

Flow Speed	Low	Medium	High
Data			

Prototype Analysis

1. What happened to your prototype as the force of the flow increased?

2. Based on your data, which direction do you think the net (total) force is acting on your prototype? What data do you have to support your claim?

3. Based on your data, do you think your prototype was successful? What makes you say that?

4. What would you do to improve your prototype? ("Nothing" is not an acceptable answer here.)

Prototype Redesign & Testing

Based on your analysis, modify your model aircraft body. In the box below, sketch your updated design. Beside the box, note any changes you will make to the materials used to build the model. Justify your changes using your data.

Make any adjustments to your prototype and repeat the testing. Record your data in the table below.

Flow Speed	**Low**	**Medium**	**High**
Data			

Final Analysis

1. What happened to your second prototype as the force of the flow increased?

2. Based on your data, which direction do you think the net (total) force is acting on your second prototype? What data do you have to support your claim?

3. Based on your data, do you think your second prototype was successful? What makes you say that?

4. Do you think your second prototype was an improvement over your first? What makes you say that?

5. In addition to the body, the wings are another important part of the aircraft design. In the space below, what shape wings would you use for your aircraft body prototype. What data do you have that supports that design?