Hypersonics STEM Curriculum

Go with the Flow

Grade	Time	Subject Area	Key Concepts
6-8	65 min	Physical Science Engineering Design	Forces Flow

Lesson Overview

In this lesson, students are presented a problem to solve. They are asked to investigate the interaction of flow on different barriers in order to then design and test a body shape for a hypersonic aircraft for the Navy.

With this lesson, you can either let students work at their own pace or gather students at the two analysis points to compare data and discuss their ideas.

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-ETS1-3 Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.

Learning Objectives

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

- Describe how the shape of a barrier affects the flow of a fluid and the force on the barrier.
- Design an aircraft body shape based on data collected about different barrier shapes.
- Test and analyze the flow around their aircraft body shape design.

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.

Viscosity – the resistance to flow. The internal resistance of fluids.

Science Concepts Overview

When any object moves, at any speed, it moves through a fluid. A fluid can be any liquid or gas. In most cases, we are looking at objects 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 skateboard. As objects move into supersonic and hypersonic speeds, understanding the flow becomes more important and largely factors into the design of the objects.

Materials List

- ☐ Devices with access to the internet (one per grouping of students)
- ☐ Go with the Flow handout (one per student)
- ☐ Optional - Colored pencils or markers or pens

Lesson Preparation

Prior to the lesson, the instructor should make copies of the handout and ensure that the devices that the students will be using to run the simulation are charged and connected to the internet.

Safety

There are no additional safety concerns beyond normal classroom procedures for this lesson.

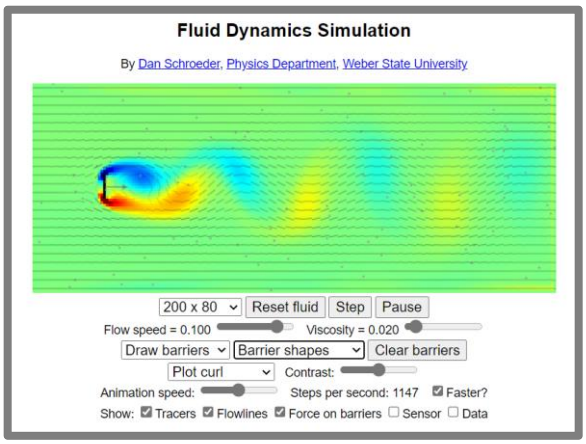
Procedure

Engage (5 minutes)

1. Open the lesson by asking the students:
    - Have you ever tried to run on a windy day or put your hand out of the window of a moving vehicle?
    - What did you feel?
    - Did you notice anything if you changed the direction of your body or hand? Can you describe your observation?
2. As a class or individual, read the Project Briefing section of the lab.
3. Students should answer the Project Briefing questions on their Go with the Flow handout:
    - How do you think flow can affect the movement of an object?
    - How do you think the shape of an object plays into that interaction?

Explore (40 minutes)

4. To work on the rest of the lesson, students can work individually or in small groups. Working as individuals or groups of two is ideal if device distribution allows for it.
5. Students will complete the rest of the lesson using the Fluid Dynamics Simulation https://physics.weber.edu/schroeder/fluids/
6. Students will begin the lesson by testing the flow around 11 premade barrier shapes. For each barrier shape, they will be asked to sketch the flow around the barrier shape including the force arrow, record their observations, and record any wonders they have. There are instructions in the Go with the Flow handout as to how to set up the simulation.

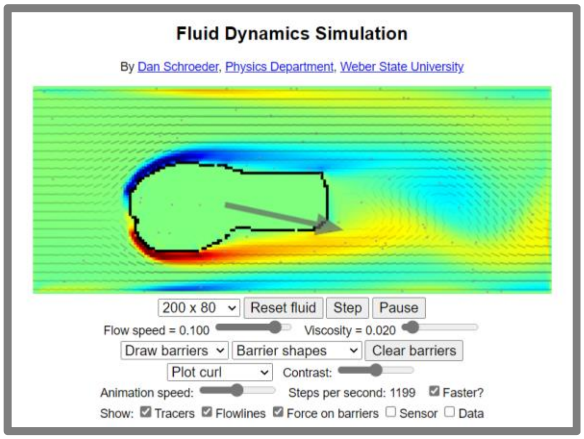


Explain (5 minutes)

7. Once the students complete the exploration data collection, they will answer the exploration analysis questions:

- Which barriers provided the most and the least steady force? What data do you have to support that claim?
- Which barrier provided the least steady force? What data do you have to support that claim?
- Which barrier, or combination of barriers, do you think would make the best front of an aircraft? What makes you say that?

Elaborate (10 minutes)



8. Based on the data they collected from the explore part of the lesson, students will propose a new body shape for the aircraft.
9. Students will draw their body shape design in the simulation and test the flow around their design. They will be asked to sketch the flow around the barrier shape including the force arrow, record their observations, and record any wonders they have.

Evaluate (5 minutes)

10. Once the students complete the design data collection, they will answer the design analysis questions:
    - Did your proposed aircraft body perform as you expected? What data supports your claim? What changes would you make?
    - Change the viscosity and flow rate of the fluid. How does your proposed aircraft body hold up to those changes?
    - This simulation models subsonic speeds. What do you think would happen to your proposed aircraft body at supersonic and hypersonic speeds? What makes you say that?

STEM Career Connections

- Aerospace engineering
- Military aircraft design
- Car racing industry

Extensions

To give students more experiences feeling flow in the *engage* part of the lesson, you could go outside and have students run with their arms out, hand in various positions, to feel the way the air moves past them.

Students could continue their investigation by completing the Hypersonics Lesson Plan Grades 6-8 – Wind Tunnel Testing. In this lesson, students build a model of their design to test in a wind tunnel.

References & Resources

National Air and Space Museum. (n.d.) *How things fly*. https://howthingsfly.si.edu/

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SciShow. (2019, July 8). *A surprisingly simple secret to supersonic flight* [Video]. YouTube. https://www.youtube.com/watch?v=kGefMLHJBKA

Talented Tuber. (2017, April 11). *Difference between subsonic, supersonic and hypersonic speed* [Video]. YouTube. https://www.youtube.com/watch?v=LBJ3tXCjzN0

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Go with the Flow

Project Briefing

The Navy is working on a new hypersonic aircraft. Their current prototype is struggling with stability and maneuverability through different flows. The Navy is asking us to help them research and design different possible body styles for their aircraft.

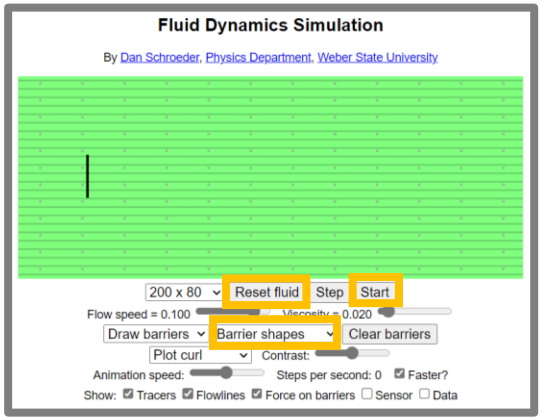
When objects move, they are moving through a ***fluid*** (a gas or liquid; air is the fluid in our case), and the fluid moves around them as they pass by. This is what you feel if you put your hand out of a window when riding in a car; the air moving around your hand. At low speeds, the motion of the fluid, or ***flow***, can mostly be ignored. But as objects move faster, especially at ***supersonic*** (faster than the speed of sound) and ***hypersonic*** (greater than five times the speed of sound) speeds, it becomes more important to understand the effect of the flow. And if you have ever experienced the air moving past your hand while riding in a car, you might have noticed that the shape that you make with your hand changes the way that the flow interacts with it.

We are being tasked with using a simulation to investigate the flow around different shapes. When looking at the different shapes, we are looking for the shape that provides the most stable ***net force*** (total force acting on an object). A stable force makes it easier to stabilize, control, and maneuver the aircraft. We will then use that data to design and test a possible body style for the new aircraft.

1. How do you think flow can affect the movement of an object? How do you think the shape of an object plays into that interaction?

Simulation Set-Up

Go to https://physics.weber.edu/schroeder/fluids/ to find the Fluid Dynamics Simulation.



To start the design testing, make sure that your simulation is set up as shown to the right:

- ☐ Check the boxes to show Tracers, Flowlines, and Force on barriers.
- ☐ Select Plot Curl in the drop down.
- ☐ You will use the Barrier shapes drop-down for the first part of your research and the Draw barriers drop-down for the second.
- ☐ You will use the Start/Pause button to start your simulation for each different shape.
- ☐ The Reset fluid button is useful if you want to restart your simulation.

Exploration Data Collection

Use the Barrier shapes drop down to change the shape of the barrier you are testing. Run the simulation for each of the different barrier shapes. Allow the simulation to run for at least 30 seconds before filling in the chart, some flows change over time. Make a sketch of the barrier and the air flow around it. Be sure to include the force arrow in your sketch (if the arrow moves, make a note of that). For each barrier shape, also record your observations of the flow as well as any wonders that you may have.

Barrier Shape	Sketch with Force Arrow	Observations	Wonders
Short Line			
Long Line			
Diagonal			
Shallow Diagonal			
Small Circle			

Barrier Shape	Sketch with Force Arrow	Observations	Wonders
Large Circle			
Line with Spoiler			
Circle with Spoiler			
Right Angle			
Wedge			
Airfoil			

Exploration Analysis Questions

1. Which barriers provided the most and the least steady force? What data do you have to support that claim?

2. Which barrier, or combination of barriers, do you think would make the best shape for an aircraft? What makes you say that?

Design Data Collection

Proposed Aircraft Body Design

Looking at your data above, if you were designing a hypersonic aircraft, what body shape would you use? Sketch your proposed aircraft body design in the box to the right.

Reset your simulation to the original settings noted in the Simulation Set-Up section. Use the simulation to draw your proposed aircraft body (Draw barrier). Run the simulation to test your design and fill in the data table below.

Barrier Shape	Sketch with Force Arrow	Observations	Wonders
Design			

Design Analysis Questions

1. Did your proposed aircraft body perform as you expected? What data supports your claim? What changes would you make?

2. Change the ***viscosity*** (resistance to flow) and flow speed of the fluid. How does your proposed aircraft body hold up to those changes?

3. This simulation models subsonic speeds. What do you think would happen to your proposed aircraft body at supersonic and hypersonic speeds? What makes you say that?