Hypersonics STEM Curriculum

Can I Give You a Lift?

Grade	Time	Subject Area	Key Concepts
High School	90 min	Physics Engineering Design	Forces Lift

Lesson Overview

In this lesson, students will design and evaluate three different aircraft wings. They will place the model aircrafts in a wind tunnel and measure the lift force on the different wing types. Students will then evaluate the three wings and propose a possible redesign based on their data.

This lesson is designed to follow the Forces of Flight lesson but can also be done on its own. Depending on the set up of the class and available materials, each group can 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

HS-PS2-1 Analyze data to support the claim that Newton's second law of motion describes the mathematical relationship among the net force on a macroscopic object, its mass, and its acceleration.

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.

Learning Objectives

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

- Design and create three different model aircraft wings.
- Use a free body diagram and Newton's second law equation to calculate the lift force created by different styles of wings.
- Evaluate and compare the three model wings based on the lift force the wings generate.

Essential/Overarching Question

How does wing design effect the size of the lift force acting on an aircraft?

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.

Mass – the amount of matter in a body; measure of inertia or resistance to change velocity.

Acceleration – the rate an object changes velocity; a change in velocity over time.

Weight – the gravitational force acting on an object; $w = m*g$.

Lift – is the vertical component of the force on an aircraft's wing or airfoil resulting from a pressure imbalance in the flow stream moving around the wing/airfoil. The direction of lift is typically perpendicular to the flow stream.

Drag – the force that opposes the motion of an object traveling through a fluid; aerodynamic friction. It is caused by the interaction between a solid and a fluid.

Thrust – the propulsion force that moves a solid through a fluid.

Free Body Diagram (FBD) – a representation of all the forces acting on an object or system. The object or system is represented by a dot or box. The forces are represented by arrows coming out of the dot or box where the arrow points in the direction of the force and the length of the arrow is proportional to the magnitude of the force.

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

There are four forces that affect objects in flight: lift, weight, thrust, and drag. Lift is the upward force on a wing caused by the flow (moving fluid – air in our case) around the wing. The lift force is perpendicular to the direction of the flow. Weight is the downward gravitational pull on an object. Thrust is the propulsion force that moves the object through a fluid, usually created by an engine. And drag is the frictional force that opposes the motion of an object moving through a fluid.

When looking more closely at lift, lift is a mechanical aerodynamic force. Lift occurs when an object is moving relative to a flow. This can mean an object is moving through a fluid or a fluid is moving past an object. When the flow moves past the object (or vice versa) the flow stream is compressed to go around the object. This compression decreases the area of the flow stream, which causes an increase in velocity and a decrease in pressure. This change in pressure results in a force on the wing/airfoil. For a lift force to be up or down, the flow needs to be moving left or right. The magnitude of the lift force depends on the shape of the object, its orientation to the incoming stream, and how much that shape compresses the flow stream.

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 their model wings (aluminum foil, cardstock, glue, tape, cardboard, popsicle sticks, balsa wood, foam, think dial rods, straws, chopsticks etc.)
- ☐ Playdough or modeling clay to function as the body of the aircraft
- ☐ Scales (one per group)
- ☐ Devices connected to the internet or books on aircrafts for students to research wing design (one per group)
- ☐ Can I Give You a Lift? handout (one per student)
- ☐ Can I Give You a Lift? Exit Ticket handout (one per student – there are two exit tickets per page)

Lesson Preparation

Prior to the lesson, the instructor should gather materials for the wind tunnel and model aircraft wing builds as well as make copies of the Can I Give You a Lift? handout and Can I Give You a Lift? Exit Ticket.

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

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 (10 minutes)

1. If the students previously completed the Forces of Flight lesson, start the lesson by reviewing the four forces of flight. The first part of the Can I Give You a Lift? Reviews the prior lesson:
    - There are four forces of flight, thrust, weight, drag, and lift. Draw a free body diagram (FBD) of an aircraft flying to the right at a constant speed. Use your FBD to write the two net force equations.
    - What causes the lift force? How can we change the magnitude and direction of the lift force?
2. Spend time as a class discussing their ideas of how the magnitude and direction of a lift force can be changed.
3. If the students did not previously complete the Forces of Flight lesson, start the lesson by discussing the four forces of flight, thrust, weight, drag, and lift prior to or while completing the first part of the Can I Give You a Lift? Handout as explained above.

Explore (60 minutes)

4. Instructions for the explore, explain, and elaborate sections of this lesson are provided on the Can I Give You a Lift? handout. Groups of 2-4 are ideal for this lesson.
5. As a class or individually, read the Project Briefing on the Can I Give You a Lift? handout. Students are asked to answer two questions about lift:
    - When the fan is off (no flow interacting with the wings), what is the reading on the scale measure?
    - When the fan is on (flow interacting with the wings), what does the reading on the scale measure?
6. Before moving forward, ensure that all students understand that the reading on the scale when the fan is off measures the weight of the object and the reading on the scale when the fan is on measures the difference between the weight and the lift force.
7. Students will research and design their three model wings to evaluate. Students may use their own knowledge, the internet, books, etc. to complete this.
8. Either students can build their own wind tunnels, or the instructor can have premade wind tunnels set up around the classroom. If students are building their own wind tunnel, instructions are provided in the Can I Get a Lift? handout:
    - 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.

9. Students will build their model aircraft wings. Instructions to build model wings:
    - Using playdough or modeling clay, create an aircraft body that will hold your wings. You will use the same body for each set of model wings.
    - Using the materials provided by your instructor, build your three sets of wings. If your wing type has two, or more, separate wings, make note if they should be mirror images of one another (opposite) or not.
    - Attach the wings to a rod that can be secured to the aircraft body and will not move once the wind tunnel is turned on.
    - Be sure to attach each wing at the same location and angle on your aircraft body to ensure you are testing wing design and not wing placement.
    - Make sure that your model aircraft will fit inside of the wind tunnel, on top of the scale, with room to spare. The wings, nor the aircraft body should not be touching the box.

10. For each wing design, students will place their model aircraft on the scale in the wind tunnel. Students should try to attach the wings at the same location and angle on their aircraft body. Changes in location and angle could affect the lift force generated.
11. They will take readings of the mass of the aircraft from the scale with the fan off and then at each of the different fan speeds. For each reading, they will need to record their results on the Can I Give You a Lift? handout and use the reading to calculate the lift force.

Explain (5 minutes)

12. Students will explain their results by answering the first four Data Analysis questions of the Can I Give You a Lift? handout:
    - Which wing created the largest lift force? What evidence to you have to support your claim?
    - Which wing created the smallest lift force? What evidence to you have to support your claim?
    - How did wind speed effect the lift? Did it effect each wing type the same way?
    - Stability and maneuverability are also important in aircraft design. Based on observations, which of your wing designs would provide the best stability and maneuverability? What evidence supports your claim?

Elaborate (5 minutes)

13. Students will elaborate on their understanding and apply their knowledge further by answering the first four Data Analysis questions on the Can I Give You a Lift? handout:
    - How would you adjust the design of your three wings?
    - As aircrafts approach supersonic speeds, they encounter a phenomenon called Mach tuck. Mach tuck happens when the lift force shifts further back on the aircraft, away from the center of pressure of the wing. This can result in an unbalanced force, causing the nose of the aircraft to point down and possibly take a nosedive. How would you redesign your wings to account for Mach tuck?

Evaluate (10 minutes)

14. Students will compete the Can I Give You a Lift? Exit Ticket:
    - What are two things from the investigation that stuck out to you?
    - If you were to describe lift forces to a 3rd or 4th grade student, what would you say?
    - What are you most confused about?

STEM Career Connections

- Aerospace engineering
- Military aircraft design
- Pilot – commercial and military
- Race car design

Extensions

Students could further their *elaborate* section by implementing one of their proposed redesigns and evaluating the updated wing.

Instead of, or in addition to, the exit ticket for the *evaluation*, students can be asked 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.

References & Resources

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Name: ____ Date: ____________________

Can I Give You a Lift?

There are four forces of flight: thrust, weight, drag, and lift. Draw a free body diagram (FBD) of an aircraft flying to the right at a constant speed. Use your FBD to write the two net force equations.

What causes the lift force? How can we change the magnitude and direction of the lift force?

Project Briefing

✈ Each of the four forces play an important role in the flight of an aircraft. We are going to focus on the lift force for our investigation. The shape of the wing changes how flow interacts with the wing, which changes the magnitude and direction of the lift force. Wind tunnels are useful in studying lift. 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 wind tunnel can simulate 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 will do in our testing, or with full size objects if the wind tunnel is large enough.

We will be placing model aircrafts inside a wind tunnel to investigate how different wing designs effect lift. While the aircrafts are inside the wind tunnel, they will be sitting on a scale. This scale reading will help us measure lift. Based on your FBD and net force equations:

- When the fan is off (no flow interacting with the wings), what is the reading on the scale measure?

- When the fan is on (flow interacting with the wings), what does the reading on the scale measure?

You will be able to choose three different wing designs to evaluate. Choose your three designs to evaluate based on either your experience with aircrafts or on research. As a note, we will only be evaluating wings, not propellers or tail wings. Once you decide on your three wings to evaluate, sketch the wings in the data tables in the Data Collection section.

Experiment 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.

Instructions to build model wings:

- ☐ Using playdough or modeling clay, create an aircraft body that will hold your wings. You will use the same body for each set of model wings.
- ☐ Using the materials provided by your instructor, build your three sets of wings. If your wing type has two, or more, separate wings, make note if they should be mirror images of one another (opposite) or not.
- ☐ Attach the wings to a rod that can be secured to the aircraft body and will not move once the wind tunnel is turned on.
- ☐ Be sure to attach each wing at the same location and angle on your aircraft body to ensure you are testing wing design and not wing placement.
- ☐ Make sure that your model aircraft will fit inside of the wind tunnel, on top of the scale, with room to spare. The wings, nor the aircraft body should not be touching the box.

Data Collection

For each wing design, place the model aircraft, with wings attached, on the scale in the wind tunnel. Take scale readings with the fan off, on low, on medium, and on high. Record your scale readings in the tables below and calculate the lift force.

Sketch of Wing Design #1				
Fan Speed	**Scale Reading (g)**	**Scale Reading (kg)**	**Scale Reading (N)**	**Lift (N)**
Off				
Low				
Medium				
High				
Observations				

Sketch of Wing Design #2				
Fan Speed	**Scale Reading (g)**	**Scale Reading (kg)**	**Scale Reading (N)**	**Lift (N)**
Off				
Low				
Medium				
High				
Observations				

Sketch of Wing Design #3				
Fan Speed	**Scale Reading (g)**	**Scale Reading (kg)**	**Scale Reading (N)**	**Lift (N)**
Off				
Low				
Medium				
High				
Observations				

Data Analysis

1. Which wing design created the largest lift force? What evidence to you have to support your claim?

2. Which wing design created the smallest lift force? What evidence to you have to support your claim?

3. How did wind speed effect the lift? Did the wind speed effect each wing design the same way?

4. Stability and maneuverability are also important in aircraft design. Based on observations, which of your wing designs would provide the best stability and maneuverability? What evidence supports your claim?

5. How would you adjust the design of your three wings?
   - Wing Design #1:
   - Wing Design #2:
   - Wing Design #3:

6. As aircrafts approach supersonic speeds, they encounter a phenomenon called Mach tuck. Mach tuck happens when the lift force shifts further back on the aircraft, away from the center of pressure of the wing. This can result in an unbalanced force, causing the nose of the aircraft to point down and possibly take a nosedive. How would you redesign your wings to account for Mach tuck?

Name: ____ Date: ___________________

Can I Give You a Lift? Exit Ticket

1. What are two things from the investigation that stuck out to you?

2. If you were to describe lift forces to a 3rd or 4th grade student, what would you say?

3. What are you most confused about?

Name: ____ Date: ___________________

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