Hypersonics STEM Curriculum

Hypersonics: A System of Systems

Grade	Time	Subject Area	Key Concepts
6-8	75 min	Engineering Design	Engineering Design Process

Lesson Overview

In this lesson, students will work as a team to design a sounding rocket that can fly as high as possible while maintaining a stable flight. While working as a team, each student is given a specific task within the design, build, and test process - working on their specific system within the system. After initial testing and analysis, the team will re-design and re-test their sounding rocket.

This lesson could be done over multiple class periods and instructors could spend additional time on this project if they choose.

NGSS Standards

MS-ETS1-1 Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.

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.

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:

- Work in a team to design a sounding rocket while having an individual aspect of the build (wing design, body design, launch design, testing design) to focus on.
- Design, test, and analyze a sounding rocket prototype.
- Re-design their sounding rocket based on data analysis from their testing.

Essential/Overarching Question

How can we work as a team to design, build, and test a model sounding rocket?

Key Vocabulary

Sounding Rocket – a rocket that is launched into Earth's atmosphere to collect data and then falls back to the ground.

Payload – the part of a rocket that contains the cargo.

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.

Aerodynamic – having a shape which reduces the drag from air moving past.

Science Concepts Overview

A sounding rocket is a rocket that is launched into Earth's atmosphere to collect data. The rocket is shot in a parabolic trajectory. As the sounding rocket rises, the payload of the sounding rocket separates from the engine. The payload contains the data collection materials and will continue to rise for a bit before returning to the Earth. Sounding rockets

can reach altitudes that range from 45 km to 1290 km and are in flight for 5 to 20 minutes. While sounding rockets are considered low speed vehicles, they do reach speeds as high as Mach 5 (1715 m/s = 6147 km/hr = 3836 mph = three times the speed of sound). Speeds at Mach 5 or higher are considered hypersonic. In reaching those speeds and altitudes, the sounding rocket needs to be built to be as aerodynamic (has a shape that allows air to move past it easily) as possible to reduce the amount of heat and friction it experiences.

In addition to the payload and the engine, sounding rockets also have other systems that need to work together such as electronics, materials, sensors, etc. All of these small systems must work together so that the sounding rocket as a whole can successfully complete its data collection, making it a system of systems. Many times, when one fails, the whole system fails.

Materials List

- ☐ Cardboard box (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)
- ☐ An assortment of materials to build their prototypes, launching site, and sounding rocket stands (aluminum foil, cardstock, glue, tape, cardboard, popsicle sticks, balsa wood, foam, think dial rods, straws, chopsticks, empty plastic bottles, modeling clay, rubber bands, empty paper towel rolls etc.)
- ☐ An assortment of materials to build a launch mechanism (rubber bands, mouse traps, Hot Wheels tracks, spring, wood planks (levers), empty water bottles, plastic tubes, etc.)
- ☐ Scissors
- ☐ Box Cutter (for teacher use)
- ☐ Tape (duct tape is best)
- ☐ Goggles or other eye protection (one per student)
- ☐ Rulers (one per group)
- ☐ Hypersonics: A System of Systems handout (one per student)
- ☐ Hypersonics: A System of Systems – Job Assignments handout (one per group)
- ☐ Hypersonics: A System of Systems – Team Evaluation handout (one per student – two per page)

Lesson Preparation

Prior to the lesson, the instructor should gather materials for the wind tunnel and sounding rocket builds as well as make copies of the Hypersonics: A System of Systems, Hypersonics: A System of Systems - Job Assignments, and Hypersonics: A System of Systems – Team Evaluation handouts. The instructor can decide what types of materials they want to make available for the students to use to launch their sounding rocket based on supply availability, launching area, and individual class safety procedures.

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

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.

Depending on the launch materials and model sounding rockets used, the launch sites could require a long, clear stretch of space. This would be a great lesson to do outside or in a room with a high ceiling such as a hallway, gymnasium, or cafeteria. When working outside, the wind affect flight patterns.

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.
- Participants should be reminded to be mindful of when and where they launch their sounding rockets. Instructors should set guidelines on this for their students based on available space.

Procedure

Engage (5 minutes)

1. As a class, or individually, read The Challenge section of the Hypersonics: A System of Systems handout.
2. Divide students into teams of four.
3. Have each team cut out the job descriptions on the Hypersonics: A System of Systems - Job Assignments handout and randomly assign each team member a job. Each square has a description of the job.
    - Wing engineer
    - Rocket body engineer
    - Launch engineer
    - Testing engineer
4. Have students answer the check-in question, “What are any wonders or questions you have at this point?”, and share with their team.

Explore (30 minutes)

5. Students will work as a team, and individually, to plan out their design for their sounding rocket. They will fill in the Sounding Rocket Design section of the Hypersonics: A System of Systems handout.

6. Students will work individually and as a team to build their sounding rocket.

7. The testing engineer may have to build a wind tunnel (if the instructor did not pre-make them). Instructions are provided in the Hypersonics: A System of Systems 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.

8. Students will work with their teams to test and collect data on their sounding rocket both in a wind tunnel and through a launch. They can record their data in the Design Testing section of the Hypersonics: A System of Systems handout.

Explain (30 minutes)

9. Students will analyze their data and explain their evaluation of their sounding rocket by answering questions 1-7 in the Design Analysis section of the Hypersonics: A System of Systems handout:
    - Overall, how did your sounding rocket perform in the wind tunnel? What worked well? What did not? What data supports your claim(s)?
    - How did your individual contribution to the sounding rocket perform in the wind tunnel? What worked well? What did not? What data supports your claim(s)?
    - Overall, how did your sounding rocket perform in the launch? What worked well? What did not? What data supports your claim(s)?

- How did your individual contribution to the sounding rocket perform in the launch? What worked well? What did not? What data supports your claim(s)?
- How would you re-design your sounding rocket?
- How will your individual contribution to the sounding rocket be affected in the redesign?
- What are any wonders or questions you have at this point?

10. Students will need to re-design their sounding rocket based on their analysis. Students will work as a team, and individually, to plan out their re-design for their sounding rocket. They will fill in the Sounding Rocket Re-Design section of the Hypersonics: A System of Systems handout. Include ideal student grouping.
11. Students will work individually and as a team to build their sounding rocket re-design.
12. Students will work with their teams to test and collect data on their sounding rocket re-design both in a wind tunnel and through a launch. They can record their data in the Re-Design Testing section of the Hypersonics: A System of Systems handout.
13. Students will analyze their data and explain their evaluation of their sounding rocket re-design by answering questions 1-2 in the Re-Design Analysis section of the Hypersonics: A System of Systems handout:
    - Overall, how did your re-designed sounding rocket perform in both the wind tunnel and the launch? What worked well? What did not? What data supports your claim(s)?
    - How did your individual contribution to the re-designed sounding rocket perform in both the wind tunnel and the launch? What worked well? What did not? What data supports your claim(s)?

Elaborate (5 minutes)

14. Students will elaborate on their experience in the engineering design process by answering questions 3-7 in the Re-Design Analysis section of the Hypersonics: A System of Systems handout:
    - How would you further redesign your sounding rocket?
    - What was one of the challenges in this design challenge?
    - What was one of the challenges in designing a small piece of a larger project, or working on one system within a system?
    - What is one thing you would change about how your team worked together?
    - What are any wonders or questions you have at this point?

Evaluate (5 minutes)

15. Each student will fill out the Hypersonics: A System of Systems – Team Evaluation handout where they will rate themselves and each of their team members on their level of cooperation, communication, listening, standard of work, and participation.
16. Instructors can also collect the students' Hypersonics: A System of Systems handout and evaluate their responses to the analysis questions.

STEM Career Connections

- Aerospace engineer
- Materials scientists

- Mechanical engineer
- Systems engineer
- Physics
- Pilot

Extensions

Instead of, or in addition to, the team *evaluation*, students can be asked to work with their team 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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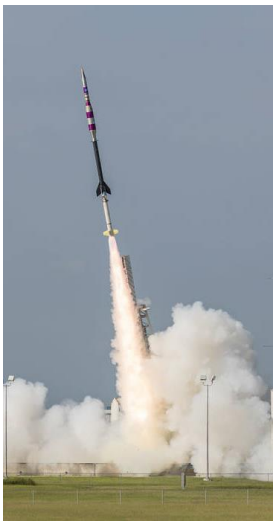
Hypersonics: A System of Systems

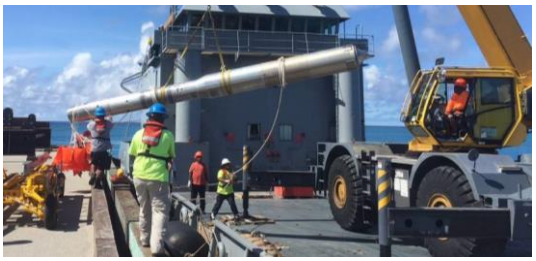


✈ The Challenge

Designing aircrafts, particularly hypersonic aircrafts, is often called a system of systems. There is a collection of small systems (electronics, materials, design, sensors, etc.) that have to work together to make the aircraft as a whole work. Many times, when one fails, the whole system fails.

We have been tasked with designing a new ***sounding rocket***. A sounding rocket is a rocket that is launched into Earth's atmosphere to collect data. After the sounding rocket launches, the top part of the rocket, or the ***payload***, separates from the rocket engine so that it can collect data, and then falls back to Earth. Sounding rockets can reach altitudes that range from 45 km to 1290 km and are in flight for 5 to 20 minutes. While sounding rockets are considered low speed vehicles, they do reach speeds as high as ***Mach*** 5 (1715 m/s = 6147 km/hr = 3836 mph = five times the ***speed of sound***). Speeds at Mach 5 or higher are considered ***hypersonic***. In reaching those speeds and altitudes, the sounding rocket needs to be built to be as ***aerodynamic*** (has a shape that allows air to move past it easily) as possible to reduce the amount of heat and friction it experiences.

We are going to build model sounding rockets, test them in a wind tunnel, and launch them to determine if our design should go further in the engineering process. We want this to go as high as possible while demonstrating a stable flight.



☐ What is your job within your team?

☐ What are any wonders or questions you have at this point?

✈ Wind Tunnel Building Instructions for the Testing Engineer

- ☐ 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.

✈ Sounding Rocket Design

With your individual job in mind, work with your team to brainstorm an overall design for your sounding rocket. You will then design and build your specific aspect of the sounding rocket. You should combine your individual pieces of the sounding rocket for testing.

Overall Design	
Sketch	Notes

Individual Design	
Sketch	Materials
Notes	

☐ What are any wonders or questions you have at this point?

✈ Design Testing

Using the testing plan created by your Testing Engineer, test your sounding rocket by placing it in the wind tunnel and by doing a test launch.

Wind Tunnel Data	Launch Data
Sketch	Sketch
Measurements and Observations	Measurements and Observations
Notes	Notes

☐ What are any wonders or questions you have at this point?

✈ Design Analysis

1. Overall, how did your sounding rocket perform in the wind tunnel? What worked well? What did not? What data supports your claim(s)?

2. How did your individual contribution to the sounding rocket perform in the wind tunnel? What worked well? What did not? What data supports your claim(s)?

3. Overall, how did your sounding rocket perform in the launch? What worked well? What did not? What data supports your claim(s)?

4. How did your individual contribution to the sounding rocket perform in the launch? What worked well? What did not? What data supports your claim(s)?

5. How would you re-design your sounding rocket?

6. How will your individual contribution to the sounding rocket be affected in the redesign?

7. What are any wonders or questions you have at this point?

✈ Sounding Rocket Re-Design

Based on your analysis above, work as a team and individually to re-design your sounding rocket and testing plan.

Overall Re-Design	
Sketch	Notes

Individual Re-Design	
Sketch	Materials
Notes	

☐ What are any wonders or questions you have at this point?

✈ Re-Design Testing

Using the re-designed testing plan created by your Testing Engineer, test your sounding rocket by placing it in the wind tunnel and by doing a test launch.

Wind Tunnel Data	**Launch Data**
Sketch	Sketch
Measurements and Observations	Measurements and Observations
Notes	Notes

☐ What are any wonders or questions you have at this point?

✈ Re-Design Analysis

1. Overall, how did your re-designed sounding rocket perform in both the wind tunnel and the launch? What worked well? What did not? What data supports your claim(s)?

2. How did your individual contribution to the re-designed sounding rocket perform in both the wind tunnel and the launch? What worked well? What did not? What data supports your claim(s)?

3. How would you further redesign your sounding rocket?

4. What was one of the challenges in this design challenge?

5. What was one of the challenges in designing a small piece of a larger project, or working on one system within a system?

6. What is one thing you would change about how your team worked together?

7. What are any wonders or questions you have at this point?

Hypersonics: A System of Systems - Job Assignments

Wing Engineer

Your task is to design the wings of the sounding rocket. You want to ensure that the wings help stabilize the rocket, help with lift, and minimize drag and friction.

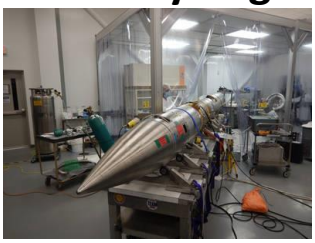
Testing Engineer

Your task is to build a wind tunnel to test your sounding rocket. You will also decide what measurements and observations you need to take to test how well your rocket performance in the wind tunnel and launch.

Launch Engineer

Your task is to design the mechanism that will launch your sounding rocket. You want your rocket to go as high as possible. You need to keep safety in mind with designing your mechanism.

Rocket Body Engineer



Your task is to design the body of the sounding rocket. You want to ensure that the rocket is as aerodynamic as possible to reduce friction, drag, and heat.

All images are from nasa.gov

Name: _____ Date: _____

Hypersonics: A System of Systems – Team Evaluation

Team Evaluation				
Fill in the names of your team members. Rate yourself and each team member, on how often [1-Never, 2-Sometimes, 3-Always] they did the following while working on your project:				
	You			
Cooperation – Worked well with others.				
Communication – Clearly and respectfully shared their ideas.				
Listening – Respectfully listened to other team members' ideas.				
Standard of Work – Focused on quality, not "just getting it done."				
Participation – Participated in all team conversations.				
Total Score (15)				

Name: _____ Date: _____

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Total Score (15)				