Hypersonics STEM Curriculum

Can You Hear Me Now?

Grade	Time	Subject Area	Key Concepts
High School	50 min	Earth and Space Science Physical Science	Atmosphere Speed/velocity

Lesson Overview

In this lesson, students will use a combination of atmospheric data and online resources to answer the question: at what altitude can you no longer hear sounds?

This lesson pairs with the Hypersonic STEM Curriculum lesson – Speeding Through the Atmosphere. It is not required, but it may help students to learn about the layers of Earth's atmosphere (troposphere, stratosphere, mesosphere, thermosphere, and exosphere) prior to this lesson.

NGSS & CCSS Standards

HS-ESS2-2 Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems.

CCSS.MATH.CONTENT.HSN.Q.A.1 Use units as a way to understand problems and to guide the solution of multi-step problems; choose and interpret units consistently in formulas; choose and interpret the scale and the origin in graphs and data displays

Learning Objectives

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

- Explain the variables that effect the speed of sound.
- Use a combination of data and online resources to determine the altitude where the air density is too sparse to support the transmission of sound.
- Apply their knowledge of the atmosphere and sound to situations involving ultrasonic sounds and hypersonic speeds.

Essential/Overarching Question

At what altitude can you no longer hear sounds?

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).

Atmosphere – the layer, or layers, of gas that surrounds a planet. Earth's atmosphere reaches from its surface to 10,000 km above.

Troposphere – the layer of Earth's atmosphere closest to its surface (0 – 12 km). The troposphere is the densest layer of the atmosphere and contains 99% of the Earth's water vapor. Temperature tends to decrease at altitude increases.

Stratosphere – the second layer of Earth's atmosphere (12 – 50 km). The stratosphere contains Earth's ozone layer. Temperature tends to increase as altitude increases.

Mesosphere – the third layer of Earth's atmosphere (50 – 80 km). Meteors tend to burn up in the mesosphere. The mesosphere is the coldest part of the Earth system with temperatures decreasing as altitude increases.

Thermosphere – the fourth layer of Earth's atmosphere (80 – 700 km). Temperatures increase as altitude increases.

Exosphere – the fifth and highest layer of Earth's atmosphere (700 – 10,000 km). The exosphere has a very low density and particles tend to escape into space.

Temperature – the measure of the kinetic energy of the particles in an object. A quantity to describe how hot or cold an object is.

Density – mass per unit volume. How compact an object is.

Ultrasonic – sounds that are at a frequency that is above the human ear's audibility limit. Sound waves above 20,000 hertz.

Anacoustic Zone – the region of the atmosphere where the air density becomes so small that air molecules are not close enough to transport audible sound waves. This zone of silence is about 160 kilometers (99 mi) above Earth.

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

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).

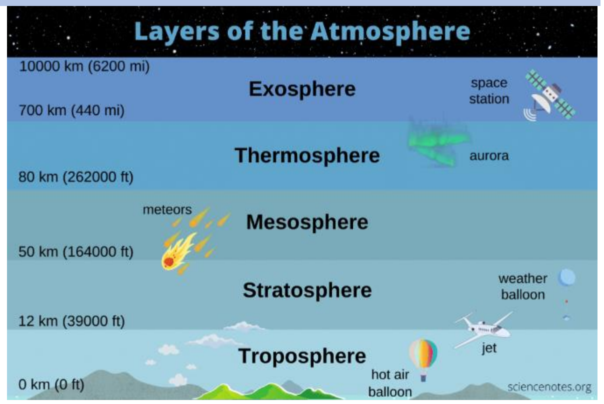
Hypersonic – speeds greater than five times the speed of sound (Mach 5 and greater).

Sonic Boom – a loud sound associated with shock waves created by an object traveling faster than the speed of sound.

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.

Science Concepts Overview



Earth's atmosphere is composed of five layers: troposphere (0-12 km), stratosphere (12-50 km), mesosphere (50-80 km), thermosphere (80-700 km), and exosphere (700 – 10,000 km). Each layer has vastly different characteristics and properties. The way that temperature varies within a layer is different for each of the five layers. Temperatures tend to vary directly with altitude in the stratosphere, thermosphere, and exosphere (temperature increase with altitude) while they vary inversely in the troposphere and mesosphere (temperature decreases as altitude increases).

The density of the air follows the same trend across the entire atmosphere, as you increase altitude, the density decreases, and it does so in a non-linear manner. Density is so small in the exosphere that most particles escape into space.

Another property that varies as you move through the different layers of the atmosphere is the speed of sound. The speed of sound depends on both temperature and the ratio of specific heats. Ratio of specific heats is the ratio of the heat capacity of a specific substance at constant pressure to heat capacity at constant volume – which helps scientist understand how the substance will react with the temperature, volume, and or pressure is changed. Understanding the speed of sound and how it changes at different levels of Earth's atmosphere is important for studying aircraft design, sonic booms, and can be applied to better understand the atmosphere of other planets.

For sound to travel, the waves need a medium to transmit the energy. As you travel higher up in the atmosphere, the air density decreases. Eventually you reach an altitude where the air density is so sparse, there are not enough particles to support the transmission of audible sound waves. This area, which is located about 160 km above Earth, is known as the anacoustic zone.

Materials List

- ☐ Can You Hear Me Now? handout (one per student)
- ☐ Can You Hear Me Now? Exit Ticket handout (one per student – there are two exit tickets per page)
- ☐ Devices with access to the internet (one per student)

Lesson Preparation

Prior to the lesson, the instructor should make copies of the Can You Hear Me Now? handout, exit ticket, and ensure that the devices that the students will be using to do the activity are charged and connected to the internet.

If possible, the instructor should provide students with either an electronic copy of the Can You Hear Me Now? handout and/or links to the websites through whatever learning platform is used at their school. This will help students more easily and quickly get to the correct resources.

Safety

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

Procedure

Engage (5 minutes)

1. As a class or individually, read the Introduction to the Can You Hear Me Now? handout. Have students read the introduction
2. Have students answer the Pre-Analysis Questions on the Can You Hear Me Now? handout prior to exploring the resources.
    - What do you think it is most important variable in determining how fast, or if, sound will travel?
    - Before you look at the data on the next page, what is your best guess at the altitude at which you can no longer hear sounds? What makes you say that?
    - Quickly review the data. Now what is your best guess at the altitude at which you can no longer hear sounds? Use the data to justify your claim.

Explore (30 minutes)

3. Students will explore a series of online resources to learn about how sound travels.

Explain & Elaborate (10 minutes)

4. Students will elaborate on their understanding and apply their knowledge further by answering the following questions on the Can You Hear Me Now? handout:
    - After reviewing the resources, what are variables that effect how sound travels?
    - Based on the resources and the data provided, what is the altitude at which you can no longer hear sounds? Use both the data and evidence from the resources to justify your claim.
    - How does your answer to the question above compare to your answer to the Pre-Analysis Questions? What information helped to shift your understanding?
    - The Tables of the U.S. Standard Atmosphere, 1976 lists the speed of sound for altitudes above the point where sound will be heard. Why do you think the speed of sound is still an important variable to know at altitudes where sound can no longer be heard?
    - Based on the resources and the data provided, what is the altitude at which ultra-sonic sensors are no longer useful? Use both the data and evidence from the resources to justify your claim.
    - One of the complications of aircraft moving at supersonic (faster than the speed of sound) and hypersonic (five times faster than the speed of sound) speeds is the creation of a sonic boom (a loud sound associated with shock waves created by an object traveling faster than the speed of sound). What do you think happens to sonic booms as aircraft fly above the altitude where sound can no longer travel? What makes you say that?

Evaluate (5 minutes)

5. Students will complete the Can You Hear Me Now? Exit Ticket where they are asked to label keys with the five key ideas they took away from this lesson.

STEM Career Connections

- Atmospheric scientist
- Aerospace engineer
- Pilots
- Planetary scientist

Extensions

Student could further *explain* and *elaborate* on their understanding of the speed of sound and hearing sounds as altitude increases by creating a comic strip to explain it. The comic strip could be designed to help elementary and middle school students understand the concept.

Students could further *explore* the question of can we hear sounds in space by reading the article Explainer: Is there sound in space? and writing a summary of the article.

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Can You Hear Me Now?

Introduction

In the early 2000's, a cell phone company had commercials that featured a man going around to different areas testing the cell phone coverage by asking "Can you hear me now?" In the commercial, he was traveling across different locations in the United States. But, what would happen if instead of moving across the country, he was moving up through the atmosphere? Would there be an altitude where you could no longer hear him talking?

Further, ***sounding rockets*** travel between 48 km (stratosphere) and 1,200 km (exosphere) into the atmosphere collecting data for scientists. Many of their sensors use ***ultrasonic*** technologies to collect their data. Ultrasonic waves are sounds waves that are at frequencies above the range humans can hear. Is there a point in the atmosphere where ultra-sonic sensors no longer work?

Pre-Analysis Questions

1. What do you think are the most important variables in determining how sound travels?

2. Before you look at the data on the next page, what is your best guess at the altitude at which you can no longer hear sounds? What makes you say that?

3. Quickly review the data. Now what is your best guess at the altitude at which you can no longer hear sounds? Use the data to justify your claim.

Once you have completed the Pre-Analysis Questions, thoroughly review the U.S. Standard Atmosphere data and the online resources. Use the knowledge you have gained from both to answer the Data Analysis Questions.

Data

All data is from the U.S. Standard Atmosphere, 1976, provided by The Public Domain Aeronautical Software (https://www.pdas.com/atmos.html)

Altitude (km)	Temperature (K)	Density (kg/m^3)	Speed of Sound (m/s)
0	288.150	1.23	340.29
5	255.676	0.736	320.55
10	223.252	0.414	299.53
15	216.650	0.195	295.07
20	216.650	0.0889	295.07
25	221.552	0.0401	298.39
30	226.509	0.0184	301.71
35	236.513	0.00846	308.3
40	250.350	0.00400	317.19
45	264.164	0.00197	325.82
50	270.650	0.00103	329.8
55	260.771	5.68×10^{-4}	323.72
60	247.021	3.10×10^{-4}	315.07
65	233.292	1.63×10^{-4}	306.19
70	219.585	8.28×10^{-5}	297.06
75	208.399	3.99×10^{-5}	289.4
80	198.639	1.85×10^{-5}	282.54
85	188.893	8.22×10^{-6}	275.52
90	186.867	3.44×10^{-6}	274.04
95	188.418	1.39×10^{-6}	275.17
100	195.081	5.60×10^{-7}	280
105	208.835	2.33×10^{-7}	289.7
110	240.000	9.67×10^{-8}	310.56
115	300.000	4.28×10^{-8}	347.22
120	360.000	2.22×10^{-8}	380.36
125	417.231	1.29×10^{-8}	409.48
130	469.268	8.15×10^{-9}	434.27
135	516.589	5.46×10^{-9}	455.64
140	559.627	3.83×10^{-9}	474.24
145	598.776	2.78×10^{-9}	490.54
150	634.392	2.08×10^{-9}	504.92
155	666.799	1.58×10^{-9}	517.66
160	696.290	1.23×10^{-9}	528.98
165	723.123	9.75×10^{-10}	539.08
170	747.566	7.82×10^{-10}	548.11
175	769.811	6.34×10^{-10}	556.21

✈ Resources

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✈ Data Analysis Questions

1. After reviewing the resources, what are variables that effect how sound travels?

2. Based on the resources and the data provided, what is the altitude at which you can no longer hear sounds? Use both the data and evidence from the resources to justify your claim.

3. How does your answer to the question above compare to your answers to the Pre-Analysis Questions? What information helped to shift your understanding?

4. Sketch a visual representation of your understanding of why you can hear sound waves on Earth's surface but not in space.

5. The Tables of the U.S. Standard Atmosphere 1976 lists the speed of sound for altitudes above the point where audible sound can be heard. Why do you think the speed of sound is still an important variable to know at altitudes where sound can no longer be heard?

6. Based on the resources and the data provided, what is the altitude at which ultra-sonic sensors are no longer useful? Use both the data and evidence from the resources to justify your claim.

7. One of the complications of aircraft moving at *supersonic* (faster than the speed of sound) and *hypersonic* (five times faster than the speed of sound) speeds is the creation of a *sonic boom* (a loud sound associated with shock waves created by an object traveling faster than the speed of sound). What do you think happens to sonic booms as aircraft fly above the altitude where sound can no longer be heard? What makes you say that?

Name: ____ Date: ____________________

Can You Hear Me Now? Exit Ticket

Label the keys below with the five key ideas you took away from this lesson.

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