National Aeronautics and Space Administration

FACILITATION GUIDE
GRADES 6 - 8

NASA's Lower the Boom

Citizen Science Activity

NEXT GEN STEM

EXPLORE FLIGHT

www.nasa.gov

This page intentionally left blank

Table of Contents

INTRODUCTION

Small Steps to Giant Leaps: Looking to the Future of NASA Aeronautics Innovation

The X-59 QueSST (Quiet Supersonic Transport) is designed to fly at Mach 1.4 and 55,000 feet above the ground.

Welcome Letter

Dear Formal and Informal Educators,

The students you work with today are tomorrow's scientists, technicians, engineers, and mathematicians. Creativity, curiosity, analytical thinking, and the ability to successfully work together to solve a problem, are skills necessary for NASA's future workforce. Collecting real-time data puts your students in the role of real scientists, allowing them to develop valuable skills through rigorous and engaging science, technology, engineering, and mathematics (STEM) content.

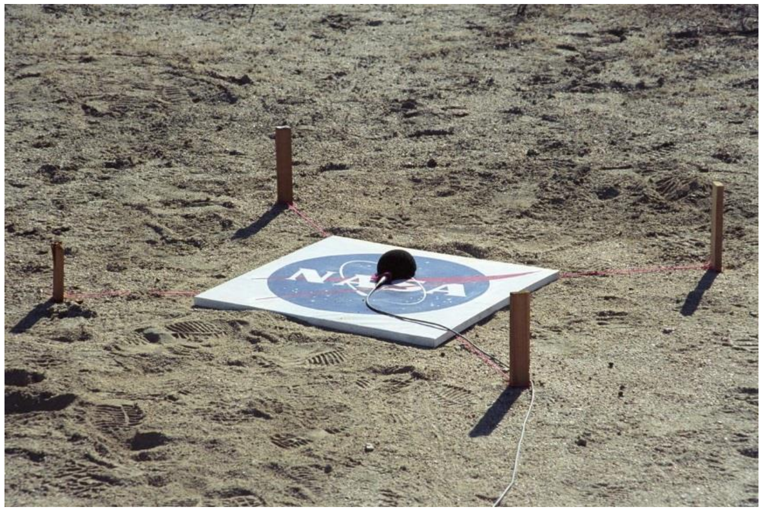
This Citizen Science Activity, NASA's Lower the Boom, was developed as part of NASA's Next Generation STEM Small Steps to Giant Leaps Student Engagement Activity. This activity is being led by NASA's Armstrong Flight Research Center (AFRC) and supported collaboratively by Glenn Research Center (GRC) and Langley Research Center (LaRC), in conjunction with Aeronautics Research Mission Directorate (ARMD).

NASA's Lower the Boom Activity connects students with current aircraft noise reduction research being primarily conducted at NASA's Ames Research Center (ARC), AFRC, GRC, and LaRC. Outlets developed at NASA are now used on commercial aircraft to reduce engine noise. One of the current premier noise reduction projects at NASA is the X-59 experimental aircraft, featured in this Guide, which seeks to reduce the noise level of sonic booms.

This Guide was designed with both you and your students in mind. The Supporting Science Investigations include explanations of relevant background information, step-by-step instructions, and reflective student worksheets. The Supporting Science Investigations are provided to help extend students' knowledge about sound and can be used individually or together as you determine your students' needs for additional information and experiences with sound.

NASA supports educators and facilitators like you who play a key role in preparing students for careers in STEM fields through engaging content and experiences. Thank you for helping us share this learning experience with your students.

NASA's Lower the Boom Citizen Science Activity



One of many microphones to record sonic booms from the F-5E SSBE aircraft

This authentic, standards-based activity provides students with opportunities to gain tangible skills that are essential in STEM careers. Acting as citizen scientists, students will work in small groups or individually to collect and submit levels of ambient noise which may be of value to NASA scientists or researchers trying to answer the question, "How quiet is quiet enough?" for a sonic boom. The tool used to collect data for this Citizen Science Activity will be a free app from Anecdata that measures sound levels in decibels downloaded to a smart phone. The app, available for both Apple and Android devices, is designed to collect sound data similar to data collected by NASA researchers. If facilitators do not want to use the Anecdata app, they may collect the data using other apps or with a decibel meter and submit them manually through the Anecdata website. This means that the data collected by students could potentially be used in the future by NASA. Students will also document other important data such as Global Positioning System (GPS) location, temperature, and humidity using other free apps. Students will submit the data they collect via Anecdata. Students are encouraged to analyze the data they gathered, as well as all of the ambient noise data collected by other students in NASA's Lower the Boom Citizen Science activity, to look for trends and patterns.

What is Citizen Science?

Citizen science is the use of non-scientists to help researchers collect and analyze data for a specific project on which they are working. Research may require vast quantities of information or for data to be gathered across wide geographic regions, which is valuable to scientists who may not have the time or money to travel to all of those places. Citizen scientists can provide valuable support to researchers by collecting data that may be impractical for research organizations to gather on their own.

Citizen Science at NASA

NASA provides citizens of all ages the opportunity to make valuable contributions to our growing understanding of the Earth, our solar system, and beyond. Citizen scientists directly experience the excitement and inspiration of participating in projects that put them in the role of a real scientist. The following section will provide facilitators with helpful information about NASA aeronautics research to support implementation of this Citizen Science Activity, and other opportunities to help NASA can be found at https://science.nasa.gov/citizenscientists .

NASA Background Information

Aeronautics Mission Directorate (ARMD)

NASA-developed aviation technology is on board every U.S. commercial aircraft and in every U.S. air traffic control tower, providing direct benefits to air transportation systems and the aviation industry. Currently, NASA's ARMD researchers are designing, developing, and testing advanced technologies that will make the future of aviation quieter and more environmentally friendly, maintain safety in more crowded skies, and, ultimately, transform the way we fly. NASA's aeronautics research is primarily conducted at four NASA Centers: Ames Research Center (ARC) and Armstrong Flight Research Center (AFRC) in California, Glenn Research Center (GRC) in Ohio, and Langley Research Center (LaRC) in Virginia.

ARMD is making air travel better for everyone!

NASA Low-Boom Flight Demonstration Mission

In 1947, the X-1 made history as the first plane to fly faster than the speed of sound, also referred to as Mach 1. This historic achievement came with one major setback: the sonic boom. The noise generated by a plane moving at such a high speed is so loud and annoying that over 70 years later this technology is still not in use for mainstream air travel, and current regulations ban supersonic flight over land. For decades, ARMD has developed and tested an array of experimental aircraft called X-planes that examine the latest ideas in flight research. They have designed planes that had different shaped and sized wings, travelled at different speeds, and used different

The X-3 (center) and, clockwise from left: X-1A (Air Force serial number 48-1384), the third D-558-1 (NACA tail number 142), XF-92A, X-5, D-558-2, and X-4.

methods of propulsion. Each X-plane has taught us something new and moved forward the science of aviation.

For the first time in decades, NASA is developing and constructing a piloted X-plane designed to fly faster than the speed of sound with quiet supersonic technology. This mission will provide data that could enable commercial supersonic air travel over land. The key to success for this mission — known as the Low-Boom Flight Demonstration — will be to demonstrate the ability to fly supersonic while generating sonic booms so quiet that people on the ground will hardly notice them, if they hear them at all. NASA's aeronautical innovators are leading a government-industry team to collect data that could make supersonic flight over land allowable, dramatically reducing travel time in the United States or anywhere in the world. For example, a typical flight from New York to Los Angeles takes a little more than 6 hours. On a supersonic jet, that time could be decreased to a little more than 2 hours!

The Low-Boom Flight Demonstration mission has two goals. First, to design and build a piloted, large-scale supersonic X-plane with technology that reduces the loudness of a sonic boom to that of a gentle thump. Then, to fly the X-plane over select U.S. communities to gather data on human responses to the low-boom flights and deliver that data set to U.S. and international regulators. The current design being studied using computer simulation and wind tunnels is called the X-59 Quiet Supersonic Technology (QueSST). The X-plane's configuration will be based on a preliminary design developed by Lockheed Martin. The proposed aircraft will be 94 feet long, with a wingspan of 29.5 feet, and have a fully fueled takeoff weight of 32,300 pounds. At a cruising altitude of 55,000 feet, the X-plane will reach speeds of Mach 1.42, or 940 mph. Its top speed will be Mach 1.5, or 990 mph. The jet will be propelled by a single General Electric F414 engine, also used by F/A-18E/F fighters.

Click the link below to watch a video about NASA's X-planes
https://www.youtube.com/watch?v=DCIbBC4wprw&list=PLTUZypZ67cdvZ3TbQbDiqLdOkrCswmkUZ&index=1

NASA's Aeronautics Research Centers are playing a key role in the Low-Boom Flight Demonstration mission, which includes construction of the demonstrator and the community overflight campaign. Each Center's roles in developing the Low-Boom Flight Demonstrator are listed below:

- **Ames Research Center** in California manages configuration assessment and systems engineering;
- **Armstrong Flight Research Center** in California is responsible for airworthiness, systems engineering, safety and mission assurance, flight/ground operations, flight systems, project management, and community response testing;
- **Glenn Research Center** in Ohio works on configuration assessment and propulsion performance; and
- **Langley Research Center** in Virginia oversees systems engineering, configuration assessment and research data, flight systems, project management, and community response testing.

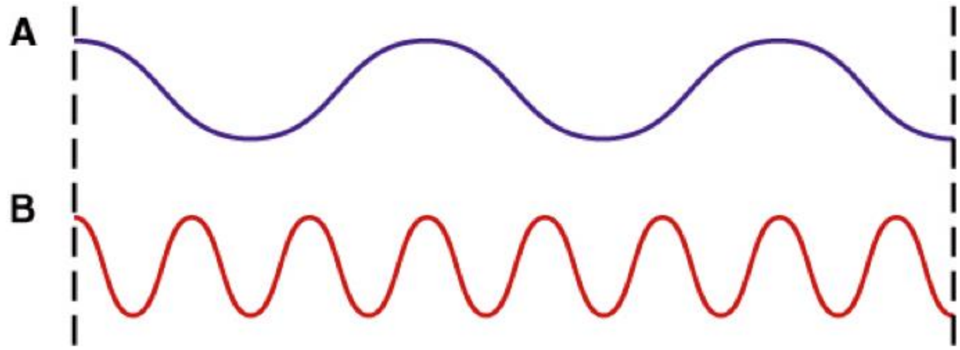
During the low-boom test flights, NASA will gather data on effectiveness of the quiet supersonic technology, in terms of public acceptance, by flying over several U.S. cities. The data collected from the public during NASA's Test Flight will be delivered to the Federal Aviation Administration (FAA) and the International Civil Aviation Organization (ICAO). The FAA and ICAO may use the data to develop new rules allowing commercial supersonic flight over land based on the public's perceived sound levels. However, the data collected by students for this Citizen Science Activity will not be delivered to the FAA and ICAO.

Science Background Information

Sound

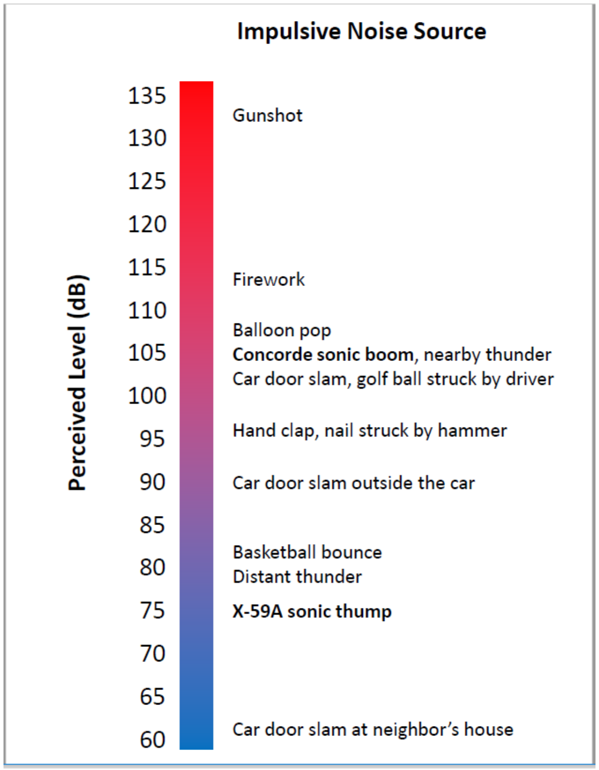
Sound is one of the many forms of **energy**. Sound is produced by vibrating objects and travels from one place to another through vibrating matter (solids, liquids or gases). The matter sound travels through is called a **medium**. Sound travels in the form of invisible waves called **compression or compressional waves**. Unlike water waves that move up and down, sound waves move toward and away from the source (repeated compressions and then spreading out of atoms or molecules of matter).

Pitch and loudness are two important properties of sound waves that affect human hearing**.** The pitch of a sound, how high or low the sound is perceived to be, is determined by the speed of the vibration; how fast the molecules in the medium are compressed and then spread out. Pitch is also referred to as the **frequency** of the sound wave. Frequency is measured in units of **Hertz** (Hz). One Hz is equal to 1 vibration or wave per second. Healthy human ears can hear sounds in the frequency range from 20 Hz – 20,000 Hz (20 kHz). Sounds that are high in frequency have a high pitch**,** like the squeak of a mouse or high notes on a piano. Low frequency sounds are low in pitch**,** like thunder or low notes on a piano.



An illustration of sounds with different frequencies but the same amplitude (Fig 1)

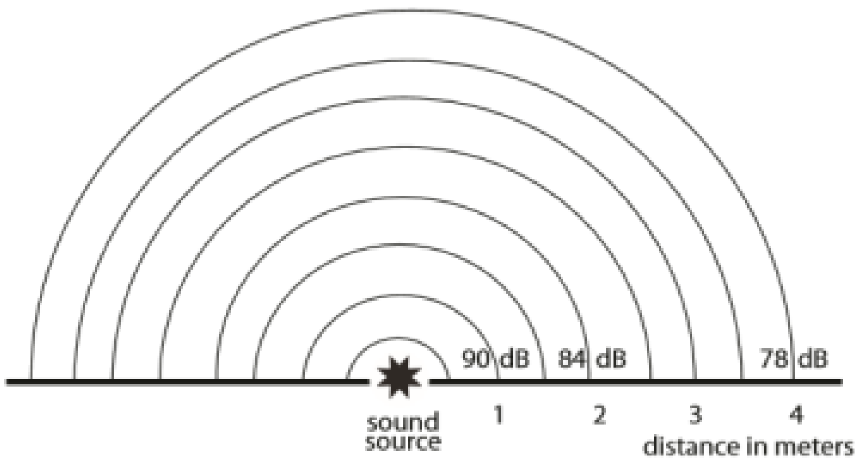
The loudness of sound is determined by the height of the sound waves (Fig 1). Scientists call this the intensity, or **amplitude** of the waves. Adding more energy to the object creating the sound makes the wave higher, producing a louder sound. Loudness of sound is most commonly measured in **decibels** (dB) (Fig 2).



The loudness of common sounds in decibels (Fig 2)

W. J. Doebler and J. Rathsam, "Stevens Perceived Levels of common impulsive noises, sonic booms, and sonic thumps," *J. Acoust. Soc. Am.* **145**(3), 2019

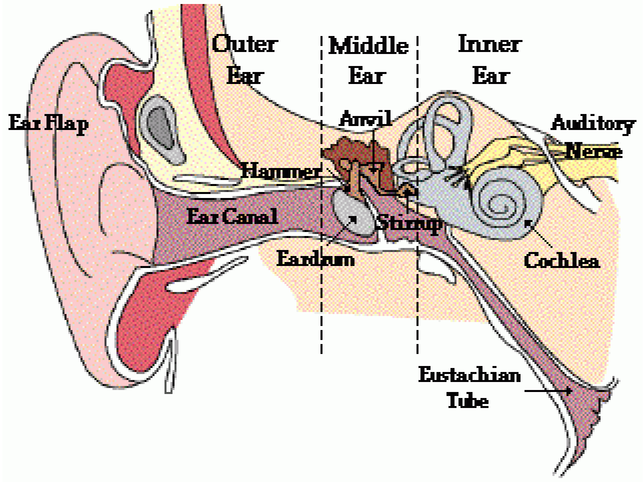
Since **sound waves** spread out as they travel away from the source, the sound intensity decreases over time. The farther the listener is from the source, the quieter the sound. See figure below.



Decrease in the loudness of sound with distance from source

An important note about the decibel scale is that it is not linear. This means that a sound that measures 10 dB is not 10 times as loud as a sound that measures 1 dB. On the decibel scale, a change of 10 decibels of intensity actually results in a sound that is twice as loud, not 10 times as loud. A sound that measures 60 dB is 8 times louder than one that measures 20 dB not 3 times louder. This type of relationship is called an **exponential relationship**.

The human ear is an amazing instrument for capturing sound and turning it into something the brain can detect. Again, it all has to do with vibration. The visible part of the ear is shaped to "catch" sound waves as they travel through the air. When the vibrating air molecules hit the eardrum, it starts to vibrate. The vibration is passed through the small bones of the inner ear: the hammer, anvil, and stirrup. The vibrations of these small bones are passed to the cochlea, which contains a fluid. As the fluid vibrates, hair cells change the vibrations to electric signals that travel through the auditory nerve to the brain. Your brain understands these electrical signals as sounds. Your brain then determines what the sounds mean and how to respond.



A diagram of the human ear
[*https://science.nasa.gov/science-news/science-at-nasa/2001/ast07aug_1*](https://science.nasa.gov/science-news/science-at-nasa/2001/ast07aug_1)

Humans and animals are subjected to background sounds all the time. This is referred to as **ambient sound**. The background noises that are present at a particular place can change with time and can be louder or softer depending on the location and time of day. Typically, there will be more background noise on a busy city street than in the woods.

Ambient sound that is so loud that it becomes annoying is called **noise pollution**. Noise pollution is caused mostly by human activity like transportation (cars, buses, planes, trains) and other types of machines (construction, factories, etc.), but there are also natural sources like thunder or volcanic eruptions. People who live close to areas where large amounts of noise are produced such as train tracks, airports, construction sites, or highways have the most problems with noise pollution.

The Sound Barrier and Sonic Booms

You may have heard the phrase "**breaking the sound barrier**," but what does it really mean? The sound barrier is "broken" when an aircraft exceeds the speed of sound. More accurately, it is the point at which the aircraft's speed increases from the **transonic range** (slower than the speed of sound) to the supersonic range (faster than the speed of sound). In rare instances, you can actually see the sound barrier being broken. The image to the left is of an F/A-18 Hornet with a white cloud enveloping the rear of the aircraft. At the precise moment the aircraft broke the sound barrier, a large drop in air pressure behind the wing created the cloud. Notice the smaller cloud that also formed near the rear of the cockpit, which is another sonic boom.

Jet breaking the sound barrier showing condensation of air shock wave

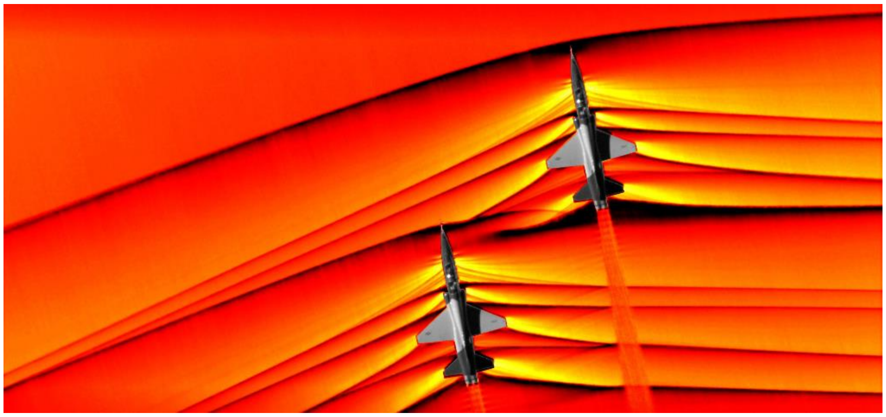
Pilots of jet aircraft often refer to their speed in relation to the speed of sound, using the term "**Mach number**", which is the ratio of the aircraft's speed compared to that of the speed of sound. **Mach One**, for example, is the speed at which sound travels or approximately 760 miles per hour at sea level. Mach Two equates to twice the speed of sound. At cruising altitude, most airliners today fly at approximately Mach .80 (M .80), or 80% of the speed of sound. A **sonic boom** is formed once a plane begins flying faster than the speed of sound. As the plane flies, air flows from the nose around the plane and past the tail. As the plane travels faster and faster, air molecules collide and build a high level of pressure around the plane. When the plane exceeds Mach 1, the air pressure becomes a **shock wave** and is quickly and constantly released as long as the plane continues to fly above the speed of sound.

NASA's Dr. Christine Darden played a major role in developing the science of sonic booms

This shock wave is actually the combination of two shock waves, one originating from the aircraft's nose and one from its tail that combine and release. To a person standing on the ground this quick release of built-up pressure produces a sonic boom, a very loud, low frequency sound that lasts less than one second. Some sonic booms are powerful enough to cause structural damage to buildings, but these are rare. The biggest concern with most sonic booms resulting from supersonic fight is that they are very loud and may annoy people if heard regularly, particularly people in the flight path. The higher the altitude of the plane and the farther the observer is from the flight path, the quieter the boom. However, even at normal cruising altitude for planes the noise is still too loud for people living near airports or along the flight path of a supersonic plane.   There are a variety of ways to mitigate this unwanted noise. The answer to how the X-plane's design makes a quiet sonic boom is in the way its uniquely shaped hull generates supersonic shock waves.

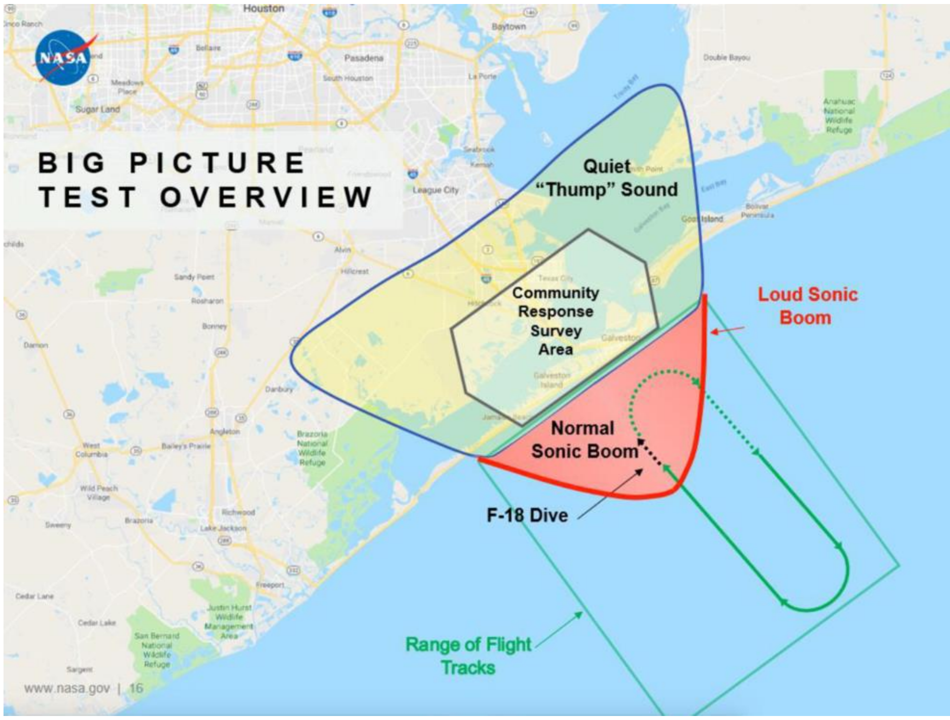
NASA's F-15B testbed aircraft with Gulfstream Quiet Spike sonic boom mitigator is a precursor to the X-59

Shock waves from a conventional aircraft design combine as they expand away from the airplane's nose and tail, resulting in two distinct and thunderous sonic booms. The X-plane's shape sends those shock waves away from the aircraft in a way that prevents them from coming together in two loud booms. Instead, the much weaker shock waves reach the ground still separated and are heard as a quick series of soft thumps, if anyone standing outside notices them at all.



Schlieren Photography lets us see shockwaves

A recent test in Galveston, Texas measured the loudness of sonic booms during a mission called Quiet Supersonic Flights 2018 (QSF 2018). Since the X-59 is still in development, another supersonic plane called the F/A-18 flew a question mark-shaped diving maneuver over the Gulf of Mexico, causing the sonic boom to be much quieter. NASA set up noise measuring devices around the Galveston area and recruited 500 residents to serve as citizen scientists to listen to the booms and submit their responses about how loud they found the sonic booms to be.

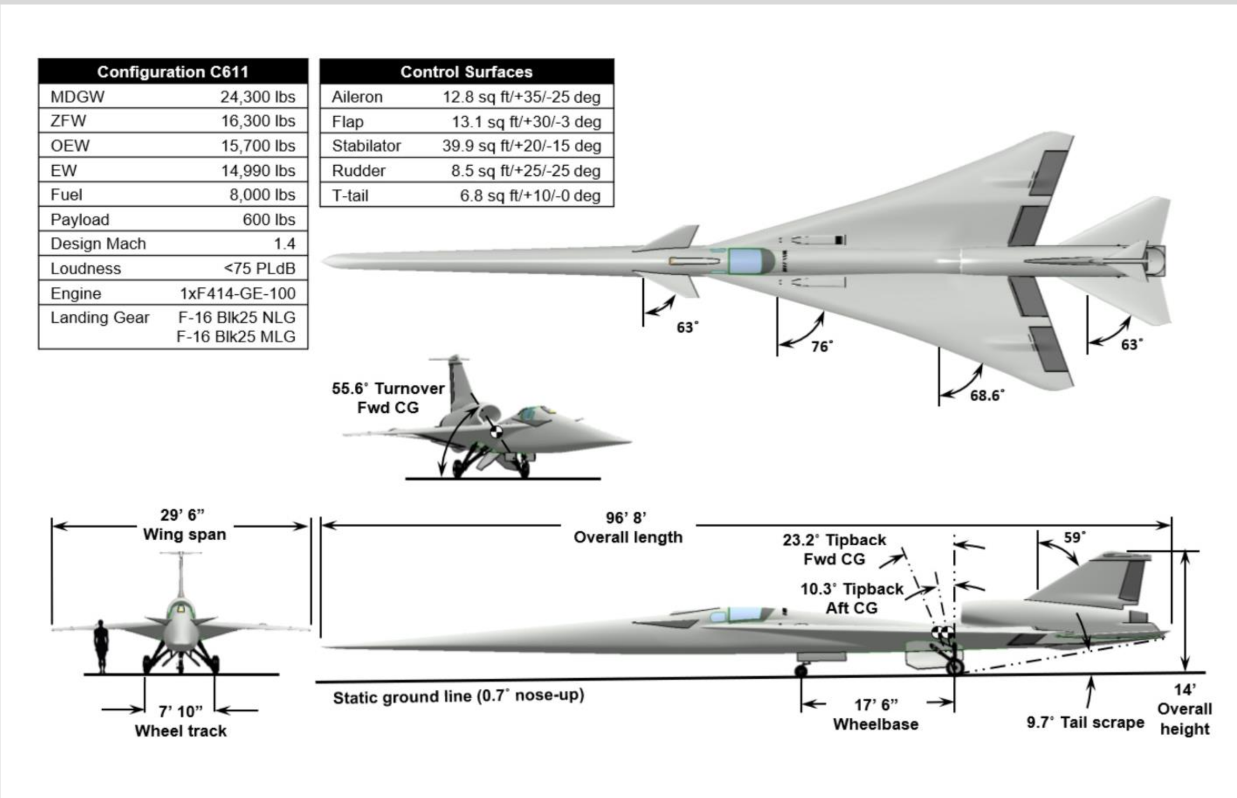


Predicted areas of QSF 18 noise level testing over Galveston, TX

Click on the link below to learn more about *How Sound Travels and the X-59*
https://www.youtube.com/watch?v=IRUoL4SBIjM&feature=youtu.be

Click on the link below to learn more about *Sonic Booms and the X-59*
https://youtu.be/OmXdeov-nYo

FACILITATOR INSTRUCTIONS



Configuration C611	
MDGW	24,300 lbs
ZFW	16,300 lbs
OEW	15,700 lbs
EW	14,990 lbs
Fuel	8,000 lbs
Payload	600 lbs
Design Mach	1.4
Loudness	<75 PLdB
Engine	1xF414-GE-100
Landing Gear	F-16 Blk25 NLG F-16 Blk25 MLG

Control Surfaces	
Aileron	12.8 sq ft/+35/-25 deg
Flap	13.1 sq ft/+30/-3 deg
Stabilator	39.9 sq ft/+20/-15 deg
Rudder	8.5 sq ft/+25/-25 deg
T-tail	6.8 sq ft/+10/-0 deg

Specifications of the X-59 QueSST

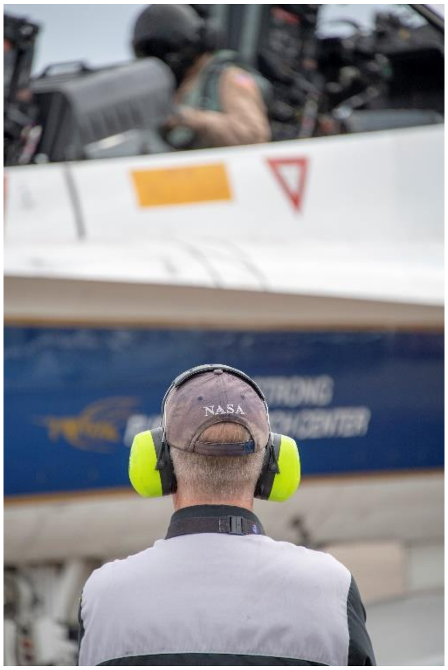
Safety

Safety is important in all areas of education, especially when conducting STEM activities. Facilitators should brief students on safety procedures before beginning any activity and provide close supervision during the activity to ensure that students are working safely; this should include a parent or other adult chaperone accompanying them at all times. Special care should be taken to make sure students have a safety plan in place when their group takes sound measurements around their community.

Data for this activity will be collected using a free online app called Anecdata. Per Anecdata's user recommendations, only students age 13 or older may enter data for submission. Recommend that students enable the safety features on both their smart phone and the Anecdata app.

Facilitators should:

1. Ensure students are aware of their surroundings, especially if collecting data near busy streets or construction sites.
2. Ensure that students are aware of appropriate hearing protections for their surroundings.
3. Ensure that each group has and uses a safety plan for collecting data around their community.



Aviation noise is so loud that hearing protection is essential

Students should:

1. Make safety a priority during all activities.
2. Assume responsibility for their own safety, as well as for the safety of others.
3. Use tools and equipment in a safe manner.
4. Stand still when using their smart phone or tablet. (Do not use mobile devices while walking or moving).
5. Wear safety glasses when conducting all Supporting Science Investigations.
6. Wear appropriate hearing protection when conducting ambient noise data collection.
7. Demonstrate respect and courtesy for others in the group, as well as for the environments in which they are collecting data.

Education Standards

The standards addressed here are tailored for middle school students based on the Next Generation Science Standards. Even if your state has not adopted these standards, similar core ideas are likely found in your state's standards. Common Core Math and English Language Arts (ELA) standards are listed below. This guide contains supplemental material that may be used in addressing the standards listed in the tables.

Next Generation Science Standards
PS4: Waves and Their Applications in Technologies for Information Transfer MS-PS4-1: Use mathematical representations to describe a simple model for waves that includes how the amplitude of a wave is related to the energy in a wave. MS-PS4-1: A simple wave has a repeating pattern with a specific wavelength, frequency, and amplitude. MS-PS4-2: A sound wave needs a medium through which it is transmitted. ESS3.C: Human Impacts on Earth Systems MS-ESS3-3: Apply scientific principles to design a method for monitoring and minimizing a human impact on the environment

Common Core – Mathematics
Measurement and Data Represent and interpret data Statistics and Probability Develop understanding of statistical variability Summarize and describe distributions Expressions and Equations Represent and analyze quantitative relationships between dependent and independent variables

Common Core – English Language Arts
CCSS.ELA-LITERACY.SL.6.4: Present claims and findings, sequence ideas logically, and use pertinent descriptions, facts, and details to accentuate main ideas or themes; use appropriate eye contact, adequate volume, and clear pronunciation. CCSS.ELA-LITERACY.SL.6.5: Include multimedia components (e.g., graphics, images, music, sound, etc.) and visual displays in presentations to clarify information. CCSS.ELA-LITERACY.W.6.7: Conduct short research projects to answer a question, drawing on several sources, and refocusing the inquiry when appropriate. CCSS.ELA-LITERACY.RST.6-8.3: Follow precisely a multistep procedure when carrying out experiments, taking measurements, or performing technical tasks.

Recommended Materials

Citizen Science Investigation

For each group:

- Smart phone or tablet with the following installed:
    - Free data app from Anecdata
    - Free oscilloscope app

For each Student:

- Copy of the student journal
- Loose leaf paper
- Graph paper

Supporting Science Investigation 1 – Good Vibrations

For the class:

- Tuning fork(s)
- Large bowl of water
- Uncooked rice
- Plastic wrap (colored wrap allows the rice to be seen more easily)
- Large empty bowl
- Metal baking pan
- Metal spoon
- Ping pong ball taped to a string approximately 20-30 cm long
- Rubber bands of various sizes
- Shoe box without a lid
- Tape
- Pencils (4)
- Tuning fork activator(s)
- Balloon taped to a string approximately 10-20 cm long
- Book

Supporting Science Investigation 2 – Making Waves

For each group:

- Pencils
- Various objects to use for creating sounds
- Smart phone with free oscilloscope app
- Tuning fork or tone generator
- Tuning fork activator
- Buzzer (optional)

Educational Strategies

Accessing Prior Student Knowledge

Prior to starting the Citizen Science Investigation, facilitators should assess students' existing knowledge and level of understanding. We suggest using a series of guided questions related to this specific activity. This discussion will allow facilitators to determine what the students already know about sound. If your students are not familiar with the principles of sound, try doing one or more of the Supporting Science Investigations with them before proceeding to the Citizen Science Activity. The following questions may provide a starting point for discussion:

- How does sound travel?
- How does sound move through different media?
- What are the frequency and amplitude of sound waves?
- How are loudness and pitch of sounds measured?
- What is ambient noise?
- What is noise pollution?
- How does noise pollution affect people? Animals?
- How quiet is quiet? How loud is loud? How can you determine this?

STEM Vocabulary

Citizen Science challenges students to collect data and make observations, reporting them to scientists who may use it for their own research. This activity will expose students to new vocabulary, such as 'decibel' and 'oscilloscope'. A list of related STEM vocabulary words is included in the Glossary at the end of this guide and are boldface throughout the guide itself. It is suggested that Facilitators use the glossary terms as often as possible in context, encouraging students to use new vocabulary as they work through the various parts of the activity.

Student Journal

After assessing students' prior knowledge about sound, provide students with copies of the Student Journal. These pages will be needed for data collection and the Supporting Science Investigations. Additional sheets should be made available as needed. Before beginning the activity, show the students the introductory video, "NASA Prepares for the Future of Supersonic Experimental Flight" located at https://www.nasa.gov/aeroresearch/videos . Click on "NASA Prepares for the Future of Supersonic Experimental Flight", (the direct link to the video is https://www.youtube.com/watch?v=ge69GyRJxLY).

Additional supporting videos are **Sound Effect Activity Demo** at https://youtu.be/ennpLpYMPv8 and **Senses of Sound Activity Demo at** https://youtu.be/KoztJbcU_tw .

Working in Groups

Students should work in groups of 2 - 4 to collect data for the Citizen Science Activity and to complete the Supporting Science Investigations. Students can choose their own groups or groups can be assigned. Assigning group roles can be a beneficial strategy for successful group work.

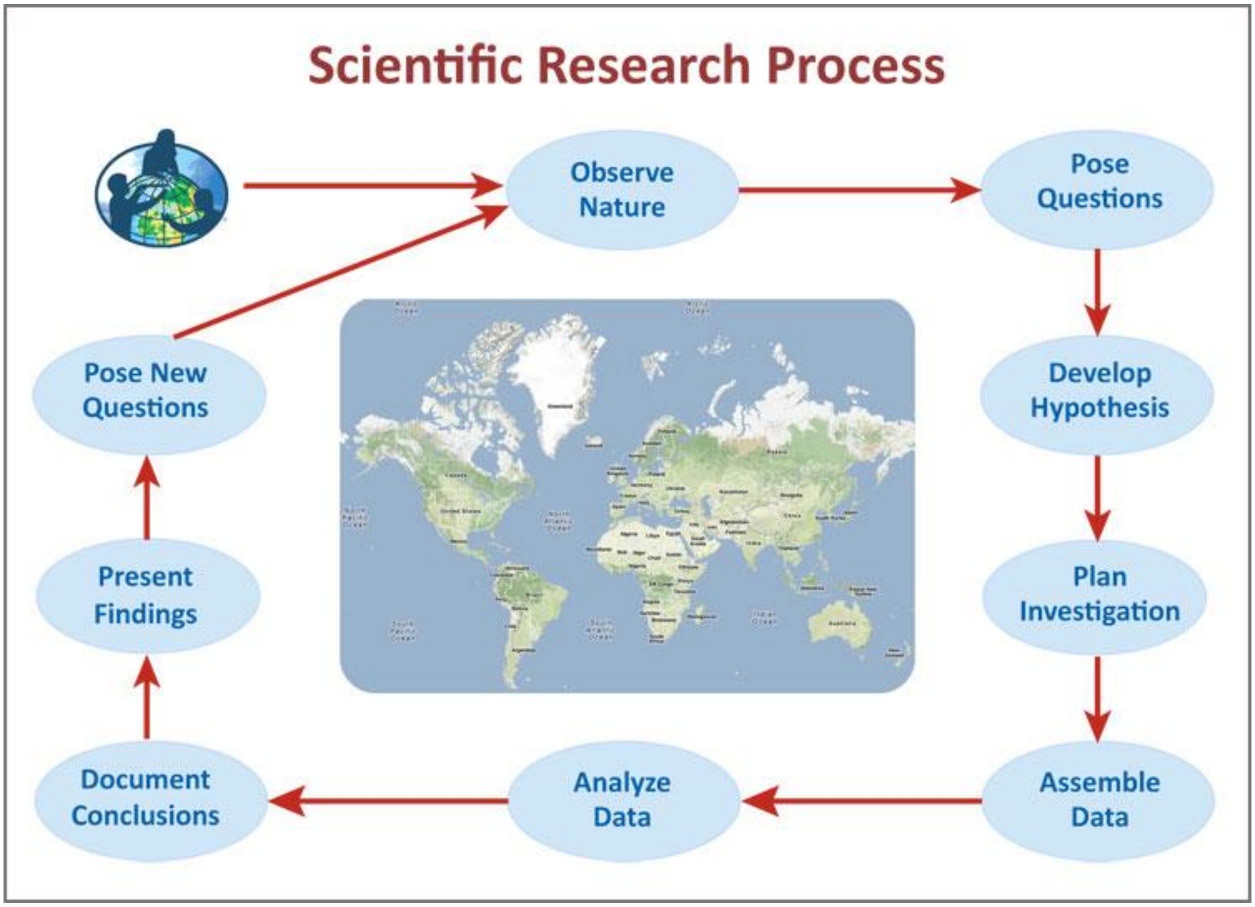
Suggestions include, but are not limited to:

- **Manager/Facilitator:** helps group stay on task, keeps track of time
- **Recorder:** writes down data
- **Spokesperson/Presenter:** presents group's ideas
- **Reflector:** helps the group come to a common conclusion
- **Encourager:** encourages deeper and continued thinking
- **Gatekeeper:** makes sure the group is listening to each other and various points of view

Options for Differentiation

- Form tiered student groups, regroup as necessary
- Provide checklist for data organization
- Make copies of all students' data for potential sharing and to fill in missing data
- Provide sample completed tables
- Data sheets may be recopied for clarity if difficult to read
- Provide pre-writing organizer or graphic organizer to help with presentation
- Encourage students to create a variety of graphs for comparison and discussion
- Provide examples of various types of graphs for students to review

The Scientific Research Process



Source: https://www.globe.gov/do-globe/research-resources/student-resources/be-a-scientist/steps-in-the-scientific-process

The Scientific Research Process (see diagram above) is a way to represent the sorts of things scientists do every day, regardless of whether they are chemists, astronomers, or physicists. There are nine steps in the process that can be repeated forever, as long as you have more time. Briefly, those steps are as follows:

- **Observe Nature** – Students begin scientific research by using their five senses to make observations around them, identifying a problem that needs to be solved or a phenomenon that needs to be understood.
- **Pose Questions** – Based on observations, students brainstorm questions that are interesting to them and are able to be answered in the time available for the module.
- **Develop Hypothesis** – Suggest an answer to the question based on what is already known. A useful hypothesis is a testable, measurable statement.

- **Plan Investigation** – Outline how data will be collected (where, when, how) to ensure that the data collected will answer the question and test the hypothesis. Useful data must also be precise (repeatable), so measurements must be performed the same way each time.
- **Assemble Data** – Following the investigation plan, take the measurements of data.
- **Analyze Data** – Data analysis often involves comparing data from different times and places, and looking for patterns and different types of variations. Construct graphs or charts to help look for patterns and trends in the data.
- **Document Conclusions** – Carefully review what was performed during the investigation. Concentrate on any trends that may have been noticed when the data was analyzed. Look at any graphs that were made. Based on the data collected, make a statement about what was learned from the data collection. Was the hypothesis supported? Explain why or why not.
- **Present Findings** – It is very important that scientists share the results of their research with their peers and the community. This can take many forms, such as a science fair or a poster presentation.
- **Pose New Questions** – It is rare that a scientific question is answered by just one experiment or investigation. Think about and record other questions that have been raised by this investigation and how to answer them.

NASA's Lower the Boom activity focuses primarily on having students **Plan their Investigation**, **Assemble Data,** and **Analyze Data** – although a facilitator may choose to explore all nine steps with students. For NASA's Lower the Boom, worksheets for these steps are provided in the Student Journal. Additionally, NASA's Lower the Boom will be using the Anecdata (available for web, Android, and iOS) for formal submission to NASA. Students will plan their investigation by selecting appropriate locations and considering how to safely and accurately collect data. Students will assemble data as they take measurements of ambient noise levels, temperature, humidity, and as they record the GPS location, time and observations of their data collection site. Likewise, students will analyze data as they prepare charts, graphs, and formulate explanations for the patterns they observe.

Steps for NASA's Lower the Boom

Facilitators should begin by leading a discussion encouraging students to share their personal knowledge of ambient (background) noise levels in their lives. Ask if they are familiar with the concept of Citizen Science or are aware of any Citizen Science Projects. Provide information on the topic of Citizen Science as needed. Provide students with information on sonic booms and current NASA-related work on supersonic flight using background information provided in this Guide or other sources. To supplement the background information and concepts, you may choose to show students supporting videos or conduct other activities listed in the NASA Resources section located in the Appendices of this guide. To participate in this Citizen Science Activity, students will use a free app from Anecdata to collect and record data. Most smart phones should be acceptable to use. If all students do not have a smart phone, they can take turns collecting data using someone else's smart phone.

Steps

1. **Plan Investigation**
   A. Students brainstorm possible areas to measure noise levels and capture data.
   B. Groups develop a plan to conduct a safe investigation.
   C. Groups identify variables that could affect the data collection process.
2. **Assemble Data**
   A. Students need to visit the Anecdata website (https://www.anecdata.org), locate the "NASA's Lower the Boom" project, and register as a participant. **For privacy purposes, be sure not to use student names when registering. Instead of Johnny Smith, use JS or possibly the group name. Note: only students 13 years or older may register.**
   B. Students then use a smart phone with the Anecdata app to collect and record noise level data. Review with students the importance of collecting high quality data, data that is accurate and precise. Note – some smart phones have a built-in feature to reduce or remove ambient noise, students need to disable this feature.
3. **Analyze Data**
   A. Students interpret and analyze their group's data.
   B. Students compare / contrast their data with other groups.

Step 1 – Plan Investigation

Part A – Brainstorm collection areas

Use the Guiding Questions below to help students brainstorm locations to measure noise levels.

Guiding Questions

- What would make an area an unsafe place to collect data?
- Where are some safe places to take noise level measurements (e.g., sports fields, school parking lot, or nearby sidewalk area)?
- Where would noise levels be at their highest? Lowest?

Part B – Develop a Plan

The facilitator should arrange students into groups of 2 to 4 students. Use the Guiding Questions below to help students create their data collection plans. Student groups should select which areas they will investigate and measure noise levels. In groups, students should write a clear plan of how they will safely collect data.

Guiding Questions

- At what site(s) will you collect data?
- At what time(s) will you collect data?
- How will the group get to the site?
- How many times will you test sound levels at the site?
- What safety measures will you take into consideration when collecting data? Remember, consider safety first and avoid potentially dangerous situations (i.e. railroad tracks or construction sites).

Part C – Identify Variables

Discuss what variables could interfere with or affect data collection. Possible responses might be nearness to traffic, presence of large nearby buildings, weather, time of day, and others. The facilitator should guide a discussion of data collection strategies.

What type of data measurements will be taken? The type of sampling will affect the data. Use these examples to create a discussion with the students:

- Convenience sampling (using a nearby location)
- Controlled variance (same spot 8 times a day)
- Random sampling (any changeable situation, location, or time of day)

Guiding Questions

- What variables will you need to control when taking your measurements?
  Example: same way of holding your smart phone**.**
- What variables are unable to be controlled?
  Examples: amount of traffic, weather.
- What type of sampling will best fit your needs?
  Use above data collection sampling information.

Step 2 – Assemble Data

Part A – Register for NASA's Lower the Boom on Anecdata

Students will collect data using a free app from Anecdata. Each group will need to register for an Anecdata account as part of the "NASA's Lower the Boom" project and download the app in order to collect data.

Follow the instructions listed below to register with Anecdata.

1. On your smart phone, go to https://anecdata.org and select the blue “Register” button.
2. Enter your email address.
3. Under “Name”, enter your first name only. Do **not** enter your full name.
4. Under “Username”, choose a name for your team. For example, use a name such as DATA CRUNCHERS or NOISE WIZARDS.
5. Choose a password and be sure to write it down.
6. For the last box, put “Signed up for NASA’s Lower the Boom project.”
7. Once you are logged in, you will click on “Projects”, located just to the right of “Home” on the top menu bar.
8. Search for “NASA’s Lower the Boom” and once there click “Join”. You are now part of the project.

When you are ready to start collecting data, you will need your smart phone, a blank data sheet, and a pen or pencil.

1. Using any weather app on your smart phone, find the current temperature in Celsius and the humidity (same as relative humidity) in percent. Record the temperature and humidity on your data sheet.
2. Write your opinion of the noise level at your location on your data sheet. You may write ‘quiet’, ‘average’, or ‘noisy’.
3. Click on the Anecdata app and log in.
4. From the items on the left, click on “Projects.” You should now see “NASA’s Lower the Boom” on your screen.
5. Click on “Add Observation.”
6. Enter the temperature, the humidity, and your opinion as to whether the site is quiet, average, or noisy.
7. Hold your smart phone as still as you can with the microphone pointed toward the direction of the sound you want to record.
8. Push the “Measure” button for five seconds to measure the ambient noise. Be sure to hold still and quiet while taking the measurement. Also, do not cover the microphone while you are taking the measurement.
9. In the “Other Notes and Comments” section add anything that might affect your reading, such as wind and weather conditions, whether a noisy bus passed by, or maybe someone coughed. Then click on the blue “Save Observation” button.
10. Be sure you record the sound level and your notes on your data sheet.
11. NOTE: When collecting data in an area where cell service is not available be sure to save your measurements. When you return to cell service area go to the data on your home page to select the measurements that have not been sent. Then choose “Upload” to send the data from those measurements to Anecdata.

Facilitators direct students as follows:

You are now ready to make another observation at that location or move to another location. Make as many observations as you like or as your facilitator directs. Make sure to press *SAVE* before moving to another location.

You can review all of your observations on your home page. When you have finished taking measurements and reviewing your data, be sure to log out of Anecdata.

Each time students take a measurement, the data will be collected automatically. The Anecdata app will calibrate the device's settings prior to recording the following:

- GPS location – Latitude in degrees North and Longitude in degrees West
- Date of data collection
- Time data was collected
- Loudness of the ambient noise in decibels(dB)
- Type of smart phone being used
- Temperature and humidity

Part B - Use of Smart Phone Apps to Collect Data

Student groups will follow their data collection plan to take ambient sound measurements and record data using an app available from Anecdata. In addition to submitting their data in Anecdata, students will record their data on the Data Table page from the Student Journal. This will help ensure all data is available for discussion and analysis.

The Importance of Accuracy, Precision and Calibration in Data Collection

It is essential that high-quality data be collected in order to answer scientific questions. High-quality data should be both accurate and precise**.** **Accuracy** refers to how closely the data collected matches the true level of the sound. **Precision** refers to how closely repeated measurements match each other. A useful way to remind students of the difference is using a bull's eye example.

 Accurate (close to center of target)	 Precise (close to each other)	 Accurate AND Precise (close to the center AND to each other)

During the Citizen Science Activity, accuracy will be limited by the type of smart phone students are using. Precision can be addressed by monitoring students' readings onsite or in a practice session. The more consistent the students are in following the data collection process, the higher the precision.

The app will configure the smart phone and calibrate the recording volume of the microphone. This calibration is built into the app. The user can remove any barriers like lint, cases, or other obstructions from the device's microphone.

Guiding Questions
Use the following questions as discussion prompts to focus student understanding.

- Is all your data entered accurately in Anecdata and legibly on the Student Data Table? Did you get a similar sound measurement using different devices?
- How precise were your sound measurements? Did you get a similar reading when you took the measurement multiple times?
- Are you missing any data for a given day or location?

Step 3 – Analyze Data

Part A – Students interpret / analyze their own data
Students should complete the Students Analyze Data page from the Student Journal.

Data analysis often involves comparing data from different times and places, and looking for patterns and different types of variations. Determine the best way to view the data to look for trends and patterns. Examples include the use of different types of graphs, charts, or re-organization of the data table.

Guiding Questions
Use the following questions as discussion prompts to focus student understanding.

- Did anything unusual happen during data collection that we should mention to NASA? Note this in the Observation column on the Data Table and in Notes on Anecdata.
- What type of graph might portray the data in an understandable way for NASA?
- Do you notice any trends or patterns in the data? What do you think they mean? What might you ask a NASA scientist to explain?

Suggestions for data analysis include comparing and contrasting data over a period of time, at different locations, or under different weather conditions. Remind students that collecting and analyzing data is an important part of the work NASA scientists do.

Part *B – Students compare / contrast the work of others*

Guiding Questions
Use the following questions and prompts to focus student understanding.

- How will you or your group present the data to your group? Will you use a poster, a video, or a slide presentation?
- Use the Presentation Criteria to help in your planning.
- Follow the checklist to be sure you include all information, e.g., the variables in your presentation.

Suggested Pacing

Facilitators should condense or expand the structure of the activity, or add additional activities to fit their specific needs. Activities could take more or less time depending on the number of students, their ages, and their background knowledge. Combine steps as needed to fit the length of your sessions.

Supporting Science Investigations

The following pages contain two Supporting Science Investigations to help develop students' understanding of sound concepts. Ideally, students will complete the investigations before starting the Citizen Science Activity. Facilitators can use the Accessing Prior Student Knowledge suggestions to determine which concepts need development, to ensure students understand how sound is produced, how it travels, and differences in its properties, such as pitch and loudness.

Note to Facilitators – In the absence of a tuning fork, students are still able to complete other parts of the Supporting Science Investigations, such as the Vocal Cord Station, Shoebox Strings Station, and Making Waves.

Investigation 1: Good Vibrations – In this investigation, students visually and audibly experience how sound is produced by vibrating matter and how sound wave vibrations travel through various media. At each station, students will gain an understanding of the way sound waves travel through various solids, liquids, and gases; such as water, air, and the human vocal cords and throat.

Investigation 2: Making Waves - In this investigation, students will use a free oscilloscope app on their smart phone to view waveforms of different sounds. They will create various sounds using their voices, hands, and everyday objects near their smart phone to see the shape of the waves on the oscilloscope. The loudness and pitch of the sounds will be illustrated by the wave height and frequency of the waveforms.

Supporting Science Investigation 1: Good Vibrations

Objective: The students will observe that sound is caused by vibration of objects; travels through solids, liquids and gases called a medium; and that the atoms or molecules that make up the medium vibrate and pass along the energy by bumping into each other.

Activity Overview: Students will travel to six different stations to observe sound vibrations and how the vibrations travel through different mediums.

Science Background: Sound energy is produced by the **vibration** of objects. **Sound waves** travel from one place to another through vibrating matter (solids, liquids, or gases). The matter through which sound travels is called a **medium**.

Materials: For the whole class, set up six stations according to the procedure below. You may want to label each station with a sign**.**

- Bowl of water
- Ping pong ball attached with tape to the end of a string, approximately 20-30 centimeters long
- Tuning fork activators
- Tuning forks
- Rubber bands of various sizes
- Shoe box without a lid
- Tape
- A book
- 4 pencils
- Inflated balloon taped to a 20-30 cm long string
- Uncooked rice
- Plastic wrap
- Large empty bowl
- Metal baking pan
- Metal spoon

Note: Tuning fork activators can be purchased where tuning forks are sold. Students can also strike the tuning fork against a rubber-soled shoe to start it vibrating. Caution students not to strike the tuning fork too hard against objects. You may also be able to borrow tuning forks from your local high school.

Vocabulary: sound waves, medium, vibration

<u>Vocal Cord Station</u>
Materials: no materials needed
Procedure:
1. Students will hold 2-3 fingers against their throat and talk, sing or hum, varying the type of speech sounds such as high or low and loud or soft.
2. In the Data Observation box, students should describe what they felt as they made sounds.

<u>Tuning Fork Station</u>
Materials: large bowl with water, tuning fork, and tuning fork activator
Procedure:
1. Add water to the bowl to approximately two inches deep.
2. Students will strike a tuning fork against a tuning fork activator and dip the prongs into the bowl of water.
3. Students should describe what happens in the water in the Data Observation box.

<u>Ping Pong Ball Station</u>
Materials: ping pong ball taped to the end of a 20 - 30 cm string, tuning fork, and tuning fork activator
Procedure:
1. One student in a standing position holds the end of the string with the ping pong ball hanging down. Try to keep the ping pong ball as still as possible.
2. Another student strikes the tuning fork against a tuning fork activator and slowly moves the prongs of the tuning fork toward the ping pong ball until it **<u>just barely</u>** touches it.
3. Students should describe what happens to the ping pong ball in the Data Observation box.

<u>Dancing Rice Station</u>
Materials: large bowl, plastic wrap, uncooked rice, rubber band to fit around bowl, metal pan, and metal spoon
Procedure:
1. Stretch and pull the plastic wrap very tightly over the top of the bowl, securing it with a rubber band.
2. Place 10-20 grains of uncooked rice on top of the plastic.
3. Have students place the metal pan next to, but **<u>not</u>** touching the bowl.
4. Student should hit the metal pan with a spoon.
5. Student should describe what happens in the Data Observation box.

<u>Buzzing Balloon Station</u>
Materials: balloon taped to a 10 – 20 cm length of string, tuning fork, and tuning fork activator
Procedure:
1. While standing, one student should hold the balloon with their arm straight out.
2. Another student should strike the tuning fork against a tuning fork activator and gently move the tuning fork toward the balloon until **<u>just barely</u>** touching it.
3. Students should describe what they see and hear in the Data Observation box.

<u>Shoebox Strings Station</u>

Materials: shoebox, book, four pencils, two rubber bands

Procedure:

1. Place one rubber band around the book and one around the shoebox. Place the shoebox on a table open side down.
2. Place two pencils beneath the rubber band on the book, 10 centimeters apart and parallel. Do the same on the shoebox.
3. The students will pluck the rubber bands between the pencils on each set up. Compare what is heard and felt on the top of the shoebox to what is felt and heard on the top of the book.
4. Students should write a description of their observations in the Data Observation box.

Facilitator Notes:

At the Shoebox Strings Station, the pencils act as “bridges” holding up the rubber bands similar to a bridge on a violin or other stringed instruments. This means they hold the rubber bands off the surface. The rubber band on the book is able to move freely because of this bridge. Plucking the rubber band adds energy, which produces sound due to the rubber band vibrating. Sound also travels through the box and the book, which students can feel.

Discussion Questions:

The facilitator should lead a verbal discussion with students using the following questions and suggestions. Written answers are not required, but this guide includes some guidance about common student responses in red.

- Where did you feel vibrations? When?
  Sample Answers may include: Vibrations could be felt when touching any of the solid objects like the book, shoebox, or metal pan. Vibrations were present only when energy was added to the object to make sound.

- How were the vibrations from the various stations different? The same?
  Student Answers will vary.

- Have students share observations from *Data Observation* boxes and discuss.

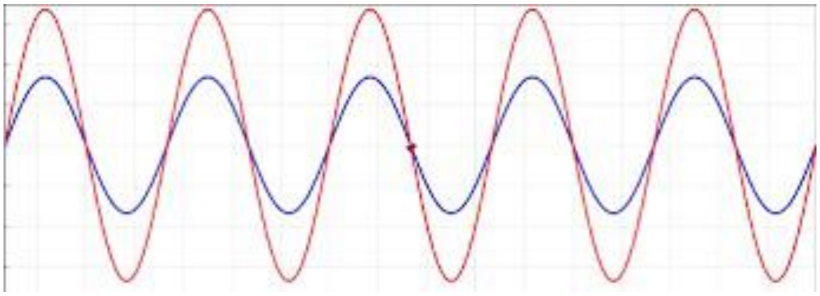
Supporting Science Investigation 2: Making Waves

Objective: Students will demonstrate how loudness and pitch of a sound are related to the amplitude and frequency of the sound waves.

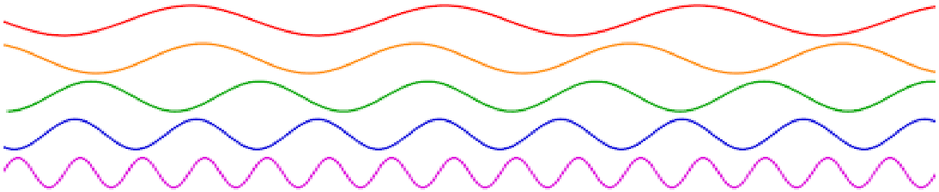
Activity Overview: In this activity, students will create various sounds using their voices, hands, and everyday objects to see an image of the frequency and amplitude of the sound waves by observing the waveform on an oscilloscope app.

Science Background: Sound and other forms of energy travel as waves. Waves have two important properties, **frequency** and **amplitude** (intensity). Frequency of sound waves is the measure of the speed of the back-and-forth vibration of the sound wave and determines the sound's pitch. The closer the waves are to each other the higher the pitch. Amplitude of a sound wave is how high the wave moves up and down. It is a measure of the loudness of the sound. An oscilloscope is an electronic instrument that shows energy waves, like sound, into a picture called a **waveform**. You will be using an app on a smart phone that acts like an oscilloscope.

In the waveform diagram below, both the red and blue waves have the same distance between waves, so they are the same pitch. The red waves are taller than the blue waves, so these waves would have a louder sound.



Amplitude: The taller wave has a higher amplitude than the shorter wave and is louder



Frequency: Waves of different frequencies, lowest frequency on top. The bottom wave has the highest pitch.

Materials: for each group

- Various objects to use for creating sounds; especially any musical instruments, even toy ones if available.
- Smart phone with free oscilloscope app downloaded.
- Tuning fork and tuning fork activator. If you don't have a tuning fork, download a tone generator app to a different device. This will generate a single frequency sound. You could also use a buzzer.

Vocabulary: oscilloscope, frequency, amplitude, waveform

Procedure:

Students should work in groups of 2 - 4. You can adjust group sizes based on the number of devices available.

1. At the start of the activity, check to see that all groups are seeing a similar waveform using a tuning fork or tone generator. You may have to make some adjustments depending on the oscilloscope app so all groups see a similar waveform.
2. While making various high, low, loud, and soft sounds, model using the oscilloscope app to display types of waveforms produced by the sounds.
3. Have students practice using the oscilloscope app and making various sounds.
4. To begin making observations, have a student in each group make a low, deep pitched hum and then a high-pitched hum. Students sketch the waveforms for each on the Data Sheet on the next page. **Remember: Try to keep the loudness the same and just change the pitch.**
5. Next, have a student hum loudly, then hum softly and sketch the waveforms.
6. Then have a student hum a single note, then hum a song and draw a sketch of the waveforms on their data sheets.
7. Have a student strike the tuning fork with the tuning fork activator, observe the waveform of this sound, and sketch it. Use a sound tone generator if tuning forks are not available. Then have someone try to imitate the tuning fork sound with their voice. Students sketch the waveform and compare it to the tuning fork's waveform.
8. If time permits, try other sounds such as clapping, singing, and any musical instruments available. Students sketch and compare the waveforms.

Discussion questions:

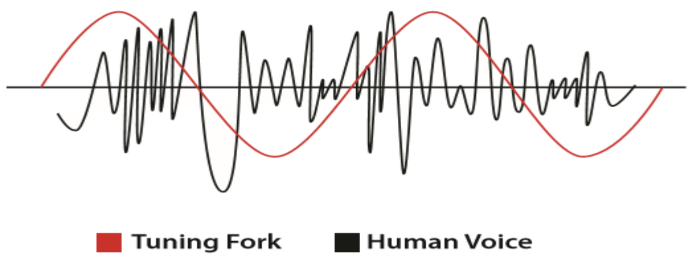
- How did the wave pattern change as the sound grew deeper? Higher?
  Sample Answer: The waves are farther apart for lower or deeper sounds, and closer together for high sounds.

- What inferences can you make about the frequencies of the two sounds?
  Sample Answer: Lower sounds have lower frequencies than higher sounds.

- How did the wave pattern change as the humming grew louder? Softer?
  Sample Answer: The waves produced by loud sounds are "taller" (bigger in the up and down direction) than soft sounds.

- What inferences can you make about the amplitudes of the two sounds?
  Sample Answer: Louder sounds have larger amplitudes than soft sounds.

- Compare the waves from the tuning fork and the voice. How are they the same? How are they different?
  Sample Answer: The tuning fork should produce a single wave of one frequency, shown below as waves that are the same distance apart. A voice talking produces a set of waves of different frequencies and varying heights. This is shown below as uneven waves.



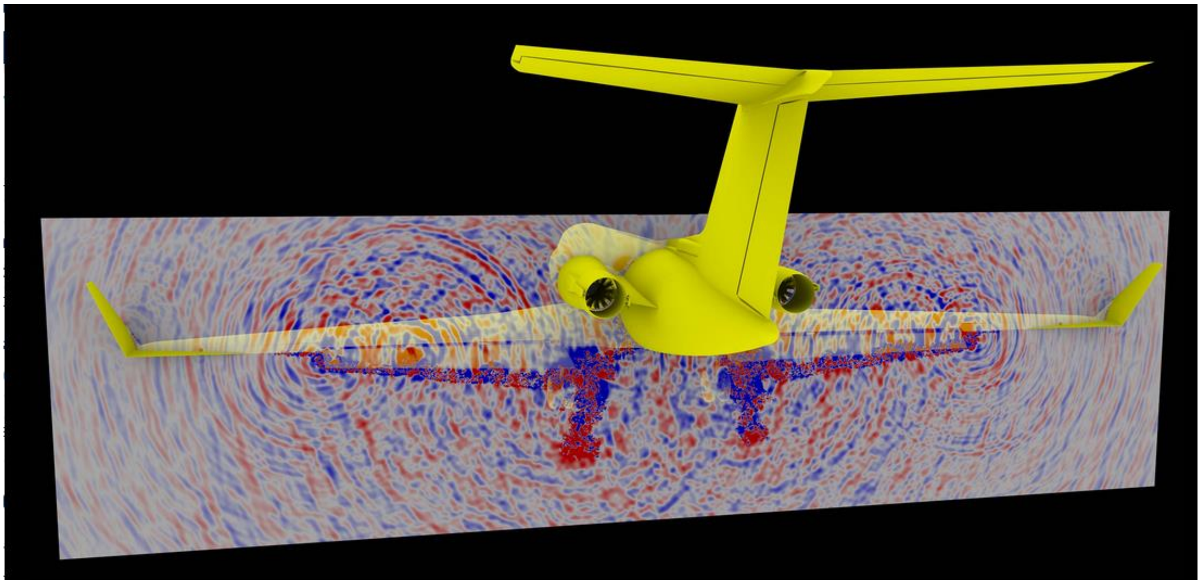
- Share with other groups the sketches you made. Are they similar? Why or why not?
  Sample Answer: Because our tuning fork was a different note than theirs.

STUDENT JOURNAL

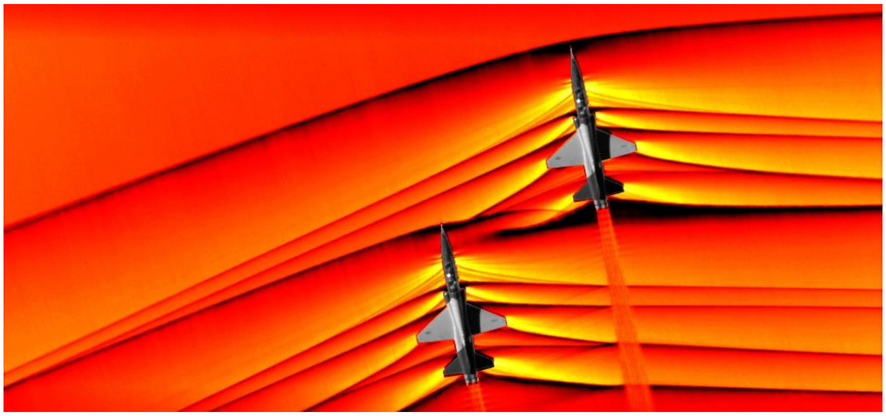
A student thinking about sound by collecting data with the Anecdata app

Introduction

Sounds are all around you – loud, soft, pleasant or annoying. We sometimes take our noisy world for granted, but should it be quieter? How quiet is quiet enough? This is also a question that NASA is tackling related to the noise produced by a supersonic jet: a sonic boom! While NASA engineers are currently designing a new plane with reduced noise levels, citizen scientists all over the country will be collecting noise data. Using your favorite smart phone, you will measure noise levels in your area and upload the data automatically through the Anecdata app. Follow your facilitator's instruction on downloading the Anecdata app. We hope you accept the challenge to find out how quiet your location is!



Computer simulation of sound waves emanating from a Gulfstream G-III aircraft during approach. Red and blue contours represent maximum and minimum sound pressure levels, respectively.



Schlieren Photography lets us see shockwaves.

Step 1 - Plan Investigation: Students Brainstorm

Within your group, brainstorm possible areas to investigate noise levels and capture data using your smart phone. Things to consider:

- What would make an area an unsafe place to collect data?
- Where are some safe places to take measurements of noise levels? Examples: sports fields, school parking lots, nearby sidewalk areas
- Where would noise levels be at their highest? Lowest?

Step 2 - Plan Investigation: Students Plan

Data Collection Plan: Fill in the chart below to help form your plan.

How will we stay safe while collecting data?	
Who will collect data?	
What data will we collect and record beyond what is collected automatically by Anecdata? (Date, Time, Location, and Type of Device)	
When will we collect data?	
Where will we collect data?	

Step 3 - Plan Investigation: Students Identify Variables

Within your group, discuss what things can affect the data collection process.

- Will the location present variables (a **variable** is anything that can change)? An example of this might be the time of day, or the date.
    - Be sure the variables are relevant to your process of collecting ambient noise. Whether you use a pen or pencil to collect data would not be a relevant variable
- Are there constants (a **constant** is anything that stays the same)? An example of this is that everyone will be using the Anecdata app.

Variables and Constants in the Data Collection: Record all variables and constants that may affect the data collected to the table below.

Variables	• Date • Time • Weather • Location • Ambient Noise • ____________________________________ (Other Variables) • ____________________________________ (Other Variables)
Constants	• Anecdata App • ____________________________________ (Other Constants) • ____________________________________ (Other Constants) • ____________________________________ (Other Constants)

Step 4 - Assemble Data: Students Submit to Anecdata

Things to consider when taking measurements:

- Determine where the microphone is on your device so that it is pointing in the direction of the sound(s) you are trying to measure.
- Stand at least several feet away from other participants that are gathering data to minimize interference.
- Be aware of nearby buildings or large structures that may block sound.

Steps for collecting data:

1. Be sure not to cover the microphone as you hold the device.
2. With the device in your hand, hold your arm straight out from your body, waist high.
3. Take 3 to 5 measurements for each location by clicking on *+ add another* after each measurement. When finished measuring press *SAVE* located in the upper right corner the Anecdata app, and record all information on the Data Sheet. Also, record all relevant details, such as a bus passed by, under *Notes* in the Anecdata app and on the Data Sheet. Repeat this step at several different times and dates.
4. After saving your data, the Anecdata app will automatically upload the data if Internet connectivity is available. If not, then upload the data when you get back to your class or after school group, and have Internet access.

NOTE: You must be at least 13 years old to enter data on the Anecdata site.

Data needed • Temperature (obtained from a weather app) • Humidity (obtained from a weather app) • Opinion of Noise Level (Noisy, Normal, Quiet)
My sources to collect the data • Ambient noise (taken with Anecdata app) • Time and Location • Type of mobile device • ___________________________________ (Other Sources)
Description of my overall strategy to collect data
Steps I will take to make sure the data is precise

Data Table							
Type of Site (playground, park, backyard etc.)							
Date	GPS location	Time AM or PM	Decibels (In dB)	Opinion of loudness	Humidity	Temperature in degrees C	Notes

Step 5 - Analyze Data: Students Analyze Their Data

Data analysis often involves looking for patterns and different types of variations. Look at your data for trends and patterns. Use the questions below to help you understand your data.

1. What obstacles did you have when collecting data and how did you overcome them?

2. Decide which type of graph might portray the data in the most understandable way. Could you use more than one type of graph? Your facilitator can give you suggestions and examples of types of graphs.

3. After constructing the graphs, look for patterns and trends on the graphs. Describe the pattern or trend.

4. List any data that seemed different from the majority of the other data? Explain why you think it was different.

Step 6 - Analyze Data: Students Compare & Contrast Data

After collecting data, students should discuss their findings with other groups to compare and contrast what they have learned. It is important that scientists share the results of their research with their peers and the community. You can create a video or slide presentation to present your data. Use the checklist below to determine what you should include in your presentation.

Checklist for Presentation:

Criteria	Completed	Still need to do	Group Member Responsible
1. Determine areas to investigate noise levels.			
2. Write a plan describing how we would collect data.			
3. Identify variables that could affect data collection.			
4. Describe the site and existing conditions and variables.			
5. Use appropriate processes and instruments to collect data.			
6. Explain how we analyzed our data and our interpretations.			
7. Plan how to present our findings of the data orally.			

Supporting Science Investigation 1: Good Vibrations – Student Pages

In this investigation, you will visit different stations to discover various ways sound travels. You will be able to see, hear, and feel the way vibrations cause sound. You may want to repeat the activities at the stations if you have additional time!

Sound is caused by **vibration** of objects. Sound travels through solids, liquids, and gases. These are called media or a **medium**. The atoms or molecules that make up the medium vibrate and pass along the energy by bumping into each other.

Safety Note: The proper way to strike a tuning fork is to strike it firmly against a tuning fork activator. Follow your facilitator's direction if you do not have a tuning fork activator. Avoid striking fragile objects or swinging the tuning fork near people. Do not strike the tuning fork against a hard object, especially a table edge. The bottom of your shoe would be a good choice.

Breaking into Groups:

1. Before breaking into groups, make sure you have a writing utensil and your Student Journal.
2. Follow your facilitator's directions for breaking into groups.
3. Follow your facilitator's directions to rotate through all of the stations.

Vocal Cord Station

At this station, you will feel how sound and vibration are related.

1. Gently hold your first two fingers against the middle of your own throat and talk, sing, or hum, varying the type of sounds such as high or low and loud or soft.
2. Using the vocabulary words you have learned, describe in detail the different feelings in your fingers, from the sounds in the Data Observation box below.
3. Using the vocabulary words, what conclusions have you made and the reasons why.

Data Observation - Vocal Cord Station

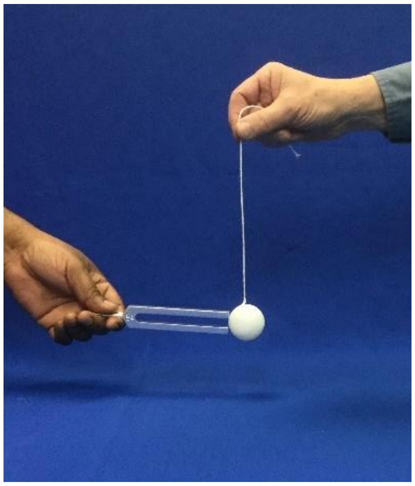
Tuning Fork Station

At this station, you will see how sound and vibration are related.

1. Pick up the tuning fork by the stem in one hand, and the tuning fork activator in the other.
2. Strike the tuning fork against the tuning fork activator firmly, but not too hard.
3. Slowly dip the prongs of the tuning fork into the bowl of water, but not all the way to the bottom.
4. Describe in detail what happened to the water in the bowl in the Data Observation box below.
5. Use the vocabulary words you have learned to explain any conclusion you have made and your reasoning.

Data Observation - Tuning Fork Station

Ping Pong Ball Station



At this station, you will see how vibrations move through the air near objects.

1. Have one student stand and hold the string with the ping pong ball hanging down. Try to hold the ball as still as possible!
2. Have another student pick up the tuning fork by the stem in one hand, and the tuning fork activator in the other.
3. Strike the tuning fork against the tuning fork activator and slowly move the tuning fork toward the ping pong ball until the prongs **just barely** touch the ball.
4. In the Data Observation box below, draw a sketch of what you see happening to the ping pong ball.
5. Using the vocabulary words you have learned, describe in detail what happened to the ping pong ball and explain why.

Data Observation - Ping Pong Ball Station **Against ball**   **Near ball**

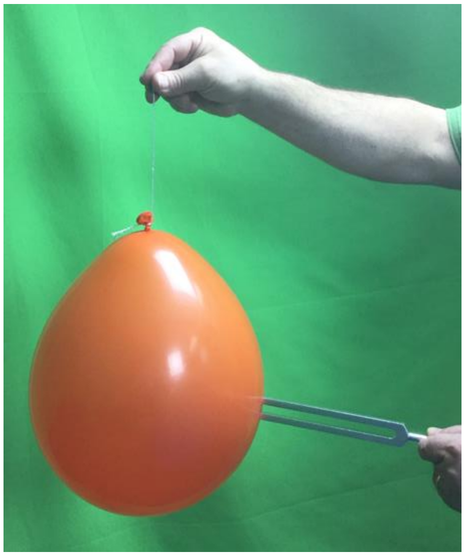
Dancing Rice Station

At this station, you will see sound energy transferring through different mediums.

1. Hold the metal upside down, next to, but **<u>not</u>** touching the bowl.
2. Hit the metal pan hard with a metal spoon.
3. In the Data Observation Box below, describe what happens to the rice.
4. Using the vocabulary words you have learned, explain why this is happening to the rice.

<u>Data Observation - Dancing Rice Station</u> **Touching the Pan**   **Not touching the pan**

Buzzing Balloon Station

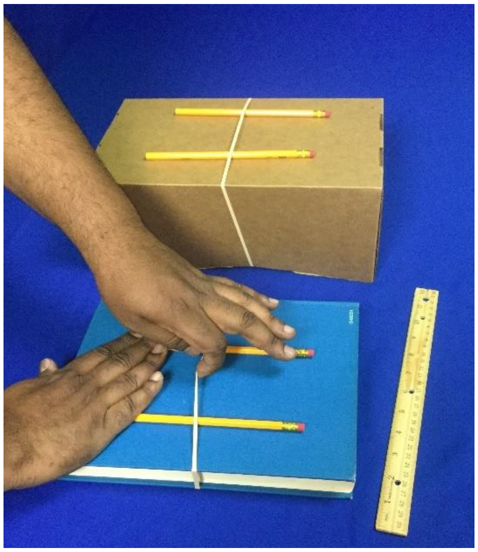


At this station, you will observe how sound waves can create other sounds.

1. Have one student stand and hold the string with the balloon at arm's length.
2. Have another student pick up the tuning fork by the stem in one hand and the tuning fork activator in the other hand.
3. Strike the tuning fork against the tuning fork activator.
4. Slowly move the tuning fork toward the balloon until it **just barely** touches it.
5. In the Data Observation box below, describe what you see and hear using the vocabulary words you have learned.

Data Observation – Buzzing Balloon Station

Shoebox Strings Station



At this station, you will see and hear how vibrations produce sound and how sound travels.

1. Keeping the pencils in place, pluck the rubber band between the pencils on the book.
2. Keeping the pencils in place, pluck the rubber band between the pencils on the shoebox.
3. Compare what you hear and feel on the top of the book to what you hear and feel on the top of the box.
4. In the Data Observation box below, using the vocabulary words you have learned, record and describe the differences you observed between the two.

Data Observation – Shoebox Strings Station: Compare top of book to top of shoebox

Extra Notes:

Supporting Science Investigation 2: Making Waves – Student Pages

In this activity, you will learn how loudness and pitch are related to the amplitude and frequency of sound waves by making sound into an oscilloscope app. Sounds have different **waveforms**. The waveforms of sounds are different depending on both the loudness and pitch of the sound.

Safety Note: The proper way to strike a tuning fork is to strike it firmly against a tuning fork activator. Follow your facilitator's direction if you do not have a tuning fork activator. Avoid striking fragile objects or swinging the tuning fork near people. Do not strike the tuning fork against a hard object, especially a table edge. The bottom of your shoe would be a good choice.

Instructions:

1. Download the free oscilloscope app as directed by your facilitator.
2. Before breaking into groups, make sure you have a writing utensil and your Student Journal.
3. Follow your facilitator's directions for breaking into groups.
4. Watch your facilitator model how to use the oscilloscope app.
5. Practice using the app and making various sounds and observe what types of waveforms are displayed.
6. Make a low, deep-pitched hum.
7. On the Data Sheet, sketch the waveform created by the low, deep pitched hum.
8. Make a high-pitched hum. **Note:** Keep the loudness the same as in #6, just change the pitch.
9. On the Data Sheet, sketch the waveform created by the high-pitched hum.
10. Next hum a pitch loudly, then hum the same pitch softly, and sketch the waveforms.
11. Next hum a single pitch, then hum a song and sketch the waveforms.
12. Strike a tuning fork with the tuning fork activator. **Note:** Your facilitator may have you use a sound generator app on another device, a tone generator, or a buzzer.
13. Observe the waveform of this pitch and sketch it.
14. Have someone try to imitate the tuning fork pitch with their voice.
15. Sketch the waveform and compare it to the tuning fork's waveform. How are they the same? How are they different?

Question/Comparisons:

1. What is the difference between the waveforms for a low-pitched sound and a high-pitched sound?
2. Compare and contrast the humming waveform sketches.
3. Compare your sketches for similar sounds and see if they match. Explain why they match or don't match.

Supporting Science Investigation 2: Making Waves – Data Sheets

Sketch the waveform(s) in each box.

Hum a low, deep pitch
Hum a high pitch; keep the loudness the same

Hum a pitch loudly
Hum the same pitch softly

Hum a single pitch
Hum a song

Strike a tuning fork
Hum the same pitch as the tuning fork

Glossary

Accuracy – refers to the closeness of a measured value to a standard or known value.
Aeronautics – the study of flight through the air.
Ambient sound – background noises present in a particular place.
Amplitude – of a sound wave is the distance the molecules vibrate back and forth from a fixed center point; determines the loudness of a sound.
Breaking the sound barrier – occurs when an aircraft exceeds the speed of sound.
Calibrate – to make, adjust, or check the setting or position of the controls used to make measurements with a tool or measuring device.
Citizen science – the use of non-scientists to help professional scientists collect and analyze data for a specific project on which they are working.
Compressional waves – a wave that transfers energy by constricting and expanding the medium through which it travels. Sound waves are compressional.
Constant – anything that stays the same.
Controlled Variable – variables that must be kept the same when doing an experiment.
Decibel (dB) – a unit of measurement used to express the intensity / loudness of a sound.
Energy – the ability to do work.
Exponent – a quantity representing the power to which a given number or expression is to be raised, usually expressed as a raised symbol beside the number or expression.
Exponential relationships - relationships where one of the variables is an **exponent**. So instead of it being '2 multiplied by x', an **exponential relationship** might have '2 raised to the power x'.
Frequency – of a sound wave is the speed at which molecules vibrate; measured as one complete back and forth vibration of a sound wave per second. **Frequency** is measured in units of **Hertz** (Hz). One Hz is equal to 1 vibration or wave per second.
GPS – Global Positioning System.
Hertz (Hz) – unit used to measure frequency. One Hz is equal to 1 vibration or wave per second.
Kinetic Energy – the energy of moving things.
Mach number – the ratio of the aircraft's speed compared to that of the speed of sound.
Mach One – the speed of sound, which is approximately 760 miles per hour at sea level.
Medium – the matter (solid, liquid, or gas) through which sound travels.
NASA – National Aeronautics and Space Administration.
Noise – sound with no set patterns in rhythm or frequency; a random mixture of frequencies. Noise is unwanted sound.
Noise pollution – ambient, loud noise that is very annoying and harmful to living things' hearing and health.
Oscilloscope – an instrument that uses electronic signals to create a moving picture of a wave. The picture represents the wave as a curve that varies in frequency and amplitude.
Pitch – the highness or lowness of a sound. Pitch is determined by the speed of the vibrating molecules.
Precision – the reproducibility of a set of measurements. In other words, how close together a set of measurements of the same value are when performed in the same way and using the same instrument.

Shock wave – a quick release of the air pressure built up by a plane traveling at or above the speed of sound, exceeding Mach 1. The plane compresses the air in front of it to the point where the pressure is so high, it must be released.
Sonic boom – the thunder-like noise heard on the ground when the shock wave is released. It is formed once a plane begins flying faster than the speed of sound.
Sound – a vibration that travels through any medium by transferring energy from one particle to another, and is heard when it reaches a person's or animal's ear.
Sound wave – a pressure that is caused by vibration in a medium that transfers energy, like air. High frequency sound waves are high pitch, and low frequency sound waves are low pitch.
Speed of sound – approximately 760 miles per hour at sea level. The speed of sound is referred to as Mach 1.
Supersonic – traveling faster than the speed of sound.
Tone generator – an electronic device that artificially creates sound frequency.
Transonic range – traveling slower than the speed of sound.
Variable – anything that can change in an investigation.
Vibration – a rapid back and forth motion of a particle or particles.
Volume – the loudness or intensity of a sound.
Waveform – a representation of the shape of a soundwave illustrated by plotting the pitch value against time.
Wavelength – the length of the repeating pattern or the length of one complete cycle of a wave.

NASA Resources

NASA – Airspace: Noise Good Vibrations (K-8 and 9-12)
https://www.nasa.gov/aeroresearch/resources/mib/noise-good-vibrations

NASA Aeronautics Research Mission Directorate (ARMD) Educator Resources
https://www.nasa.gov/aeroresearch/resources/description

NASA Aeronautics Research Mission Directorate (ARMD) Videos
https://www.nasa.gov/aeroresearch/videos

NASA Langley Research Center (LaRC) – Quiet Supersonic X-plane to Be Designed
https://www.youtube.com/watch?v=x8r-Pm1-dVc

NASA – Low-Boom Flight Demonstration
https://www.nasa.gov/mission_pages/lowboom/index.html

NASA Prepares for Future of Supersonic Experimental Flight – Design and Testing of the X-59
https://www.youtube.com/watch?v=ge69GyRJxLY

NASA – Seeing Sound: STEM Learning Module
https://www.nasa.gov/aeroresearch/stem/seeing-sound

NASA Small Steps to Giant Leaps Resources | https://www.nasa.gov/STEM/SSGL

NASA STEM – History of X-planes
https://www.youtube.com/watch?v=DCIbBC4wprw&list=PLTUZypZ67cdvZ3TbQbDiqLdOkrCswmkUZ&index=1

NASA STEM – How Sound Travels and the X-59
https://www.youtube.com/watch?v=IRUoL4SBIjM&feature=youtu.be

NASA STEM – Senses of Sound Activity Demo | https://youtu.be/KoztJbcU_tw

NASA STEM – Sonic Booms and the X-59 | https://youtu.be/OmXdeov-nYo

NASA STEM – Sound Effect Activity Demo | https://youtu.be/ennpLpYMPv8

NASA – Supersonic Flight – X-59 Flight Simulator
https://www.nasa.gov/centers/armstrong/multimedia/imagegallery/Simulator/AFRC2018-0040-07.html

NASA – X-Plane Looks to the Future of Supersonic Flight – Low Boom Flight Demonstrator
https://www.youtube.com/watch?v=pojK7Zcypz4

Online Articles/Releases

Nov. 19, 2018
RELEASE 18-093
NASA's Quiet Supersonic Technology Project Passes Major Milestone
https://www.nasa.gov/press-release/nasa-s-quiet-supersonic-technology-project-passes-major-milestone

Oct. 25, 2018
X-59 QueSST Model Flies the Simulated Skies at NASA Langley Wind Tunnel Testing Session
https://www.nasa.gov/feature/langley/x-59-quesst-model-flies-the-simulated-skies-at-nasa-langley-wind-tunnel-testing-session

July 18, 2018
RELEASE 18-060
NASA, French Aerospace Lab to Collaborate on Sonic Boom Prediction Research
https://www.nasa.gov/press-release/nasa-french-aerospace-lab-to-collaborate-on-sonic-boom-prediction-research

More information about NASA Citizen Science

If you would like to receive more information about NASA's Science Mission Directorate citizen science projects or for other opportunities of public involvement in NASA's science and technology programs, please sign up on NASA's email listserv.
https://lists.hq.nasa.gov/mailman/listinfo/nasa-solve
https://www.nasa.gov/stem/express

You may also visit the NASA Solve website for other NASA citizen science activities. Click on Explore Opportunities. https://www.nasa.gov/solve/index.html

PTI – LIB 06.2019