National Aeronautics and Space Administration

STEM LEARNING:
Noise–Chevron Design Educator Guide

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NOISE–CHEVRON DESIGN EDUCATOR GUIDE

One of NASA's goals is to explore technology to reduce engine noise. To simulate the work of NASA acoustic engineers, student teams will design an "engine chevron" in an attempt to alter and dampen the noise coming from a Thunder Drum, which simulates an aircraft jet engine. Teams of 2-4 students will use the Engineering Design Process to help them develop, test, and re-design the chevron.

Objective

Students will use the engineering design process to design sound-altering technology and qualitatively and/or quantitatively observe results.

Materials Needed

- Thunder Drum (small or large drums work for this activity)—several per class
- Various building materials, such as paper, cardstock, aluminum foil for chevron construction
- Reference materials for this lesson, including:
  - Careers handout
  - Sound vs. distance handout (https://www.nasa.gov/sites/default/files/atoms/files/seeing_sound_k-8.pdf, page 11)
  - Sound levels handout (https://www.nasa.gov/sites/default/files/atoms/files/seeing_sound_k-8.pdf, page 12)
- Student Engineering Log Worksheets
- Measuring devices:
  - Oscilloscope to measure change in sound (real or app version)*
  - Decibel meter (real or app version)

**While not necessary for the lesson, the use of an oscilloscope and/or sound decibel meter vastly improves the quantitative aspects of the lesson. If you don't have access to physical oscilloscopes or sound decibel meters, there are also free or inexpensive app versions available for electronic devices such as tablets or smartphones.*

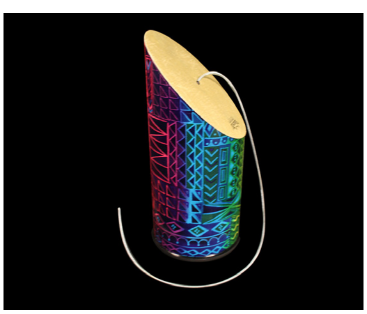


Image Left: Thunder Drum

NGSS Standards

Disciplinary Core Ideas

MS. Waves and Electromagnetic Radiation

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-PS4-2:
Develop and use a model to describe that waves are reflected, absorbed, or transmitted through various materials.

MS. Engineering Design

MS-ETS1-1-4

HS. Waves and Electromagnetic Radiation

HS-PS4-1:
Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.

HS. Engineering Design

HS-PS4-1:
Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.

Science and Engineering Practices

- Asking questions and defining problems
- Developing and using models
  - Develop a model to describe unobservable mechanisms (MS).
  - Develop and use a model based on evidence to illustrate the relationships between systems or between components of a system (HS).
- Planning and carrying out investigations
  - Plan an investigation individually and collaboratively, and in the design: identify independent and dependent variables and controls, what tools are needed to do the gathering, how measurements will be recorded, and how many data are needed to support a claim (MS).

  - Conduct an investigation and evaluate the experimental design to produce data to serve as the basis for evidence that can meet the goals of the investigation. (MS)
- Analyzing and interpreting data
- Constructing explanations and designing solutions
  - Apply scientific ideas or principles to design an object, tool, process or System. (MS)
  - Undertake a design project, engaging in the design cycle, to construct and/or implement a solution that meets specific design criteria and constraints. (MS)
  - Design, evaluate, and/or refine a solution to a complex real-world problem, based on scientific knowledge, student-generated sources of evidence, prioritized criteria and tradeoff considerations. (HS)
- Use mathematical and computational thinking
  - Use mathematical representations to describe and/or support scientific conclusions and design solutions. (MS)
  - Use mathematical representations of phenomena or design solutions to describe and/or support claims and/or explanations. (HS)
- Obtaining, Evaluating, and Communicating Information
  - Communicate technical information or ideas (e.g. about phenomena and/or the process of development and the design and performance of proposed process or system). In multiple formats (including orally, graphically, textually, and mathematically). (HS)

Crosscutting Concepts

- Cause and effect
  - Cause and effect relationships may be used to predict phenomena in natural or designed systems.
  - Systems can be designed to cause a desired effect.
- Systems and system modules
  - Models can be used to represent systems and their interactions—such as inputs, processes and outputs—and energy and matter flows within systems.
  - When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models.
- Structure and function
  - Investigating or designing new systems or structures requires a detailed examination of the properties of different materials, the structures of different components, and connections of components to reveal its function and/or solve a problem.
- Interdependence of Science, Engineering, and Technology
  - Engineering advances have led to important discoveries in virtually every field of science, and scientific discoveries have led to the development of entire industries and engineered systems.
- Influence of Science, Engineering and Technology on Society and the Natural World
  - The uses of technologies and any limitations on their use are driven by individual or societal needs, desires, and values; by the findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions. Thus technology use varies from region to region and over time.
  - Technologies extend the measurement, exploration, modeling, and computational capacity of scientific investigations.
- Energy and Matter
  - Energy may take different forms.
  - The transfer of energy can be tracked as energy flows through a designed or natural system.

BACKGROUND

Since the 1960s, NASA engineers have worked to reduce aircraft noise that can be generated from many different sources. Although most of that noise comes from engines, other noise-generating airplane components include the landing gear, where the engines and airframe or body meet, as well as “high lift devices” such as wing flaps. Such noise is often described as polluting the air, especially around airports and inside the aircraft itself (passengers sitting near the engines during a plane trip know exactly what aircraft noise feels and sounds like).

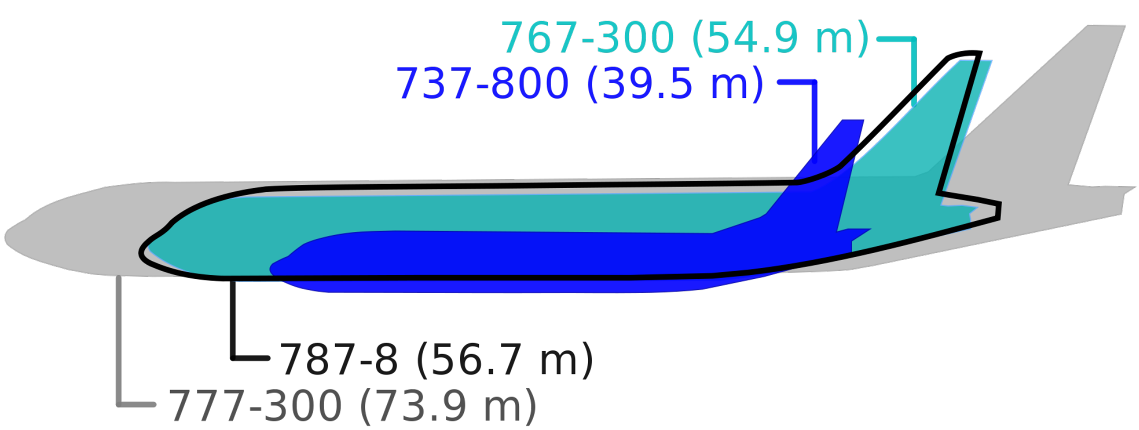
With many different planes taking off and landing each day, and more planes filling the sky, noise pollution from individual aircraft will continue to increase unless something is done. In earlier airplane designs, when engines increased in power and speed, noise mostly increased as well. With newer designs, however, that isn’t necessarily the case. For example, even though Boeing’s 777s and 787s are larger and have more powerful engines, these newer aircraft are quieter than engines on the smaller 737’s. The image below gives you an idea of the size difference in the three planes.

While noise cannot be completely eliminated from jet engines, it can be reduced. One noise-reducing technology NASA helped to develop that is now being used on commercial jet engines is the **chevron**.

A chevron is a sawtooth shape designed into the ends of the casing around the outside of the jet engine and/or into the interior engine nozzle itself. (see Figure A). The noise we hear from jet engines mainly comes from turbulent air created by two streams of air – one hot and one cold – mixing at the back of the engine. The air coming out of the jet engine itself is extremely hot, while the air flowing around the outside of the engine case is much cooler. When the stream of hot air leaving the inside of the engine meets the stream of cooler air from outside the engine, the air becomes turbulent and noise happens!

NASA discovered that the chevrons can smooth out the point where the two air streams meet, reducing turbulence and therefore the noise. One NASA researcher described the effect as having two lawn mowers and turning one of them off.

When NASA first started exploring chevron technology in the 1980s, it wasn’t easy to figure out which chevon shapes and depths would work the best; especially when engineers didn’t have the technology to know exactly how sound waves behaved. James Bridges, one of the engineers involved with aircraft noise research at NASA, describes some of the problems with creating chevron designs: “Early on, we didn’t have the advanced diagnostics, instrumentation and insight to know what we



Size comparison of 737, 777, 787.
Image credit: User:Rolypolyman on en.wiki, SVG conversion by Surachit derivative work: Altair78 licensed with Cc-by-sa-3.0, GFDL. https://commons.wikimedia.org/wiki/File:Boeing_787_size_comparison.svg

had done to make it worse instead of better." He outlines the process used to develop early chevrons: "You have an idea and then you cut out a piece of metal and try it. Sometimes the kernel of the idea might have worked out, but the way you did it wound up causing more noise." Because aircraft manufacturers are always interested in technologies that reduce noise, chevrons took just a few years to move from being an idea to being included in designs for new engines. Years might seem like a long time, but this is relatively fast for modifications to aircraft engines that have to pass very strict testing. NASA also needed time to develop ways to test the results. Without proper ways to measure noise, turbulence, air temperature, and noise-reduction abilities, building and testing chevrons wouldn't have been productive. Another challenge was figuring out how to maintain engine thrust while also reducing engine noise. Since the beginning of chevron development, many different styles and shapes have been tried and used. Earlier chevrons had a more symmetrical shape. As you can see from Figures A and B, the chevron shapes look the same all the way around.

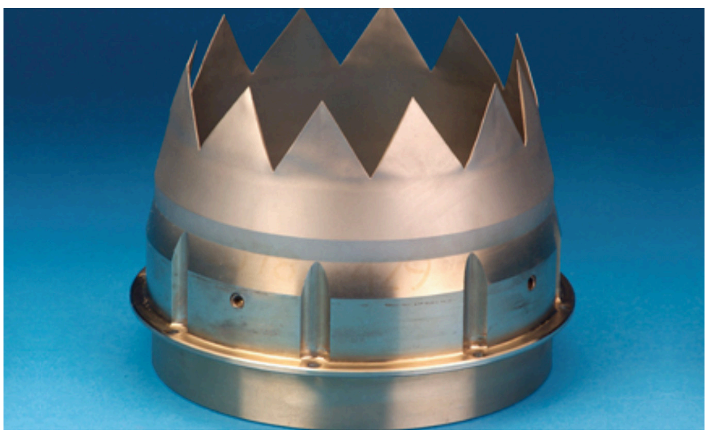


Figure A: An early chevron test article with symmetrical notches.

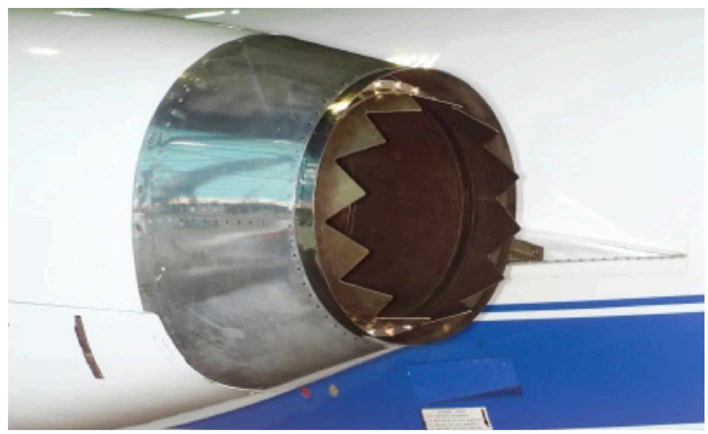
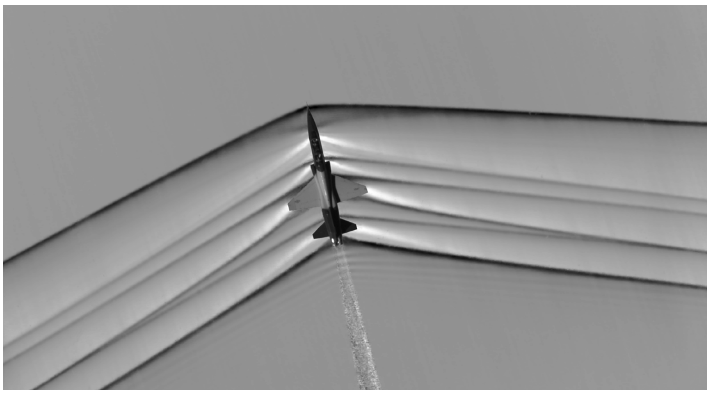


Figure B: An early chevron test article inside an engine nozzle.

Figure C: Final chevron shapes—asymmetrical—in place on engine casing and nozzle.

However, as chevron technology has matured, some newer designs have a less symmetrical shape. Figure C shows chevrons on the engine casing and the nozzle; the chevrons on the top of the casing are deeper than those on the bottom.

THE SCIENCE OF SOUND



Although sound is something most of us take for granted, rarely do we consider the physics involved. Sound comes from many sources – a voice, machinery, musical instruments, computers – but all are transmitted the same way: through vibration.

In the most basic sense, when a sound is created it causes the molecule nearest the source to vibrate. Since this molecule is touching another molecule, it causes that molecule to vibrate too. This continues, from molecule to molecule, passing the energy on as it goes. This is also why at a rock concert, or even being near a car with a large subwoofer, you can feel the bass notes vibrating inside you. The molecules of your body are vibrating, allowing you to physically feel the music.

As with any energy transfer, each time a molecule vibrates or causes another molecule to vibrate, a little energy is transferred to the atoms and molecules the wave touches, which is why sound gets quieter with distance and why louder sounds, which cause the molecules to vibrate more, travel farther. The loudness of a sound is measured in decibels, or dB, with sounds above 120dB having the ability to cause permanent hearing loss to humans.

Jet plane at takeoff	110-140dB
Loud rock music	110-130dB
Chain saw	110-120dB
Thunderstorm	40-110dB
Vacuum cleaner	60-80dB
Normal voices	50-70dB
Whisper	20-50dB
Purring cat	20-30dB
Falling leaves	10dB
Silence	0dB

The loudness of a sound is more of a human perception and interpretation than a scientific quantity or property. However, volume can be measured in terms of the amount of energy that travels over a specified distance within a specific period time. This is measured in watts per square meter, where a watt is energy/time (joules/sec). Another important point of note is that it takes 10 times as much energy to produce a noise that sounds only twice as loud as another. Correspondingly, in order to halve the noise something produces, we have to reduce its energy by a factor of 10.

Lesson and Background Connection Note:
The following lesson asks students to develop chevron designs that will attach to the back of a simulated engine (in this case, a Thunder Drum) in an attempt to alter and dampen sound coming from the drum. While this is similar to how chevrons are used on jet engines, it will not be the same, since engine chevrons also deal with hot air leaving the engine and mixing with cool air that is moving around the outside of the engine. However, the concept of altering sound waves is similar, and will show students some of the research and development that NASA does in aeronautics. In addition to working to reduce noise coming from aircraft engines, NASA aeronautics is also working on altering the shock waves that form around supersonic aircraft and create sonic booms. sound waves that come from supersonic aircraft. The goal is to prove that an aircraft can fly at supersonic speed over land without having a negative impact on the public. More information about NASA's research and development in sound and other topics can be found at https://www.nasa.gov/aero, and via these links to recent stories.

NASA web story on chevron research:
https://www.nasa.gov/topics/aeronautics/features/bridges_chevron_events.html

NASA video on chevrons with researcher James Bridges (2010):
https://www.youtube.com/watch?v=xnjIFKNalCg

NASA Prepares for Quiet Supersonic Flights over Galveston, Texas
https://www.nasa.gov/aero/nasa-prepares-to-go-public-with-quiet-supersonic-tech

NASA Starts to Build Quiet Supersonic X-Plane
https://www.nasa.gov/lowboom/new-nasa-x-plane-construction-begins-now

NASA Researchers Explain Sonic Boom and How to Make it Quiet
https://youtu.be/zAlh7NJ49ak

What a Sonic Boom Shockwave Looks Like
https://www.nasa.gov/image-feature/stark-beauty-of-supersonic-shock-waves

NASA Tests Tech to Make Airplanes More Quiet
https://www.nasa.gov/press-release/nasa-technologies-significantly-reduce-aircraft-noise

PROCEDURE (FOR THE EDUCATOR)

Before beginning the lesson, students should be familiar with the basics of sound waves.

Background information, lessons, and activities in NASA's Museum in a Box series can provide support for this: https://www.nasa.gov/aeroresearch/resources/museum-in-a-box

- "Noise: Good Vibrations" grades K-8 and 9–12
- "Noise: Speed of Sound" grades 9–12
- "Noise: Seeing Sound" grades K-8

INTRODUCTION

Using the Background Information, introduce the topic of noise pollution and chevrons.

DEMONSTRATION

Use the Thunder Drum to show students how sound is amplified when traveling down a tube. Ask students to picture what is happening to sound waves inside the Thunder Drum as well as when the sound travels out the trailing end of the drum. On the student worksheet, they will also describe various qualities of sound coming from the drum.

**To make this activity more quantitative, use an oscilloscope and/or sound meter to record sound levels.*

STUDENT ACTIVITY

1. Divide students into teams (no more than 4 students per team is suggested so that each student has a job duty). Assign job duties. Suggestions include, but are not limited to:
   - **Manager:** Oversees the design, ensures design parameters are followed, keeps track of time, coordinates decision-making
   - **Illustrator, recorder** (can be split into two jobs): Writes down design ideas, measurements, and test results
   - **Builder:** Leads (but is not entirely responsible for) the building of the chevron

2. Sound meter/oscilloscope practice: If using a sound meter and/or oscilloscope, give students several minutes to practice using the devices. Distribute or display the "Sound Levels" chart (see page 6), which provides a comparison chart of more common sounds and their decibel levels. Ask students to see if they can reach some of the same decibel levels as the chart, then either raise or lower the levels. Likewise, let them experiment with creating a variety of frequencies while watching the results on the oscilloscope. (If more than one of each of these devices is available, that will help better facilitate the lesson as well. There are many free and low-cost oscilloscope and decibel apps available, which can be used on smartphones and tablets.)

   NOTE: if using an app on a device, make sure to point the microphone at the source of the sound for best results.

3. Provide students with the design challenge and the parameters, including the diameter of the Thunder Drum and materials available for their design. Suggestions for time needed are as follows:
   - "Identify the problem" — (5 min.; this can also be done together as a whole group)
   - "Brainstorm possible solutions" and "Select a design"—(10-15 min.)
   - Build a model or prototype—(10 min.)
     - Test the model and evaluate—(5 min.)
     - Refine the design—(5 min.)
   - Share the solution—(10-15 min.)

4. Teams construct their chevrons. Be sure to remind students that while they are trying to dampen the sound coming from the trailing edge of the Thunder

Drum, they are simulating the chevron for a jet engine, so they need to be careful not to cut off the “thrust” that would come from the engine. When designs are complete, have teams attach their chevrons to the trailing edge of the Thunder Drum. Students will then test the differences in sound before the chevron is attached and after it is attached.

**Even though students heard the Thunder Drum during the introductory demonstration, make sure they first listen to the drum without the chevron, record their observations, then attach and test the chevron. Again, they should record their observations. If an oscilloscope and/or sound decibel device is available, allow students to quantitatively measure their results, both with and without the chevrons.*

5. The amount of time spent refining and re-testing design ideas depends on the length of time available. Similarly, design sharing can be completed in several ways, also depending on time available. Presentations can be made, designs can be shared, and results can be gathered using oral presentations, group data accumulation, team posters, etc.

6. Conclude the activity by letting students know that the design, testing, and implementation of actual aircraft chevrons took over a decade to complete, and that ongoing research is still being conducted on noise reduction. Links to current research and development can be found in this lesson

Going Further

If students used an oscilloscope and/or decibel meter, ask students to calculate the percentage change in decibels, or the change in frequency from the original sound coming from the unaltered Thunder Drum to the new sound made due to the addition of the chevron. Graphical comparisons could also be made that show each chevron’s results.

Assessment

The included rubric can be used to evaluate student participation in the activity.

	0-1 point	**2-3 points**	**4-5 points**
Engineering Log	Little to no parts of the Engineering Log were completed.	Most parts of the Engineering Log were completed.	All parts of the Engineering Log were completed.
Chevron Construction and Testing	No chevron was constructed or it did not follow many of the design constraints. Little or no performance was tested.	Chevron was constructed, but did not follow all design constraints. The chevron’s performance may or may not have been tested.	Chevron was built following all design constraints. The chevron’s performance was tested using the methods the educator asked for.
Evaluation and re-design (if applicable)	Little to no evaluation of the chevron performance. If a re-design was required, little to no re-design was made.	An attempt was made to evaluate the performance of the chevron, which may have included data. If a re-design was made, it may not have been based on evaluation results.	Effectively evaluated the performance of the chevron, recording information and data a instructed. If a re-design was made, the new design was an improvement made on the results of the evaluation.
Teamwork and participation	Did not contribute to the team project.	Contributed to the team project by **either** adding to the design and testing **or** allowing others to be active contributors to the team.	Contributed to the team project by both adding to the design and testing **and** allowing others to be active contributors to the team.

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Headquarters
300 E. Street, SW
Washington, DC 20546

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