Science and Innovation

A Boeing/Teaching Channel Partnership

DESIGN A QUIETER CABIN

Teacher Handbook

Tch TeachingChannel

Design a Quieter Cabin

Days 1 and 2: How Sound Travels Away from an Airplane Engine

Grade Level	Early Middle School (Grade 6)
Lesson Length	Two 50-minute sessions (if possible, consider adding another day)

Lesson Overview

In this two-day lesson, students are introduced to the design problem of creating a quieter cabin for airplane passengers. First, students create a Driving Question Board (DQB) to drive their learning throughout the module. Next, students engage in a series of investigations to figure out how airplane engines make sound and how the sound travels from the engine to the passengers' ears. Finally, students develop and revise models to show how sound waves travel.

Connecting to the Next Generation Science Standards

On Days 1 and 2, students make progress toward developing understanding across the following three dimensions:

- **Science and Engineering Practices:** Asking Questions and Defining Problems, Developing and Using Models, Constructing Explanations and Designing Solutions, Engaging in Argument from Evidence
- **Disciplinary Core Ideas:** ETS1.A Defining and Delimiting Engineering Problems, PS4.A Wave Properties
- **Crosscutting Concepts:** Influence of Science, Engineering, and Technology on Society and the Natural World, Systems and System Models

In the following table, the specific components addressed in this lesson are underlined and italicized. The specific connections to classroom activity are stated.

Performance Expectations
This lesson contributes toward building understanding of the following *engineering* performance expectations: MS-ETS1-1. *<u>Define criteria and constraints of a design problem with</u>* sufficient precision to ensure a successful solution, *<u>taking into account relevant scientific principles</u>* and potential impacts on people and the natural environment that may limit possible solutions.
This lesson contributes toward building understanding of the following *physical science* performance expectations: MS-PS4-1. Use mathematical representations to *<u>describe a simple model for waves that includes how the amplitude of a wave is related to the energy in a wave</u>*. MS-PS4-2. *<u>Develop and use a model to describe that waves are</u>* reflected, absorbed, *<u>or transmitted through various materials.</u>*

Specific Connections to Classroom Activity

In this lesson, students are introduced to the engineering design problem of creating a quieter cabin for airplane passengers. Students consider the criteria and constraints of the design problem. Students develop models for how sound waves travel from an airplane's engines to the cabin. Students build on their knowledge of matter developed in 5th grade (PS1.A) and their initial understanding of waves (PS4.A) to develop an initial understanding of longitudinal waves. Students use a model to explore amplitude and energy.

Dimension	NGSS Element	Connections to Classroom Activity
Science and Engineering Practices	**Asking Questions and Defining Problems** • *Define a design problem that can be solved through the development of an object, tool, process, or system, and includes multiple criteria and constraints, including scientific knowledge* that may limit possible solutions. **Developing and Using Models** • *Develop and use a model to describe phenomena.* • *Develop a model to describe unobservable mechanisms.* **Constructing Explanations and Designing Solutions** • *Construct a scientific explanation based on valid and reliable evidence obtained from sources (including students' own experiments)* and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. **Engaging in Argument from Evidence** • *Use an oral and written argument supported by evidence to support or refute an explanation or a model for a phenomenon.*	When students are introduced to the design problem of creating a quieter cabin, they are given an initial list of criteria and constraints. Throughout the module, students develop an understanding of the science ideas surrounding the design problem to further define the criteria and constraints. In this lesson, a heavy emphasis is placed on developing models to describe how airplane engines make sound and how the sound travels to airplane cabins. Students construct an initial model for the phenomenon and revise the model based on engagement with additional investigations, explanations, and reasoning. As part of the modeling process, students work to construct an initial scientific explanation for how airplane engines make sound and how the sound travels to cabins. Students engage in whole class consensus discussions, in which they support arguments for their scientific explanations and revise explanations based on others' arguments.
Disciplinary Core Ideas	**ETS1.A: Defining and Delimiting Engineering Problems** • *The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful.* Specification of constraints includes consideration of scientific principles and other relevant knowledge likely to limit possible solutions. **PS4.A: Wave Properties** • *A simple wave has a repeating pattern with a specific wavelength, frequency, and amplitude.* • *A sound wave needs a medium through which it is transmitted.*	In this lesson, students are introduced to the design problem and the associated criteria and constraints. In later lessons, students further refine their criteria and constraints based on science ideas developed throughout the module. Students engage in significant work related to PS4.A. Ideally, students should have already explored mechanical waves, such as waves in water, prior to engaging in this exploration of sound waves. In this lesson, students create models for how sound waves are generated and how the waves travel through air. Students consider the ways by which changes in energy can change the amplitude of a sound wave.

		Students also gain an initial understanding of the idea that sound waves must travel through a medium (in this case, air).
Crosscutting Concepts	**Influence of Science, Engineering, and Technology on Society and the Natural World** • *The uses of technologies and limitations on their use are driven by individual or societal needs, desires,* and values; by findings of scientific research; and by differences in such factors as climate, natural resources, and economic conditions. **Systems and System Models** • *Models can be used to represent systems and their interactions—such as inputs, processes, and outputs—and energy, matter,* and information *flows within systems.*	The goal of the design challenge is to minimize the noise inside an airplane cabin. The problem (noise in the cabin) is related to using the technology of flight and is driven by societal desires to have a quieter flight experience. When students develop their initial model for how sound waves travel, they use the model to represent a system and how energy flows from one part of the system to another.

Basic Teacher Preparation

This lesson sets the stage for much of the exploration and concept discussion that occurs later in the module. To prepare to introduce the design problem, build a prototype cabin prior to class. See the Suggested Teacher Resources for this lesson for detailed instructions.

Students need to be organized into design teams of three or four. They work in their design teams throughout this module. Establish these teams before beginning the first lesson.

Review the Talk Science Primer, the Transmission of Sound Designmaster video, and the ScienceMan Sound Waves video to help you prepare to lead the class consensus discussions.

Make a copy of the Design a Quieter Cabin Student Handbook for each student in your class. Bind the Design a Quieter Cabin Student Handbook so it will last throughout the module. You may find it helpful to give students a daily "stamp" of completion as they work through the lessons. Refer to the Design a Quieter Cabin Student Handbook ahead of time so you can address any questions students might have. All Day 1 documents can be found on pages 1–4 in the Design a Quieter Cabin Student Handbook. The documents used in this lesson are:

- Engineering Design Process (page 1)
- Introduction to the Engineering Design Problem (page 2)
- Engineering Design Problem (page 3)
- How Airplane Engines Make Sound (page 4)

Required Preparation	Links/Additional Information
❑ Gather or purchase the required materials for the lesson	Refer to the Materials List below
❑ Download, print, and copy the Design a Quieter Cabin Student Handbook (1 copy for each student)	Design a Quieter Cabin Student Handbook [Resource Link]

❑ Review the videos, software, and resources in the Suggested Teacher Resources	Refer to the Suggested Teacher Resources at the end of this lesson
❑ Build a cabin model to demonstrate the model to students	Refer to the Suggested Teacher Resources at the end of this lesson

Materials List

Item	Description/Additional Information	Quantity	Where to Locate/Buy
Design a Quieter Cabin Student Handbook	Download, print, copy, and bind	1 per student	[Resource Link]
Audio source	Phone or mp3 player to provide signal to speaker (a small PA system [audio amplifier] makes a more impressive effect, as depicted in the How To video)	1 per class, or more if there will be multiple testing sites	Small PA system available in some schools, or bring phone or mp3 player from home
Decibel meter		1 per class, or more if there will be multiple testing sites	Decibel meter [Web Link]
PVC pipe selection	4 inches diameter x 4 inches length	1 per class (more if multiple testing sites will be set up)	PVC pipe [Web Link]
PVC cap	4 inches diameter x 4 inches length	1 per class (more if multiple testing sites will be set up)	PVC cap [Web Link]
Cardboard	4 inches diameter with a hole in the middle to insert the decibel meter	1 per class (more if multiple testing sites will be set up)	Office supply store
Box fan	Any size fan large enough for the entire class to see	1 per class	Local store
Slinky		1–3 per class	Slinky [Web Link]
Pebble or marble		1 per team	Marbles [Web Link]
Sink or container	For holding water	1 per team	Bucket [Web Link]

Day 1: How Sound Travels Away from an Airplane Engine

Introduction (10 minutes)

Begin the module by explaining that students will assume the roles of engineers who have been hired by an airline to minimize the amount of engine noise passengers hear when they are inside an airplane cabin. As engineers, students must develop and test prototype airplane cabins (using PVC pipe) that are quieter than existing airplane cabins. Introduce students to the Driving Question for the module:

How can we design a quieter airplane cabin for airline passengers?

Post the Driving Question to the Driving Question Board (DQB).

Tell students they will work through the engineering design process as they design quieter airplane cabins. Review the Engineering Design Process on page 1 in the Design a Quieter Cabin Student Handbook (also available in Appendix A).

To help students think more deeply about the design problem, have students respond individually to the first Introduction to the Engineering Design Problem prompt on page 2 in their Design a Quieter Cabin Student Handbook. The prompt is:

- *Once seated in an airplane, what are some of the sounds passengers might hear coming from outside of the aircraft?*

If some students have never flown in an airplane, play the Boeing 777 takeoff video. Guide students to listen closely to hear the various sounds.

Once students complete their responses in their student handbooks, have them share their ideas with the class.

Important Note

The Driving Question Board is used throughout the module to guide student learning. Make sure the DQB is placed in a prominent location and can be easily accessed by students.

NGSS Key Moment

Engineers often refer to the **engineering design process** when they discuss their work. In NGSS, the Science and Engineering Practices are used in place of the engineering design process. Students should understand that the engineering design process is not linear in practice. Rather, engineers engage in all of the steps, often jumping between steps. Students may want to think of the engineering design process as a web of practices.

Video Link

Show the 1 minute portion from 5:00–6:00.

- Boeing 777 takeoff [YouTube Link]

Share with students that aircraft manufacturers go to great lengths to ensure the comfort of their passengers. This includes shielding the cabin (the area where the people sit) from exterior sounds. Instruct students to take several minutes of silent response time to individually respond to the second Introduction to the Engineering Design Problem prompt on page 2 in their Design a Design a Quieter Cabin Student Handbook. The prompt is:

- *Describe how you think airplane cabins are constructed to keep out as much sound as possible.*

Give students several minutes to share their responses with their design teams. Each student should record their team's responses below the third Introduction to the Engineering Design Problem prompt on page 2 in their Design a Quieter Cabin Student Handbook. The prompt is:

- *Describe how you think airplane cabins are constructed to keep out as much sound as possible. Shared team responses:*

Extension

As an optional extension, consider having students read more about creating quieter airplane cabins.

- Quieter Airplanes through Science [Web Link]
- The Quiet Cabin: No Simple Solution [Web Link]
- BBC: How to Cut Noise in a Plane Cabin [Web Link]

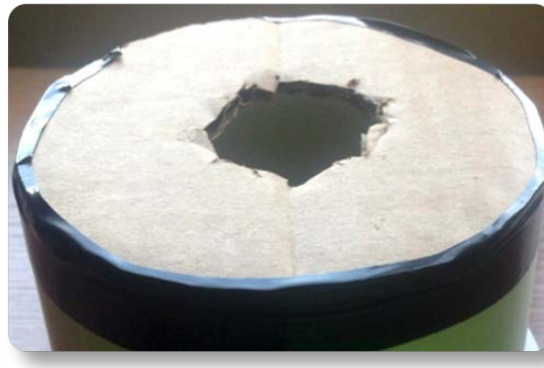
Design Work: The Design Problem (10 minutes)

Tell students their engineering design challenge is to shield a passenger's ears (represented by a decibel meter) from exterior sounds (represented by a sound source 3 feet away). The cabin that surrounds the passenger will be a 4-inch length of a 4-inch diameter piece of PVC pipe (see Figure 1). Directions for setting up the model cabin are provided in the Suggested Teacher Resources for this lesson.

Demonstrate the use of the decibel meter by having all students clap or stomp. Show students the reading on the decibel meter. Have students repeat the sound three times and take an average reading. Discuss with students why the decibel meter readings varied.

Show students the cabin model and the final testing setup (see Figure 2, PVC Cabin Placed in Cap, and Final Setup). Refer to the Cabin Assembly Guide in the Suggested Teacher Resources at the end of this lesson for directions for cabin assembly. Place the decibel meter in the cabin. Have students repeat the sound and show the new decibel reading. Repeat three times and take an average reading. Discuss with students why the readings inside the cabin differed from the readings outside the cabin.

▲ Figure 1



▲ Figure 2

▲ PVC Cabin Placed in Cap

▲ Final Setup

After demonstrating the cabin model, refer students to the Engineering Design Problem on page 3 in their Design a Quieter Cabin Student Handbook. Review the initial constraints of the engineering design problem:

- You have a $10,000 budget to add materials to the interior of an airplane cabin to make it more resistant to sound.
- All materials must be fastened or laid inside the cabin so they are no more than 1.5 inches away from the container's walls.
- Materials can be placed on the cardboard lid, but the height of the lid should not exceed .5 inches.
- At no point should the material come in direct contact with the decibel meter.
- You must consider the properties, cost, and placement of each material.
- You must justify all design decisions using science ideas developed throughout the module.

Whole Group Discussion: Our Questions (10 minutes)

Tell students they need to know more about the engineering design problem before beginning the design work. Have students develop a list of questions about the design problem. Start by developing one question as a class and then have students work with their design teams to develop the remaining questions. Questions might include:

- *How does the engine of a plane make sound?*
- *How does sound travel from the engine to passengers' ears?*
- *How does sound travel through cabin walls?*
- *What materials block or amplify sound?*
- *Do we need to block all sounds?*

Engage the class in a whole group discussion. The goal of this discussion is to organize student questions into a few main categories. Start by having students share the questions developed by their design teams. Guide students to categorize the questions into a few main categories. Guide the class to reach consensus about the categories.

At a minimum, develop the following three categories, although additional categories might emerge:

- *How does sound travel from an airplane engine to the outside of the cabin?*
- *How does sound travel through cabin walls?*
- *How does sound travel from the cabin wall to passengers' ears?*

Tell students that these three (or more) questions will drive their work over the next several days. In addition, these questions will help students answer the overarching Driving Question, *How can we design a quieter airplane cabin for airline passengers?* Post the questions on the DQB so students can clearly see them. Leave space under the questions to add sticky notes.

DRIVING QUESTION BOARD

How can we design a quieter airplane cabin for airline passengers?

How does sound travel from an airplane engine to the outside of the cabin?

How does sound travel through cabin walls?

How does sound travel from a cabin wall to passengers' ears?

Investigation: How Airplane Engines Make Sound (15 minutes)

Tell students they are going to start with the first question, *How does sound travel from an airplane engine to the outside of the cabin?* First, students consider how airplane engines generate sound. Next, students consider how sound travels from an engine to an airplane cabin.

Begin the investigation by asking students to think about how they think airplane engines make sound. Consider showing students an image of an airplane engine. Instruct students to record their ideas in the How Airplane Engines Make Sound space provided on page 4 in the Design a Quieter Cabin Student Handbook.

Set up a fan so all students can see it. Tell students that the fan operates in a similar way to an airplane engine. Turn the fan on low and instruct students to listen carefully to the sound produced by the fan.

Instruct students to develop an initial model to explain how turning on an airplane engine creates sound that we can hear. Prompt students to think about this phenomenon in terms of the particulate nature of air. Remind students that in 5th grade, they should have developed the idea that air is made of particles too small to see and air particles move freely around in space. Tell students to use these ideas in their initial model. At this point in the lesson, student models do not have to be "correct." Rather, this modeling activity is designed to draw out student ideas.

NGSS Key Moment

To develop explanations for how a fan produces sound, students must have made grade-appropriate progress on PS1.A. Specifically, students should understand that air is made of particles that are too small to see and move freely around in space. Students should also have a beginning understanding of the science ideas related to air pressure. In this exercise, students build on science ideas related to PS1.A by arguing that the air particles move when the fan turns and our ears somehow "feel" that movement.

As students begin creating their models, prompt them to explain how the sound travels from the engine to their ears. At this point, students do not need to know how the ear processes the sound.

As students work on their models, they will likely generate new questions. Prompt students to include a section of the model called "Questions I still have" and to list their questions.

Lesson Close (5 minutes)

Give students several minutes to share their initial models with their design teams. Students should share their reasoning and explanations. Encourage students to revise their own models after sharing with their classmates. During Day 2, students continue to work on their models.

Day 2: How Sound Travels Away from an Airplane Engine

Introduction (5 minutes)

Tell students they are going to revisit their models for how an airplane engine makes sound. At the end of Day 1, students shared their models with their teams. Students should have revised their models based on their team's input. Instruct students to share their revisions with their teams.

Whole Class Discussion: How Airplane Engines Make Sound (15 minutes)

Gather students in a circle for a whole group discussion. Remind students that their goal is to develop a model to explain how an airplane engine (or fan) generates sound. Their models should use science ideas related to the particulate nature of air.

The goal of the whole class discussion is to come to a class consensus model about how the fan generates sound. During the discussion, encourage students to share, challenge, and revise their ideas.

By the end of the discussion, students should have generated a class consensus model that demonstrates that the fan causes a change in the movement of particles (in this case, air particles). The change in the movement of particles travels to our ears, and our ears "feel" the change. Students should conceptually understand that sound is a **longitudinal wave**. Once students have developed the concept of a longitudinal wave, give students the word *longitudinal* to refer to sound waves.

During the discussion, new questions might emerge. Capture these questions on the consensus model as "Questions we still have."

> ### NGSS Key Moment
>
> Whole group discussions, particularly consensus discussions, can be an effective way to engage students in the science practices of *argumentation* and *explanation*. Leading whole group discussions requires proper preparation. Refer to the Talk Science Primer for useful strategies.

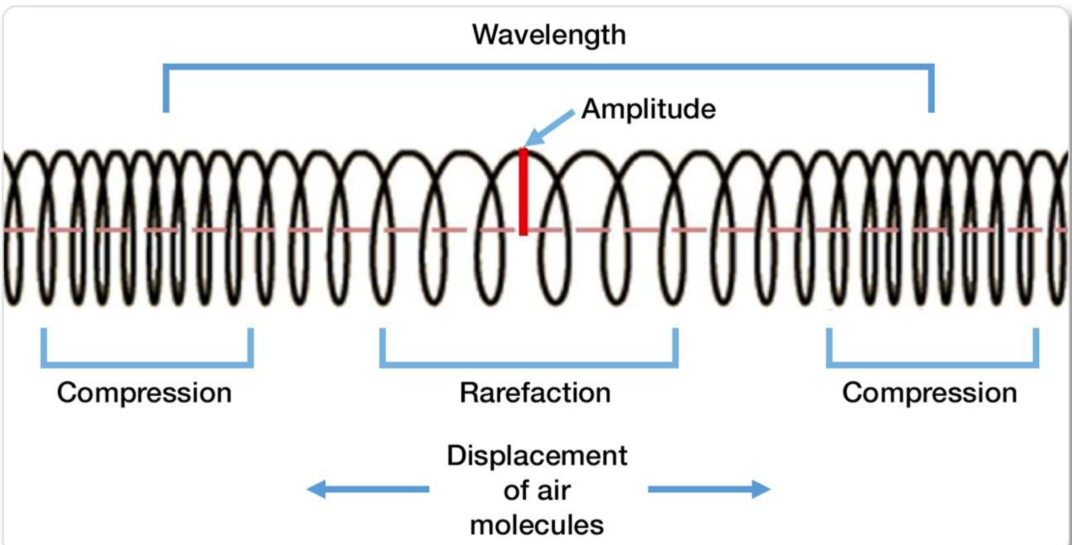
The Transmission of Sound—Designmaster video and the ScienceMan Digital Lesson—How Sound Waves Travel video can help you prepare to lead the class consensus discussion. The videos also help in Days 3 and 4, as students consider the ways by which sound waves travel through liquids and solids. You might want to use clips of these videos to support the class during their consensus discussion, but recognize that the core science ideas should be generated by the students.

> ### Video Links
>
> - Transmission of Sound—Designmaster [YouTube Link]
> - ScienceMan Digital Lesson—How Sound Waves Travel [YouTube Link]

Investigation: Model Longitudinal Waves with a Slinky® (10 minutes)

To further expand on the idea of a longitudinal wave, model longitudinal wave behavior with a Slinky. Direct two students to lay a Slinky® flat on the floor and apply slight tension to each side. Have the rest of the class gather around the students. While one of the two students tightly holds the Slinky® against the floor, have the other student push forward so the energy from the student's hand is transferred into the Slinky. As the energy moves throughout the Slinky, facilitate a discussion relating the Slinky to sound waves.

You might want to touch on key vocabulary, but the most important takeaway for students is to develop a conceptual understanding of how waves work.



Source: Adapted from http://www.studypage.in/physics/sound-and-communication

After the initial demonstration, ask the class how the two students on the floor could increase the amplitude of the wave. Tell students *amplitude* refers to the distance a Slinky coil travels away from its resting position. The students should test their classmates' theories until they add additional energy by giving the Slinky a harder push. Manipulating wavelength or other properties can also be demonstrated in this fashion.

Keep in mind that students should be demonstrating longitudinal waves, as they might consider ways to change the wave by making it a transverse wave (moving the Slinky up and down as opposed to pushing it).

Relate the discussion back to sound waves. Help students consider the idea that when energy increases, the amplitude of a wave increases. Relate this finding to a discussion about sound volume.

Helpful Tip

Consider demonstrating the setup and giving students time to explore the demonstration on their own.

Investigation: How Sound Waves Travel (5 minutes)

Ask students to think about how a sound wave travels from its source. Organize students into their design teams to drop a marble or a pebble into a small body of water (sink or container). It should be wide enough to allow the students to witness the ripple effect and the energy flow away from the center. Engage students in a discussion in which they consider the following questions:

- *What happens to the energy of the water when you drop the pebble into the water and the wave spreads out from the source of the ripple?*
- *How is this similar to sound energy as it travels through the air after being generated by an airplane engine?*

Extension

During the discussion, listen for students' current understanding of wave properties, especially how they travel. If students exhibit confusion or uncertainty, strongly consider including the **Day 3: Shake, Rattle, and Roll (Optional Extension)**.

Lesson Close (15 minutes)

Ask students to revise their models to show how sound waves travel. For now, focus only on the volume (or amplitude) of the source (On Day 7, students explore the relationship between amplitude and frequency, and how the human ear "hears" each). As students work on their models, they will likely generate new questions. Prompt students to include a section of the model called "Questions I still have" and to list their questions.

Reference the lesson question on the DQB, *How does sound travel from an airplane engine to the outside of the cabin?* Ask students if they think they made progress in answering the question. Tell students to record their progress on sticky notes. They should answer the question with as much evidence as they can. When students are finished, have them read their sticky notes out loud to the class and post them to the DQB.

Listen to students read their sticky notes, and/or read the sticky notes that students post to assess their progress in answering the questions on the DQB.

Assessment

Several opportunities for formative assessment exist in this lesson:

- Design a Quieter Cabin Student Handbook entries can be used to monitor student progress during the module.
- Initial student models on page 4 can be used to track student progress on the key physical science performance expectations.

- Consider gathering evidence of student progress through small group and whole group discussions.
- Student contributions to the Driving Question Board can be monitored.

Use the identified assessment opportunities to monitor student progress on disciplinary core ideas, science and engineering practices, and crosscutting concepts. Provide appropriate supports or extensions when necessary.

Reference Appendix B for suggestions for meeting the needs of all learners.

Community Connections

Connect with the 5th-grade students who are working on (or who have already developed) an understanding of PS1.A. Have students share their ideas about how sound waves travel through air particles, which are too small to see and freely moving.

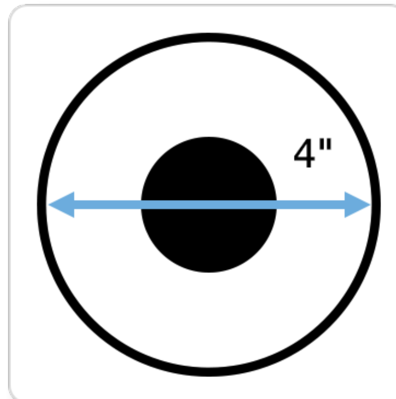
Suggested Teacher Resources

Engineering Design Process	Design a Quieter Cabin Teacher Handbook, Appendix A
Meeting the Needs of All Learners	Design a Quieter Cabin Teacher Handbook, Appendix B
Design a Quieter Cabin Student Handbook	[Resource Link]
Talk Science Primer	[Web Link]
Boeing 777 takeoff video	[YouTube Link]
Transmission of Sound—Designmate (video)	[YouTube Link]
ScienceMan Digital Lesson—How Sound Waves Travel (video)	[YouTube Link]
Quieter Airplanes through Science	[Web Link]
The Quiet Cabin: No Simple Solution	[Web Link]
BBC How to Cut Noise in a Plane Cabin	[Web Link]

Cabin Assembly Guide

The “cabin” that surrounds the passenger will be a 4-inch length of a 4-inch diameter piece of PVC pipe (see Figure 1 on the next page). To make the PVC cabin, visit the local hardware store and have 4-inch lengths of 4-inch diameter PVC pipe cut. Next, cut a 4-inch diameter circle out of cardboard and cut a hole in the middle to allow for the insertion of the decibel meter (see Figure 2). The hole should be just large enough to allow for the insertion of the decibel meter. Use tape to fasten the cardboard to the PVC pipe (see Figure 3). On the other end of the PVC pipe, place a PVC cap. The PVC cap can be purchased at a local hardware store.

▲ Figure 1



▲ Figure 2

▲ Figure 3

▲ PVC Cabin Placed in Cap

▲ Interior of Completed Test Cabin

▲ Final Setup