A. What is Sound?

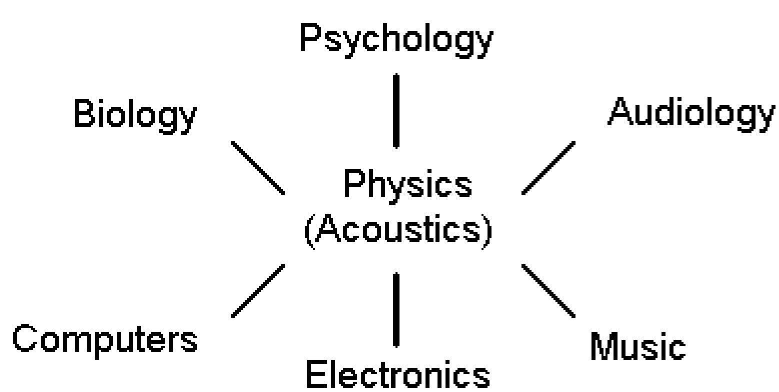
Physics, of course, is considered by many to be inaccessible due to its emphasis on mathematics. This text counteracts by presenting physics within the context of a broad cultural background, using concepts, diagrams, and tables instead of obscure math. We will illustrate this liberal-arts approach with our reflection on the inquiry "What is Sound?" This question draws many responses, depending on your point of view. To a musician, the answer includes pitches, harmony, and beauty. Musical tones serve as a palette for the artist to compose.

A building inspector often looks at sound in terms of its loudness or sound level. Our campus physical plant manager has a meter to check if sound levels are within specifications for office areas, classrooms, and hallways. A biologist studies living organisms and examines the structure of the ear, our detector of sound.

Psychologists investigating perception are interested in how the brain perceives sound. A physicist pays attention to the physical manifestations of sound such as the vibration of air. A philosopher may ponder the interesting question "Is there sound if a tree falls in a forest and no one is present to hear it?"

This text presents sound in both its physical context and its connection to a variety of disciplines. We can place any subject such as music or biology in the center of a diagram and show the connections to other fields. We will place physics in the center since this text uses physics as a foundation in our study of sound and its applications. Physics is also the fundamental discipline that deals with basic physical quantities in our world. It is a good place to start in our study. It will pave the way for our understanding of sound.

Fig. A-1. Major Fields Dealing with Sound.



In Fig. A-1 above, the major fields that involve sound are listed. Physics deals with the fundamental physical world and is concerned with basic aspects such as matter, energy, and their relationships. The subfield of physics that focuses on sound is acoustics. However, acoustics usually means room acoustics so we will stick with physics. The three related areas in the upper part of Fig. A-1, biology, psychology, and audiology, include human detection and perception of sound. Audiology deals with hearing loss and methods to evaluate such loss. Reading clockwise, the three fields in the lower part of the figure are music, electronics, and computers. An important ingredient of these fields is the production of sound. Physics describes sound by looking at physical characteristics. These are features that can be measured and assigned numbers. You should not feel intimidated about the use of numbers. You use numerical values to describe your own physical features. A number describes your height, another your age. We begin our study of sound in the realm of such descriptions.

Since sound interacts with the ear, we will turn to the study of biology at some point. Sound is perceived by the brain, which brings in the psychology of perception. The perception of pleasant harmonies takes us into music. You will learn about consonance, the pleasant combination of sounds, and dissonance, unpleasant sounds. However, these are to some extent subjective. Modern music often breaks away from traditional harmonies and introduces more dissonance.

In recent generations and today, we see the marvelous reproduction of sound with records, tape decks, and CDs. In the 1950s, with the improvement of records, the description of excellent sound reproduction was often called *hifi* (a word coined in 1950), meaning *high fidelity* (1934). One would often refer to one's home sound system as the hifi, and later as *the stereo* for the overall description of a sound system.

The reproduction of sound requires the use of electronics. We will a little basic electronics without detailed math. You will learn how to read simple modular synthesizer block diagrams. Once again, physics will be important to our understanding. There are only a very few fundamental laws of physics, from which all of these great technological innovations come. You will find that symbols and neat diagrams will be very powerful in describing electronic inventions such as the speaker, microphone, record player, and tape deck.

The sociologist Alvin Toffler (1980) wrote in his book *The Third Wave* that there have been three major technological revolutions throughout history. These are the *Agricultural Revolution* (beginning about 10,000 years ago), the *Industrial Revolution* (beginning in the 1700s), and a *Third Revolution* that began in the middle of the 20th century. This third wave of change involves information: the computer, microelectronics, genetic engineering, etc.

A common thread of third-wave technology is the application of microscopic science. We can correlate the three major historical waves of technological change with the development of sound production (Table A-1).

Table A-1. Historical Overview of Sound Production.

1. Voice	Speech, Song
2. Musical Instruments	Strings, Pipes, and Membranes
3. Synthesizers	Electronics and Computers

In agricultural settings we find speech and song. We also find simple instruments. Traditional orchestral instruments reach a peak in the industrial age that began to flourish during the 1800s. Here we have the big orchestras and concert halls.

Musical instruments use strings, pipes, and membranes in their constructions. In the early 1960s, the music synthesizer was invented. One of the key inventors was Bob Moog, who spent most of the last quarter century of his life in Asheville, NC. This is part of the third-wave of musical sound production. Then, in the 1980s, a standard was set that allows for the computer to control music synthesizers. This standard is called *MIDI*, which stands for *Musical Instrument Digital Interface*.

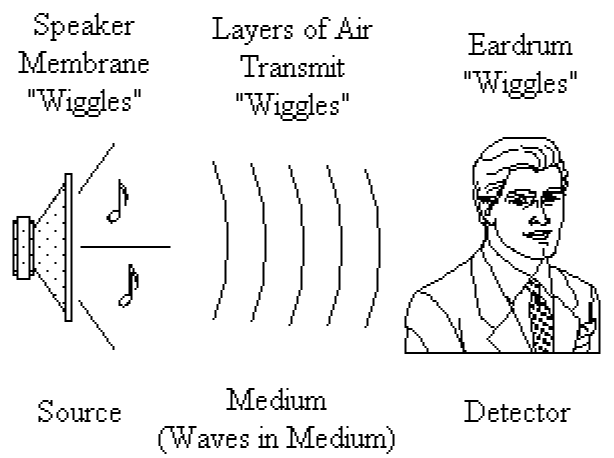
Sound as Vibration

When we hear anything, our eardrums vibrate back and forth very rapidly. It is possible to bypass the eardrum by allowing vibrations to pass through our bones, but these are still vibrations. Thinking of a vibrating eardrum gives us insight into the physical properties of sound. The eardrum responds to vibrations in the air.

The air vibrates in the first place due to a source of sound. Energy at the source is used to make the vibrations, which then travel through the air to reach our ears.

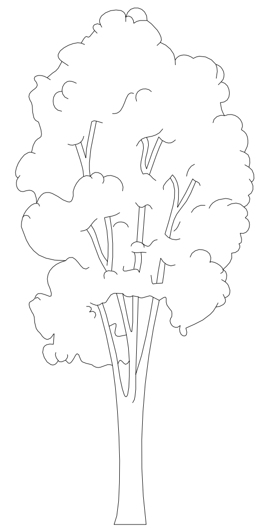
We can summarize this by saying that there is a source or speaker making vibrations, a medium such as air through which the vibrations travel, and a detector or hearer that receives the vibrations. Figure A-2 provides us with this summary.

Fig. A-2. Source, Medium, and Detector.



We can now revisit the question "Is there sound if a tree falls in a forest and no one hears it?" This question came up in the July 17, 1995 issue of *Time* magazine, where the cover story was on the mind and consciousness. The comments of a neuroscientist working at New York University Medical School, Dr. Rodolfo Llinás, are as follows.

"Light is nothing but electromagnetic radiation. Colors clearly don't exist outside our brains, nor does sound. Is there sound if a tree drops in the forest and no one hears it? No. Sound is the relationship between external vibrations and the brain. If there is no brain, there can be no sound." Rodolfo Llinás, MD, New York University Medical School, quoted in "Glimpses of the Mind" by Michael D. Lemonick, *Time*, July 17, 1995, p. 44.



The good doctor's analysis drew the following strong negative response from a reader.

"You quote neuroscientist Dr. Rodolfo Llinás as saying colors and sound don't exist outside our brains, concluding that if a brain doesn't perceive color and sound, then they don't exist. He was using the famous metaphor of a tree falling in the woods with no one around to hear it. I couldn't disagree more with Llinás' conclusion. Light is the energy given off by a heated or excited object in the form of photons.

“Sound is the vibration of molecules in a medium caused by an object. Just because there are no receivers around to pick up the light and sound does not mean they don't exist. When a tree falls in the woods, it hits the ground and vibrates the air and ground. That vibration of the air molecules is, by definition, sound. There is sound present, just no receptors to hear it. If I cannot hear my favorite radio station's broadcast, it doesn't mean that its radio waves don't exist; it just means that my radio is off.” Greg Serrano, Lansing, Michigan, Via E-mail. Letters to the Editor, *Time*, August 7, 1995, p. 7.

The way out of this dilemma is to note that if sound is defined as "the relationship between external vibrations and the brain," then you obviously need a brain for the sound to be present. On the other hand, if sound is defined solely as "vibration of the air molecules," then you do not need a brain.

Consider a strictly perceptual definition of sound, i.e., if you hear the sound in your head, sound has been experienced. However, there may have not been an external object making the sound. The strictly physical definition calls for external vibrations only. If the tree falls, there are physical vibrations in the air. So there is sound, whether someone hears it or not.

A third definition of sound includes both external vibrations and a perception of these vibrations. Table A-2 lists two questions and answers from these three different viewpoints. Which of the pairs of answers below would our medical doctor agree with? Reread his quote on the previous page if necessary.

Table A-2. Different Viewpoints on the Existence of Sound.

A Tree Falls in the Forest, But No One is There to Hear It. Is there sound?

Physically	Perceptually	Both
Yes	No	No

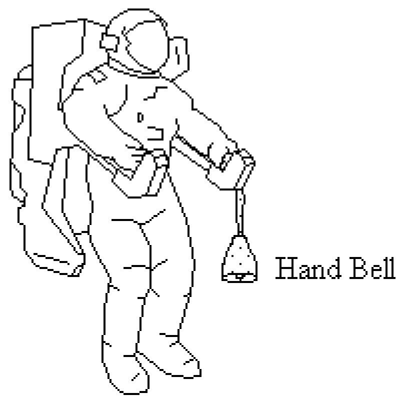
A Hearer Hallucinates a Tree Falling, But No Tree is There. Is there sound?

Physically	Perceptually	Both
No	Yes	No

The Medium

According to the viewpoint of physics, we have sound as long as we have a source of sound and a medium to transport these vibrations. We do not need a hearer. However, the medium is important. There would be no sound coming from an astronaut shaking a hand bell in outer space. See Fig. A-3. The structure of the bell would vibrate, but the vibrations would have no way of leaving the bell.

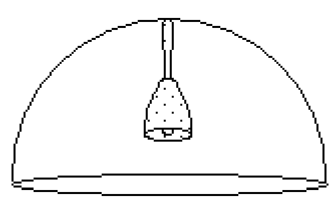
Fig. A-3. Astronaut Shaking a Hand Bell in Outer Space.



No sound vibrations would be able to travel through the emptiness of outer space. However, we would be able to see the astronaut and the bell. Light can travel through the near vacuum of outer space.

The laboratory version of shaking a bell in outer space involves pumping the air out of a container. We do not hear sound from the bell. This demonstration is often referred to as the bell-jar demonstration (see Fig. A-4).

Fig. A-4. Hand Bell in Vacuum Jar.



Air Pumped Out of Jar.
An Electronic Bell is
Typically Used.

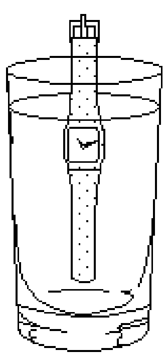
For good results, the bell must hang from the glass in such a way that sound vibrations are not permitted to pass directly from the bell to the glass. Also, a vacuum must be nearly achieved; otherwise, a faint sound will be heard.

The bell inside the glass jar can be seen even when the air is pumped out. We expect this result since light can travel through vacuum. That's how we get light from the sun. It is also how we can see the moon and the stars at night.

In conclusion, sound needs a medium in which to travel. The vibrations from a source of sound vibrate the surrounding medium and the sound travels through this medium. The medium is usually air. However, the medium can be a different gas. The medium can also be a solid. You can usually hear sound from another room by placing your ear up against a wall.

Sound also travels under water. A simple experiment to demonstrate that sound travels in water is shown in Fig. A-5 where a watch alarm is heard through a glass of water.

Fig. A-5. Watch Alarm in Glass of Water.



The Speed of Sound

Sound travels fast, but not so fast that we can't easily get a handle on its speed. If you ever heard an echo, you have experienced the finite speed of sound. Suppose you shout and a short time later hear your echo. The sound has traveled from your mouth, through the air, bounced off some large object, and returned to you. The speed of sound can be determined if you know the distance the sound traveled and the time.

You can determine the speed of a car going to Raleigh if you are given the information that the distance from Asheville to Raleigh is 250 miles and the trip takes 5 hours. The answer is 250 miles per 5 hours, or simply 50 miles per hour. This is an average time because the car does not maintain exactly 50 miles per hour at every moment. That's because you are driving and need to stop occasionally. You also need to vary your speed in traffic. Sound doesn't have to worry about such things. If the air is calm with the same temperature and pressure everywhere, sound travels at a faithful speed.

In science, we do experiments to see how the world works. So far, we have seen an experiment with a bell jar to examine if sound needs a medium to travel. We saw another experiment with a watch in water to determine if sound can travel in water. You may have had a direct experience of hearing sound underwater. If so, this counts as an experimental observation. You should have a distrust of information, even that given in this text, unless it can be supported by an observation, demonstration, or experiment.

This is a healthy scientific attitude. Science employs models that describe the real world. These models are based on observation. The scientific method includes hypotheses (which may or may not be based on the currently accepted model) and experiments to test these hypotheses. Science then consists of two components: theory and experiment. Each must support the other. If not, the theory or model is discarded for a better one. A theory that has withstood countless experiments can be considered a law. However, history has shown us that even the best theories or laws need to be modified from time to time. We now proceed to an experiment in order to measure the speed of sound.

Speed is defined as how far you go per some time interval like an hour or second. For example, 60 miles per hour, which we usually write as 60 mi/h in physics rather than 60 mph, is also 1 mi/min (i.e., 1 mile per minute). Whenever you see the symbol "/," just read it as "per." Abbreviations in science do not have periods, except for inches (in.).

Once we agree on our definition for speed, we can apply it to sound. The "echo technique" to measure the speed of sound requires a source of sound and an obstacle to reflect from. Our scientific instrumentation includes a measuring device to measure the distance and a watch to measure the time.

UNCA Convocation, an event held at the start of the academic year since the mid 1980s presents an excellent opportunity to measure the speed of sound when they hold it outdoors in front of the library.

Convocation is a ceremony to show incoming students that *UNCA* is a serious institution of higher learning. The faculty often dress in academic regalia, there is a procession, and speeches follow. As the decked-out faculty march, students are often dressed in T-shirts and shorts.

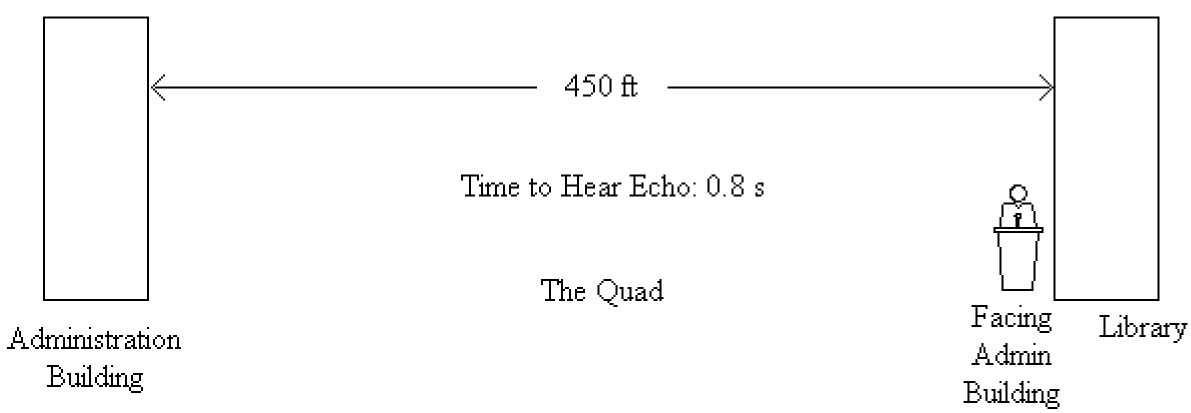
During the first year, some played Frisbee, creating a surrealistic setting. Also, someone in the distance had a radio playing rock music in competition with the serious processional music.

In the 1980s, the faculty often sat up near the library doors, like they do at graduation. If the public address sound system is positioned correctly near the steps of *Ramsey Library*, you get excellent reflections off the *Administration Building* across the *Quad*.

One year in the 1980s, the author was getting bored with the speeches and wanted to amuse himself. He noticed that during the Chancellor's speech, a faint echo could be heard. He used his digital watch to measure the time between the Chancellor's words and the associated echoes. With a little practice, the echo time was measured at 0.8 s, i.e., 4/5 of a second. The author's watch has a chronograph that measures 100ths of a second. However, due to human response time and uncertainties in distances, rounding off to the nearest 10th of a second is appropriate. The author was grateful to get such good data in the 1980s, because now, *Convocation* is usually elsewhere and the current Chancellor is never boring.

If you would like to do a similar experiment, you may be able to find a place where a delayed echo occurs. If not, you can always try it at graduation during the commencement address. Fig. A-6 gives a layout of the experiment. The distance from the *Administration Building* to the *Library* is about 450 ft (i.e., 450 feet).

Fig. A-6. Measuring the Speed of Sound.



Sound must travel from the *Library* to the *Administration Building* and back again before we can hear the echo return to the *Library*. The total distance traveled is therefore 2 x 450 ft = 900 ft. Therefore sound travels 900 ft in 0.8 s. We know immediately that the answer is approximately 900 ft/s (900 feet per second) or about 1000 ft/s since 0.8 s is nearly one second.

The actual result is worked out below using 0.8 s. The trick in dealing with the decimal is just to note that if you go 900 ft in 0.8 s, you go 9000 ft in 8 s (which is 10 times longer). We then divide to get the result per second. We round off at the end because our data is just not that accurate. The conclusion is that the speed of sound is 1100 ft/s.

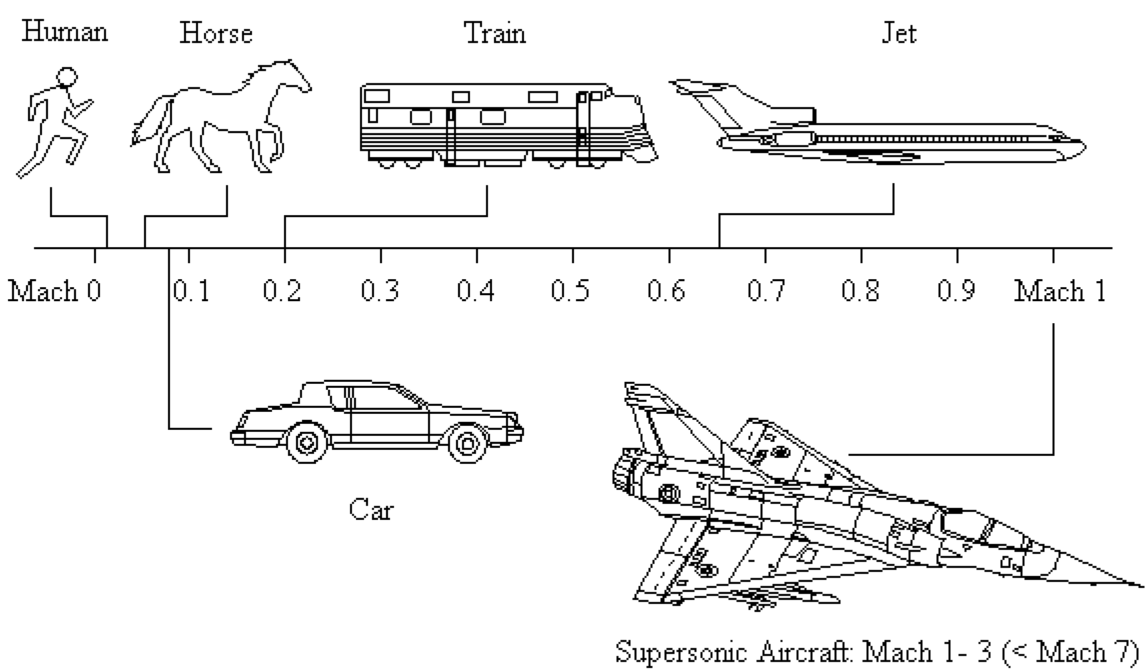
$$\text{Speed of sound} = \frac{\text{distance}}{\text{time}} = \frac{900 \text{ ft}}{0.8 \text{ s}} = \frac{9000}{8} = 1125 \text{ ft/s} = 1100 \text{ ft/s} \quad \text{(rounding off).}$$

Or reduce by halving numerator and denominator again and again: 9000/8 = 4500/4 = 2250/2 = 1125. Think money: half of $9000 is $4500 and half of $4500 is $2250. Your mind will work faster.

Mach Speed

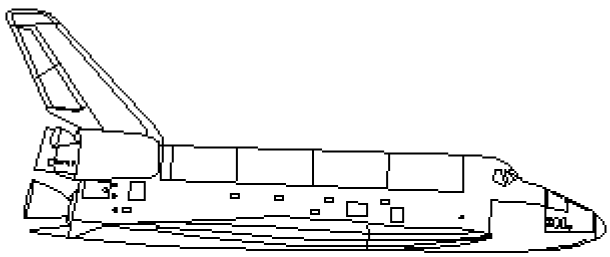
In Fig. A-7 we compare modes of transportation with the speed of sound. The Mach scale is used, where the speed of sound is Mach 1. Mach 0.5 indicates 1/2 sound speed (i.e., 50%).

Fig. A-7. Modes of Transportation and Sound Speed.

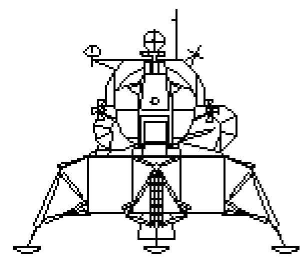


The Mach speed is defined in terms of the speed of sound at a given altitude. The speed of sound depends on the temperature and pressure of the air, which varies with altitude. For example, the speed of sound at freezing temperature is 3% lower than that at room temperature. We can loosely define "Mach 1" as the speed of sound at room temperature and pressure, ignoring this technicality. This is often done today when one refers to the speed of the space shuttle. Strictly speaking, since sound doesn't travel in outer space, Mach speed cannot be applied there. However, if we take "Mach 1" to be the fixed value of 1100 ft/s, then we can assign speeds in outer space a Mach value (refer to Fig. A-8).

Fig. A-8. "Mach" Values Assigned to Speeds in Outer Space.



Space Shuttle: "Mach 20" (17,000 mi/h)



Lunar Visit: "Mach 30" (25,000 mi/h)

Exceeding the Speed of Sound

From the past section we know that the speed of sound can be exceeded. However, in the 1930s and 1940s there were debates as to whether an aircraft could travel faster than the speed of sound. Engineers anticipated instabilities. One began to talk about the sound barrier due to the difficulty in moving faster than the vibrations you generate. We will look at a simple model for this shortly.

Sound speed is fast, 1100 ft/s. This is also about 750 mi/h. In the metric system, sound speed is 340 m/s (340 meters per second). The metric system is the official system of units used by the scientific community throughout the world. Most of your work in this course will involve the metric system.

Think of a meter as being slightly longer than a yard. Sound speed is therefore roughly 340 yard/s, or approximately 3 football fields per second. Imagine how long it takes to run across a football field. Now imagine covering 3 football fields in one second. Or imagine going from the *Library*, across the *Quad* to the *Administration Building*, and back to the Library, in about one second. If you can imagine this, you have a good feeling for the actual speed of sound.

Humans exceeded the speed of sound in the late 1940s. Today, we are accustomed to hearing about supersonic aircraft. The word supersonic refers to speeds faster than the speed of sound. The word entered our vocabulary in the 1920s. Supersonic can also refer to pitches that are too high for us to hear. So the word refers to two different concepts.

The "sound barrier" was broken on October 14, 1947 by Captain Charles E. Yeager of the US Air Force in the X-1. This experimental rocket plane was dropped out of a larger aircraft (a B-29) in flight. The designation X referred to experimental aircraft. During the next decade, breaking the sound barrier became commonplace in the X-series of research aircraft. The last aircraft of this type was the X-15, which was introduced in 1959. It was dropped out of a B-52 Bomber. One X-15 reached an incredible Mach 6.7 during the 1960s.

As early as 1962 Great Britain and France began plans for a supersonic commercial aircraft. The year 1958 saw the first use of commercial jets (US), and in 1970 the wide Boeing 747 jet began flying (US). The US was also developing a supersonic commercial jet, but in 1971, Congress cut off funding. Concerns included noise and air pollution, and danger to the ozone layer. The ozone layer protects us from harmful ultraviolet light.

The Russians developed a supersonic transport (SST) which began carrying passengers in 1975. It was discontinued in a few years. England and France began operation of the Concorde in 1976, which continued until it was retired in 2003.

The Concorde cruised at about Mach 2 at 18 km (about 12 miles or 60,000 ft). At this speed, it crossed the Atlantic in little over 2 hours. The Concorde flew into the Asheville Airport once.

Since more and more people need to fly long distances, in the early 1990s the US once again began working on SST projects. But this was discontinued in 2000 due to the expense involved.

The engineers had been working to lower noise pollution and reduce the risk to our ozone layer. However, there is no way to prevent the "sonic boom." When the sound barrier is broken, a loud boom is generated. Observers on the ground hear it once as the aircraft passes overhead. Echoes of the boom can be heard if mountains are nearby. We turn now to this very interesting phenomenon.

The Sonic Boom

In order to understand the "sonic boom" we look for a model or an analogy. What is similar to an aircraft generating vibrations in a medium? One answer is a boat generating disturbances in water. These disturbances are waves: the water surface moves up and down as waves travel. Although water waves have some marked differences with sound vibrations in air, the analogy can give us a general idea of what is going on. Later we will learn the difference between water waves and sound waves.

Fig. A-9 illustrates a motorboat traveling faster than the waves. The boat drags the waves with it in a "V" formation. This "V" represents a large wave crest since the dragging waves build up. This "V" becomes narrower if the boat goes even faster. Someone in the water will experience a "jolt" as the large wave passes by. This "water jolt" is analogous to our sonic boom. Note that an observer treading water experiences this "jolt" once, as the "V" passes by.

Fig. A-9. Motor Boat Exceeding the Speed of Water Waves, Dragging the Waves Behind It.

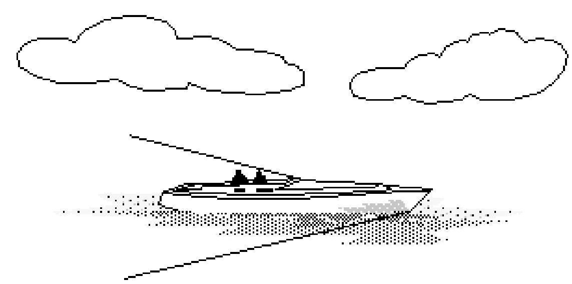
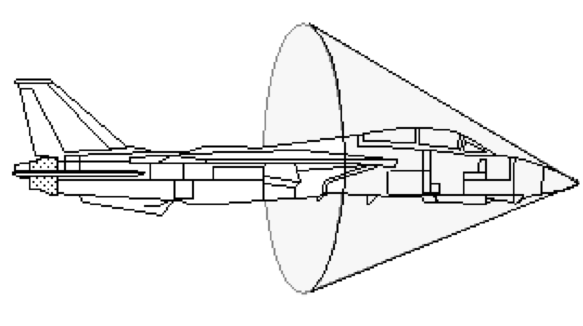


Fig. A-10 illustrates an aircraft exceeding the speed of sound. The supersonic jet drags the sound waves along with it. It does this because it is traveling faster than the sound waves.

Fig. A-10. Supersonic Aircraft Exceeding the Speed of Sound, Dragging the Sound Waves Behind It.



Note that the "V" of the boat is now replaced by a "cone." This is due to the fact that the jet flies through the air while the boat travels on the surface of the water. The case for the boat is a two-dimensional phenomenon, while the case for the jet is a three-dimensional effect.

The "cone" sweeps over observers on the ground. When it does so, the observers experience the large wave as a loud boom, the *sonic boom*. This large wave is also called a shock wave. The boom is only heard once for each observer. After one observer hears it, then another observer down the road hears it as the jet passes by this second observer, and so on.

The space shuttle makes such a sonic boom as it returns to the ground from Earth orbit. Why isn't there a sonic boom when the space shuttle is in orbit, even though it is traveling at "Mach 20"?

Another thing to consider is the whip. The tip of a whip of a cowgirl can exceed the speed of sound. The crack of the whip is actually a baby sonic boom.

There is a *speed limit* in the universe. It is obviously not the sound barrier. It is the light barrier. Einstein's *Theory of Relativity* states that there is a speed limit in the universe as a law of nature. This speed is 300,000 km/s (186,000 mi/h), the speed of light. Light speed is so fast that light appears to instantly arrive whenever it travels. It is beyond the scope of this text to delve into this mystery.

We can use the fact that light travels so fast to estimate how far storms are away from us. The lightning and thunder occur at the same time, but the light travels to us almost instantly. We start counting and wait for the thunder. How many seconds do you have to count for a storm one mile away? Hint: One mile equals 5280 ft, i.e. about 5000 ft. Sound speed is roughly 1000 ft/s.

Condensation Cloud. Dramatic conical shape cloud formations can occur when planes travel near Mach 1 due to complex pressure variations and rapid condensation. This is not a sonic boom. See the F-18 (Hornet) below.

Fig. A-11. F-18 and Condensation Cloud.

Courtesy United States Navy

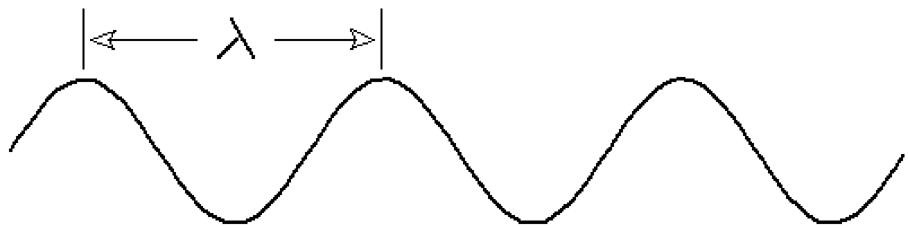
Simple Harmonic Motion

Before we leave this chapter we would like to get a better understanding of sound vibrations or waves. Just what are they? How can we draw a picture of a vibration? Let's consider a simple system for generating sound. You pick up a guitar and pluck the string. The string vibrates rapidly back and forth. The string's vibrations cause the surrounding layers of air to vibrate. These vibrations are in step with the vibrations of the string. The vibrations are transmitted through the air and reach our ears. Our eardrums vibrate in step with the vibrations of the air.

Strings are part of nature and vibrate in a most natural way. But since the string vibrates so fast, we will use another vibrating system to get a handle on natural vibrations. You. Since you are part of nature, and a "natural" person, you should be able to shake in a natural way. Take your hand and wave it up and down. Be natural. You will not hear any sound unless you can shake your hand up and down about 20 times a second. Probably not. But you can see your hand move. If you were to walk across a blackboard moving your hand up and down with a piece of chalk in it, you would trace out something like Fig. A-12 on the blackboard.

This simple or natural wave is called a *sine wave*. The distance from one peak to the next is called the *wavelength*. The wavelength is designated by the Greek letter lambda, written as λ. Note the natural way the wave rises and falls. The natural type of vibrational motion that generates such a wave is called *simple harmonic motion*.

Fig. A-12. Simple or Sine Wave with Wavelength λ.



The number of times you shake your hand back in forth per second is called the *frequency*. There is nothing special about a second. The number of times you shake back and forth per minute is also a frequency. Shaking once per second is equivalent to shaking 60 times per minute. The key idea is to count the number of cycles or times you shake during some designated time interval. Be careful that you count up and down as one cycle and not double count. A complete cycle takes you up and down.

We are now ready to observe an interesting phenomenon. If you shake your hand more rapidly and walk across the blackboard, the wiggles are spaced closer together; i.e., the wavelength is shorter. If you shake your hand less rapidly, the wiggles are spaced farther apart; i.e., the wavelength is longer. Shaking more rapidly means the frequency is greater. We say the frequency is higher.

This is heard as a higher pitch if the frequency is within the range of human hearing. Shaking less rapidly implies a lesser or lower frequency. These observations are summarized in Fig. A-13.

Fig. A-13. Relationship Between Frequency and Wavelength.

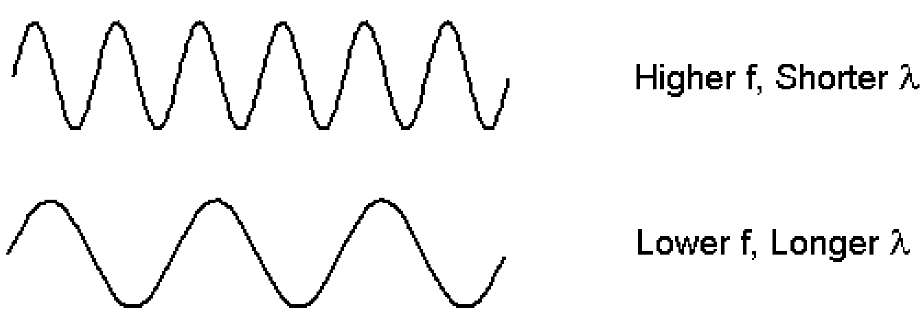
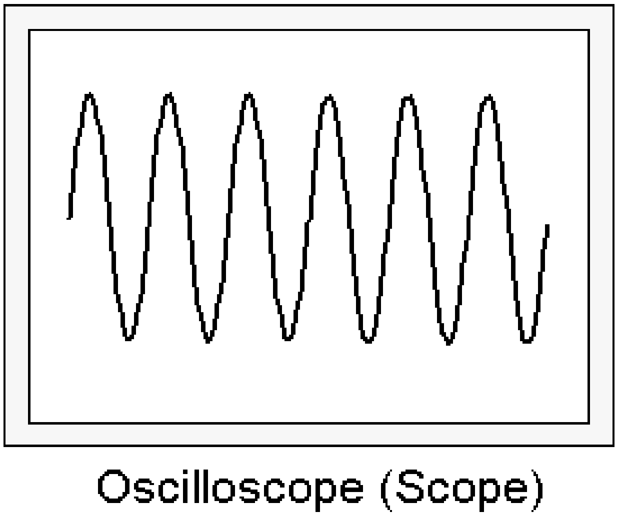


Fig. A-14. Sine Wave on an Oscilloscope.



The oscilloscope is an electronic device that shows us a picture of a sound wave much like the way the blackboard shows a picture of your hand wave. A microphone converts the air vibrations to electrical vibrations. The oscilloscope (or scope) sweeps out the picture, performing the electrical analog of tracing the wave on the blackboard.

We can use an oscillator in a music synthesizer to generate a wave for us electronically. These can be monitored with an oscilloscope. They can also be sent to a speaker, where the electrical waves become mechanical as the speaker membrane vibrates.

The moving membrane creates sound waves in the air. We can call these acoustical waves, where air is implied. Technically, these are also considered mechanical by engineers. When the waves reach our ears, an interesting sequence occurs, just the opposite as before.

The sound waves enter the ear canal as acoustic waves in air. These waves cause the eardrum to vibrate, converting the oscillations to mechanical vibrations on a membrane. Finally, these mechanical vibrations are converted to electrical signals in the inner ear. The brain receives electrical information. So we begin and end with electrical information. This sequence is listed in Table A-3.

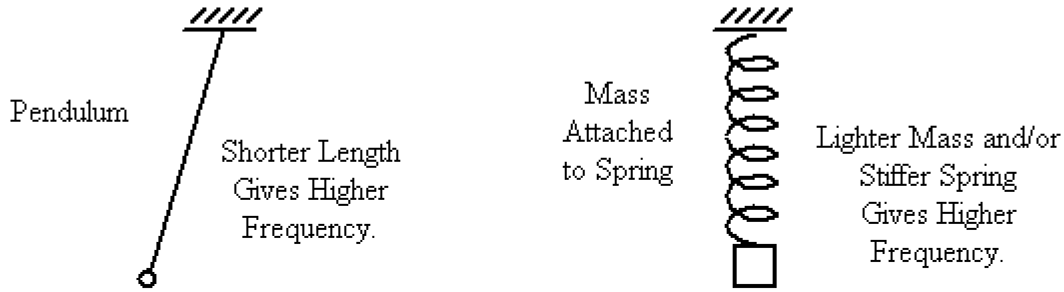
Table A-3. Different Forms of Energy as a Signal Travels from a Synthesizer to Our Ears.

Energy	Location
Electrical	Circuit
Mechanical	Speaker
Acoustical	Air
Mechanical	Eardrum
Electrical	Inner Ear/Brain

Two Examples of Simple Harmonic Motion

Finally, consider the motion of a pendulum and a mass attached to a spring (see Fig. A-15 below). These systems exhibit simple harmonic motion. Technically, the swing of the pendulum must not be too great for simple harmonic motion. The frequency of the pendulum and spring system depends on the string or spring length (shorter length for higher frequencies). The pendulum frequency does not depend on the mass of the swinging bob. All masses fall or swing at the same rate! However, the mass attached to the spring does affect the frequency of oscillation (lighter masses for higher frequencies). The stiffness of the spring is also relevant. Stiffer springs provide for higher frequencies of vibration.

Fig. A-15. Two Mechanical Systems that Exhibit Simple Harmonic Motion.



Deciding if Motion is Simple Harmonic

For your homework, you will be challenged to determine whether motion qualifies for simple harmonic motion. For example, is the up and down dribbling of a basketball by Michael Jordan simple harmonic motion?

This question is equivalent to asking "Can the motion be described by a sine wave?" Consider the following when analyzing any motion for simple harmonic motion.

- Is there a middle position where the object "would like" to be at rest?
- Is there motion on either side of the middle position?
- Do the fastest speeds occur at the middle position?

The simplest mechanical configuration for harmonic motion is a system with a linear restoring force. This means that when the distance from equilibrium doubles, the force doubles. A force law of this kind is said to satisfy Hooke's Law. A spring is an excellent example of a linear restoring force. For such systems, periodic motion is harmonic. For more complicated systems, like waving your hand in class, the real test is to graph the motion. If you get a sine wave, the motion is harmonic.

Do not worry if the harmonic motion eventually dies down. This is called damped harmonic motion and we will study it in the next class. You have to keep supplying energy to keep any motion going. Note that motion can be periodic and not be harmonic. We will encounter many waveforms such as the triangle, square, and ramp waves.

A sure-bet way to tell if the motion is simple harmonic is to try to mimic or follow the motion with your hand moving up and down. Now stick a pencil in your hand, move your hand across a sheet of paper, and let your motion across the paper draw a picture of the movement you are investigating. This is called a trace.

--- End of Chapter A ---

