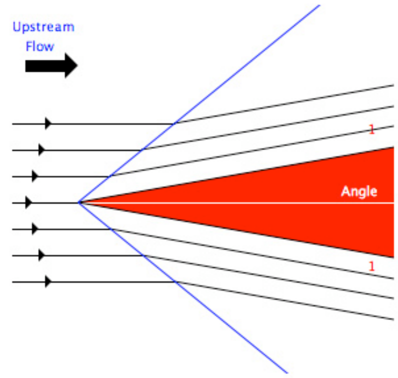
Modeling Shock Waves
Demonstration



Time:
50 minutes

Objective:
The students will know and understand the general look and shape of a shock wave.

Content Standards:
- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry
  - Identify questions and concepts that guide scientific investigations
  - Design and conduct scientific investigations
  - Recognize and analyze alternative explanations and models
- Physical Science – Content Standard B
  - Motions and forces
  - Conservation of energy and increase in disorder
  - Interactions of energy and matter

Equipment, Materials, and Tools:
Part 1
- Wave tank (or rectangular flat glass baking pan)
- Mini pump (small fish tank or fountain water pump)
- Objects to interrupt flow
- High intensity lamp and a way to attach it above that tank.
- Support for pan and prop to set negative angle (gentle reverse slope) to provide background flow
- Large pieces of white paper for the students to trace the shapes of the waves

Part 2
- Fan with fan guard
- Long pieces of string [3-5 feet]

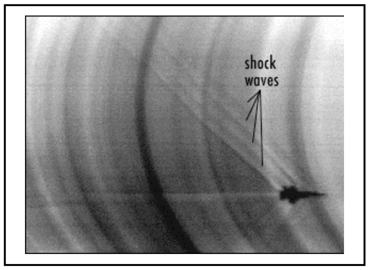
Background Information:
Shock waves that we now call sonic booms first made their impression on mankind in the form of thunderclaps. Before long, man learned to create his own sonic boom by cracking a whip, in which the tip of the whip exceeds the speed of sound.

The concept behind shock waves is that some object stops the flow of a medium (gas, liquid, or plasma) causing the medium to move around the object. However, the relative speed is such that the medium does not have time to move out of the way. A "shock wave" is set up in the medium that informs the medium and does the job of moving it away with a characteristic shape.

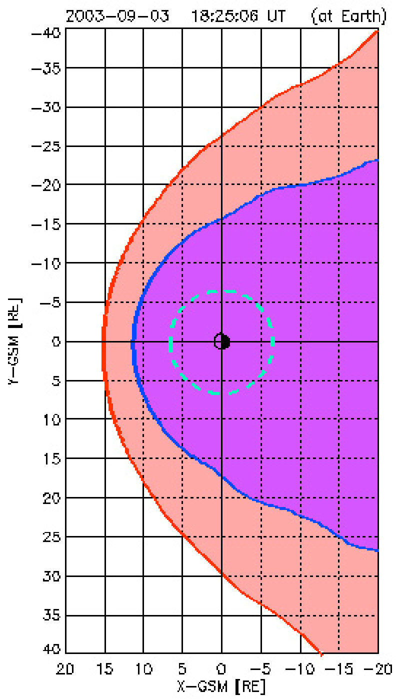
Whether fluids are composed of air or water, they behave similarly. Fluids move as thin sheets that move, bend, and slide past one another. Such turbulent flow creates spinning pockets of fluid called vortices; air passengers encounter this effect as turbulence. The aerodynamics of fluid motion is another concept central to science and engineering.

We are confronted with shock waves all the time. Ordinarily, when we think of sonic booms, we picture a supersonic-airplane flying overhead. The sonic boom tracks along the ground at the same speed as the aircraft--the faster the plane, the more the boom lags behind. Larger meteors entering the atmosphere create shock waves that can be detected on the ground as low-frequency vibration known as infrasound.

As an airplane flies faster than the speed of sound, it "pushes" on the sound waves in front of it. But sound waves obey the speed limit--they can't travel faster than the speed of sound. So the waves pile up against each other as they are created. These "piled up" waves are called shock waves. The greatest shock waves are at the tip and tail of the plane. This NASA photograph shows the shock waves created by a plane in flight (The "rings" in the photograph are camera artifacts and are not part of the shock waves).



Shock waves result when the matter through which the wave is passing is compressed and the molecules collide and vibrate. When the velocity of the disturbance is extreme, such as in the case of a meteor, electrons are knocked loose and the molecules are ionized.



Depiction of the Earth's bow shock and magnetosphere emanating from solar wind traveling left to right. The Earth is at the center.

In space, explosions are constantly occurring. It is somewhat paradoxical that the ultimate explosion, the "Big Bang" from which the universe is believed to have been created some 20 billion years ago, could not have produced a shock wave. Although "things" were sent flying in every direction, space was a total vacuum then and there was nothing to compress. Now, there are a few particles in every cubic centimeter of space and shock waves are abundant.

The shock waves that affect us most directly originate from solar flares on the sun. When a large solar flare erupts, electromagnetic radiation in the form of X-rays and radio waves travel to the earth at the speed of light and arrive here in about 8 minutes. The shock wave, however, is produced by an expanding, teardrop-shaped "piston" of ionized gases driving toward the earth at about 600 miles a second (the shape traces out magnetic field lines of the sun).

On arrival, the shock wave and the ionized solar gases interact with the earth's magnetic field. The hot gas is so tenuous that it scarcely affects conditions in our atmosphere, but it profoundly affects radio communications, often resulting in a total "blackout." It is also during times of large solar flares that we are likely to experience the most brilliant and spectacular auroras.

Instructions:

Part 1: Water flow

Setup small water pump to flow into rectangular wave tank. Mount intense light above so that image of waves is projected onto white paper on table. Sketch waves right onto paper. Note the shape of the shock wave. Have students sketch results of several different angle settings. Place different objects in the tank to disrupt the flow. Sketch the results. Possible modification is to have iron filings in water with strong magnet taped to bottom of tank to observe interaction of magnetic field with an on-coming flow.

Part 2: Air flow

Attach strings to fan guard. Turn fan on slow and observe the strings. The strings show flow with good examples of turbulence at far end. Discuss the shape of the turbulent area and the crossing of the “field” lines. Model a storm by increasing the flow of air. Compare shapes before and after.

To view simulations on the web, visit the following sites:

Moving Point Source:Doppler effect and shock wave
http://www.phy.ntnu.edu.tw/java/Doppler/Doppler.html

Interplanetary Shock Wave Passes Earth
http://www.southpole.com/headlines/y2000/ast21feb_1.htm

Shock wave simulator
http://www.grc.nasa.gov/WWW/K-12/airplane/shock.html

Modeling of the Earth’s Bow Shock and Magnetosphere
http://pixie.spasci.com/DynMod/