Exceeding the Speed of Sound

Unit: Mechanical Waves & Sound

NGSS Standards: N/A


AP Physics 1 Learning Objectives: N/A

Knowledge/Understanding Goals:
- Understand what happens when an object moves faster than sound.

Skills:
- Calculate mach number.

Language Objectives:
- Understand and correctly use the term “mach number.”
- Accurately describe and apply the concepts described in this section using appropriate academic language.
- Set up and solve word problems involving mach numbers.

Labs, Activities & Demonstrations:
- Crack a bullwhip.

Notes:
The speed of an object relative to the speed of sound in the same medium is called the Mach number (abbreviation Ma), named after the Austrian physicist Ernst Mach.

\[
Ma = \frac{v_{object}}{v_{sound}}
\]

Thus “Mach 1” or a speed of Ma = 1 is the speed of sound. An object such as an airplane that is moving at 1.5 times the speed of sound would be traveling at “Mach 1.5” or Ma = 1.5.
When an object such as an airplane is traveling slower than the speed of sound, the jet engine noise is Doppler shifted just like any other sound wave.

When the airplane’s velocity reaches the speed of sound (Ma = 1), the leading edge of all of the sound waves produced by the plane coincides. These waves amplify each other, producing a loud shock wave called a “sonic boom”.

The shock wave temporarily increases the temperature of the air affected by it. If the air is humid enough, when it cools by returning to its normal pressure, the water vapor condenses forming a cloud, called a vapor cone.

The “crack” of a bullwhip is a small sonic boom—when a bullwhip is snapped sharply, the loop at the end of the bullwhip travels faster than sound.
When an airplane is traveling faster than sound, the sound waves coincide at points behind the airplane at a specific angle, $\alpha$:

$$Ma > 1$$

The angle $\alpha$ is given by the equation:

$$\sin(\alpha) = \frac{1}{Ma}$$

I.e., the faster the airplane is traveling, the smaller the angle $\alpha$, and the narrower the cone.