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Exceeding the Speed of Sound

Unit: Mechanical Waves

NGSS Standards/MA Curriculum Frameworks (2016): N/A

AP® Physics 2 Learning Objectives/Essential Knowledge (2024): N/A

Mastery Objective(s): (Students will be able to…)

- Explain the what a "sonic boom" is.
- Calculate Mach numbers.

Success Criteria:

- Explanations account for observed behavior.
- Variables are correctly identified and substituted correctly into the correct equations.
- Algebra is correct and rounding to appropriate number of significant figures is reasonable.

Language Objectives:

- Explain how a sonic boom is produced.

Tier 2 Vocabulary: sonic boom

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.

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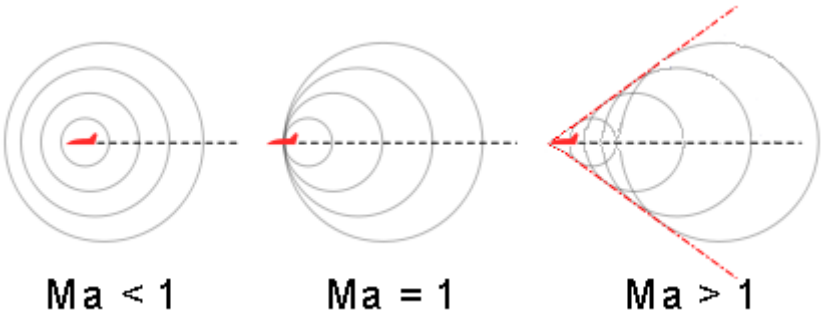
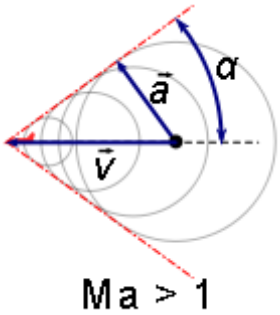
When an object such as an airplane is traveling slower than the speed of sound (Ma < 1) , the jet engine noise is Doppler shifted just like any other sound wave. When the airplane's velocity reaches the speed of sound (Ma = 1), the leading edge of all of the sound waves produced by the plane coincides. These waves amplify each other, producing a loud shock wave called a "sonic boom".



When an airplane is traveling faster than sound, the sound waves coincide at points behind the airplane at a specific angle, α:



The angle α is given by the equation:

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

Note that the airplane cannot be heard at points outside of the region defined by the angle α. Note also that the faster the airplane is traveling, the smaller the angle α, and the narrower the cone.

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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 and forms a cloud, called a vapor cone:

The "crack" of a bullwhip is also a sonic boom—when a bullwhip is snapped sharply, the end of the bullwhip travels faster than sound and creates a miniature shock wave.