1.3 The Speed of Sound

Sound is a longitudinal wave that requires a medium to travel in. No air, no sound. Star Wars??? No air in space! We often draw sound waves a transverse sine waves. *Generally,* the denser the material, the faster the speed of sound. This makes sense since the molecules of a solid are bonded together and thus transmit vibrations more easily than in the loose molecular arrangement of a gas or liquid. On the other hand, denser materials tend to decrease a wave's amplitude (loudness) more quickly than less dense ones.

Since the speed of sound depends on the vibrations of the molecules in the medium, it stands to reason that sound travels faster in warmer air since the molecules have more energy at higher temperatures. This is a bit of a paradox since warmer air is also less dense than cooler air but molecular kinetic energy is a greater influence in this case. The relationship between the speed of sound and temperature is:

$$\boxed{V = 331 + 0.6T \ [m/s]}, \quad T = \text{temperature in } ^\circ C$$

ex. Find the speed of sound at 27ºC

$$S = 331 + 0.6(27) \ m/s$$
$$= 331 + 16.2 \ m/s$$
$$= 347.2 \ m/s$$

$$347.2 \frac{m}{\cancel{s}} \cdot \frac{3600 \cancel{s}}{1 \ hr} \cdot \frac{1 \ km}{1000 \ m}$$
$$= 1249.92 \ km/hr$$

ex. You see lightning strike and 2.5 seconds later you hear thunder. How far away is the storm if it is 25ºC?

$$V_{sound} = 331 + 0.6(25)$$
$$= 331 + 15$$
$$= 346 \ m/s$$

find $d = vt$
$$= (346 \ m/s)(2.5 \ s)$$
$$= 865 \ m$$

The lightning is about 870 m away

$\hookrightarrow 8.7 \times 10^2 \ m$

Ex. Try this one

https://www.youtube.com/watch?v=3TXJ2sk02JA

$\hookrightarrow$ assume $T = 25^\circ C$

$t = 7.151 \ s$

$V = 346 \ m/s$ $\quad d = vt$
$$= 2470 \ m$$
$$= 2.47 \times 10^3 \ m$$

ex. While at a water park, a fire alarm sounds. If they have installed alarms under water as well, how much quicker would you hear the under water alarm from a distance of 50m if the air was 21ºC? The speed of sound in water is 1498 m/s.

given:
$T = 21°C$
$d = 50 m$
$V_{water} = 1498 \, m/s$

rtf:
$t_{air} - t_{water}$

$V_{air} = 331 + 0.6(21)$
$= 343.6 \, m/s$

$t_{air} = \frac{d}{V}$
$= \frac{50 \cancel{m}}{343.6 \cancel{m}/s}$
$= 0.1455 \, s$

$t_{water} = \frac{d}{V}$
$= \frac{50 m}{1498 m/s}$
$= 0.03338 \, s$

$\therefore t_{air} - t_{water} = 0.1121... = 0.1 \, s$

$\therefore$ we hear the alarm 0.1 seconds sooner.

When an object approaches the speed of sound, we use a different unit.

Mach 1 is defined as the speed of sound at a given temperature. Travel above this speed is called supersonic ; subsonic below. Travel at Mach 5 or above is called hypersonic.

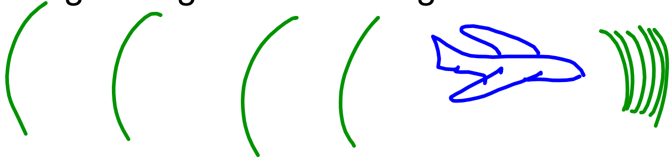
ex. find the Mach number for v = 2700 km/h at 5ºC.

$V_{sound} = 331 + 0.6(5)$
$= 331 + 3$
$= 334 \, m/s$

$2700 \frac{\cancel{km}}{\cancel{hr}} \times \frac{1 \cancel{hr}}{3600 \, s} \times \frac{1000 \, m}{1 \cancel{km}} = 750 \, m/s$

$Mach \# = \frac{750 \, m/s}{334 \, m/s} = 2.2$

As a objects's velocity approaches that of sound, the sound waves in front of it get increasingly more compressed. This compression of waves means that pushing through and breaking the sound barrier requires additional energy.



Aircraft that break the sound barrier leave a shock wave behind them much like a boat. This acoustic pressure can be strong enough to shatter glass.

https://www.youtube.com/watch?v=R1HyrowolnE

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