16-8. The Doppler Effect

(a) At rest

(b) Firetruck moving
Wave Fronts

Top View

Wave fronts

Point Source

2-D

3-D
Moving Listener & Stationary Source

Speed of sound: \( v \)
Speed of moving listener towards source: \( v_L \)
Speed of sound relative to listener: \( v + v_L \)
Source frequency: \( f_S \)
Sound frequency received by listener:

\[
f_L = \frac{v + v_L}{\lambda} = \frac{v + v_L}{v / f_S} = \frac{v + v_L}{v} f_S = (1 + \frac{v_L}{v}) f_S
\]

Moving towards source, \( + v_L, f_L > f_S \)
Moving away, \( - v_L, f_L < f_S \)
Approaching Source & Stationary Listener

Approaching Source

\[ \lambda' = \lambda - v_s T = v T - v_s T = \frac{v - v_s}{f_s} \]

Frequency received by a stationary listener

\[ f_L = \frac{v}{\lambda'} = \frac{v}{(v - v_s) / f_s} = \frac{v}{v - v_s} f_s \]
Receding Source & Stationary Listener

Receding Source

\[ \lambda' = \lambda + v_S T = v T + v_S T = \frac{v + v_S}{f_S} \]

Frequency received by a stationary listener

\[ f_L = \frac{\nu}{\lambda'} = \frac{\nu}{(v + v_S) / f_S} = \frac{\nu}{v + v_S} f_S \]
Moving Listener & Moving Source

\[ f_L = \frac{v + v_L}{\lambda'} = \frac{v + v_L}{(v + v_S) / f_S} = \frac{v + v_L}{v + v_S} f_S \]

Signs:  Separately consider the source & listener

Whenever source / listener approaches the other, \( f_L > f_S \)
- Approaching source, \(-v_S\)
- Approaching listener, \(+v_L\)

Whenever source / listener recedes from each other, \( f_L < f_S \)
- Receding source, \(+v_S\)
- Receding listener, \(-v_L\)
Doppler Effect for Electromagnetic Wave

Taking into account relativistic effects

\[ f_R = \sqrt{\frac{c - v}{c + v}} f_S \]

\( v \) positive: \( f_R < f_S \), source is moving away from receiver

\( v \) negative: \( f_R > f_S \), source is approaching receiver
16-9. Shock Waves & Sonic Boom

Mach number
\[ \frac{v_{\text{obj}}}{v_{\text{snd}}} \]

>1 for supersonic speeds

Credit: Ensign John Gay
USS Constellation, US Navy