Example 16.19

A 300Hz siren moves away from L at 45m/s relative to the air, while L moves towards S at 15m/s relative to the air. What is \( f_L \)? (a=340m/s)

- **Solution:** Both velocities are positive, so...

  \[
  f_L = 300 \text{ Hz} \times \frac{(340+15)}{(340+45)} = 277 \text{ Hz}
  \]

Example 16.20

The police car now moves towards a wall at 30m/s. What is \( f_L \) for the driver listening to the echoed siren?

Example 16.20 (2)

- **Solution:** There are 2 Doppler shifts. (a) siren = S and wall = listener_\text{L} = W then \( f_w = f_S \frac{(u+u_L)}{(u+u_w)} \)

  \[
  = 300 \text{ Hz} \times \frac{(340+0)}{(340-30)} = 329 \text{ Hz}
  \]

Example 16.20 (3)

(b) Now wall = source_\text{W} = W & driver = L

so \( f_L = f_w \frac{(u+u_L)}{(u+u_w)} \)

\[
= 329 \text{ Hz} \times \frac{(340+30)}{(340+0)} = 358 \text{ Hz}
\]

Doppler effect for EM waves

- For electromagnetic waves, there is **no medium**!
  - Speed \( c \) is constant
  - A receiver R sees
    \[
    f_R = \frac{c \text{ - } \nu}{c + \nu} f_S
    \]
    from a source S moving at \( \nu \) relative to R
  - For \( \nu > 0 \), \( \lambda \) gets longer: “Red shift” used to measure astronomical distances

Shock waves

- As source speed approaches sound speed, \( \lambda \) in front of source goes to 0
- What happens if something travels **faster** than the sound speed (supersonic)?
Shock waves (2)

- Waves pile up in front of moving object — a large force is needed to compress fluid & hence there is large drag. The resulting disturbance in the fluid is called a shock wave.

- Common examples: wake of ship, stockwhip, aeroplane, rifle bullet.

\[ \alpha \sin \alpha = \frac{\nu}{\nu_S} \]

\[ \frac{\nu_S}{\nu} = \frac{1}{\sin \alpha} \]

The Mach cone

- Formation of a shock wave — the wavefront forms a **Mach cone** with half-angle \( \alpha \):

  \[ \sin \alpha = \frac{\nu}{\nu_S} \]

  - **Mach number**
    
    \[ \frac{\nu_S}{\nu} = \frac{1}{\sin \alpha} \]

Example 16.21

A jet flies at Mach 1.75

\( h = 8000 \text{m} \) where

\( \nu = 320 \text{ms}^{-1} \)

How long after it passes do you hear the sonic boom?

**Solution:**

\[ \tan \alpha = \frac{h}{\nu_S t} \]

\[ = \frac{h}{1.75 \nu t} \]

so \( t = \frac{h}{1.75 \nu \tan^{-1} (1/1.75))} = 20.5 \text{s} \)