

The purpose of this project is to simultaneously simulate, both visually and numerically, the Doppler effect; by simulating a stationary observer and a moving wave-source, the reduction and increase in the observed frequency, relative to the movement of the source is explored

When the **source** of a sound wave moves through the medium at speed v_e while the listener remains at rest, each crest is emitted from a new position, shortening or lengthening the spacing between successive crests that reach the listener. This changes the wavelength and therefore the frequency that the listener perceives following this equation:

$$\nu_R = \frac{\nu_E}{1 \mp \frac{v_e}{v}}$$

- v → velocity of the wave
- ν_E → frequency emitted
- ν_R → frequency received

The sign is positive when the source is moving away from the listener (pitch drops if is a sound wave and the frequency emitted is bigger than the one received).

The sign is negative when the source is moving toward the listener (pitch rises if is a sound wave and the frequency emitted is lower than the one received).

For the special case when the velocity of the source is bigger than the velocity of the wave we can calculate the Mach and the angle of the cone formed:

$$Mach = \frac{v_e}{v}$$

$$\sin \alpha = \frac{v}{v_e}$$

```
function [Nu_R_Approach,Nu_R_Away,Mach,alpha]=Dopplereffect(Vsource,Vwave,Nuemitted,DeltaT)
```

This is the main structure of the code; a function was created where various inputs (characteristics of the system that would impact the phenomenon being explored) can be altered in order to view the different impact of said variables upon the Doppler effect. The functions also takes into account the possibility of cases in which the velocity of the wave-source exceeds that of the waves emitted (supersonic cases).

```
if Vsource<Vwave
    Nu_R_Approach=1/(1-(Vsource/(Vwave))).*Nuemitted;
    Nu_R_Away=1/(1+(Vsource/(Vwave))).*Nuemitted;
```

Computationally, this is quite a significant part of the code as it produces the observed frequencies

within the simulation function. Not only this but it distinguishes between subsonic and supersonic cases; for supersonic cases Mach speed and the cone angle are also outputted.

```
while t < Tmax
    % The source is moving
    SourcePosition = SourcePosition + Vsource * DeltaT;

    % Wave emission
    if mod(t, 1/Nuemitted) < DeltaT%this is made to have only integer multiples of the wavelength
        WaveData = [WaveData; t, SourcePosition];
    end
```

```
for i = 1:size(WaveData,1)
    t_em = WaveData(i,1);
    x_em = WaveData(i,2);
    radius = Vwave * (t - t_em);
    if radius > 0
        theta = linspace(0, 2*pi, 100);
        x_circ = radius * cos(theta) + x_em;
        y_circ = radius * sin(theta);
        plot(x_circ, y_circ, 'b');
    end
end

drawnow;

%Time progression
t = t + DeltaT;
```

The core of the code, the point of the function at which the simulation actually comes to life.

Here the function enters a loop where throughout the movement of the wave-source, which advances iteratively based on one of the inputs provided to the function, the various wavefronts of the wave are plotted as the point source moves, expanding in place at a rate proportional to the wave speed.

Visual representation of the Doppler Effect

The following figures display an exploration of the Doppler effect via the code created and how the frequency observed relative to a stationary observer changes as the wave/source is in motion< within the figures the blue lines represent wavefronts emitted by the source.

- For figures 1 and 2 we used the following starting conditions:
 - $V_{source} = 0.9 \text{ m}\cdot\text{s}^{-1}$
 - $V_{wave} = 1 \text{ m}\cdot\text{s}^{-1}$
 - $\text{Freq.Emitted} = 0.4 \text{ Hz}$
- Figure 3 presents the numerical calculations
- Figure 4 displays how the simulation changes when the frequency emitted is increased

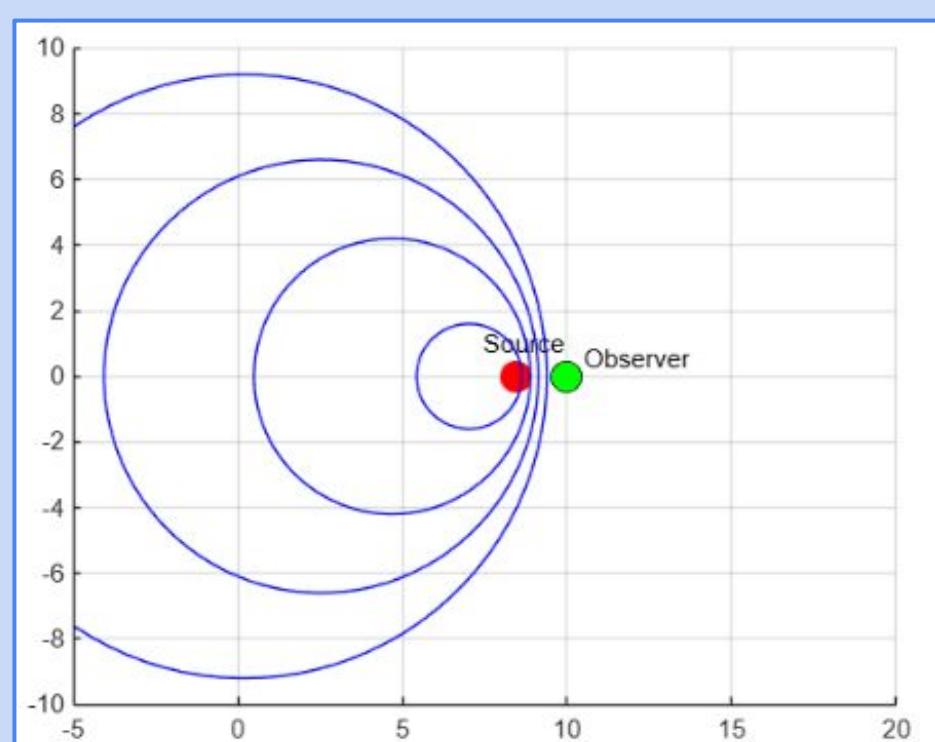


Figure 1. Observed Frequency on Approach is Higher than that Emitted

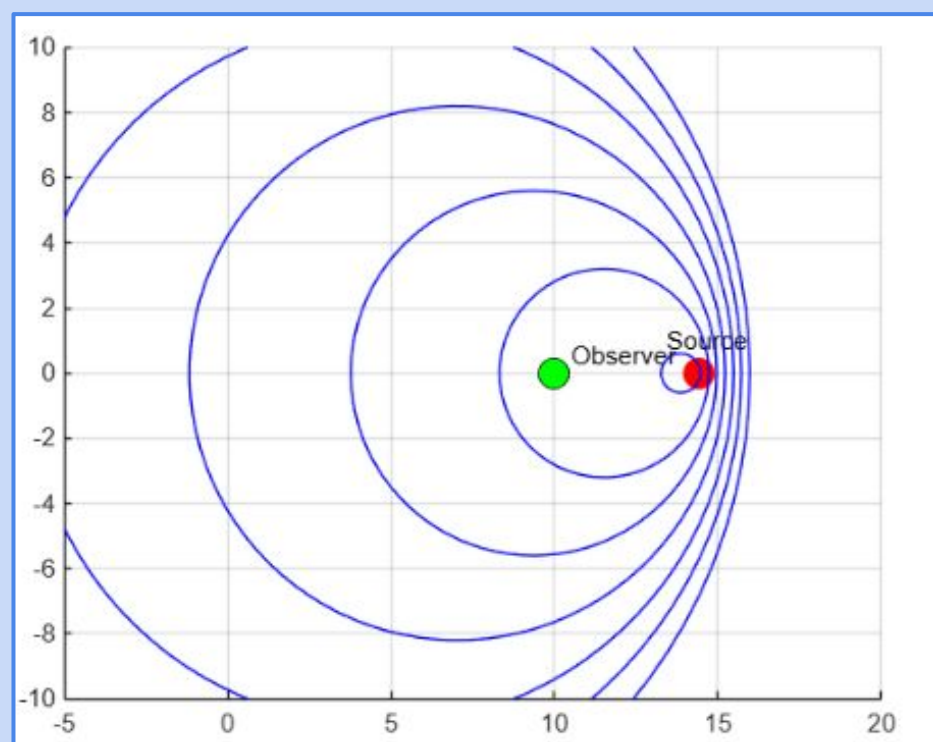


Figure 2. Observed frequency is Lower relative to the Emitted one

```
Nu_R_Approach = 6.0500
Nu_R_Away = 0.6050
Mach = 0.8182
alpha = "A shock wave is not created, there is no cone angle"
```

Figure 3. Calculations for the Example Displayed in the Previous Figures

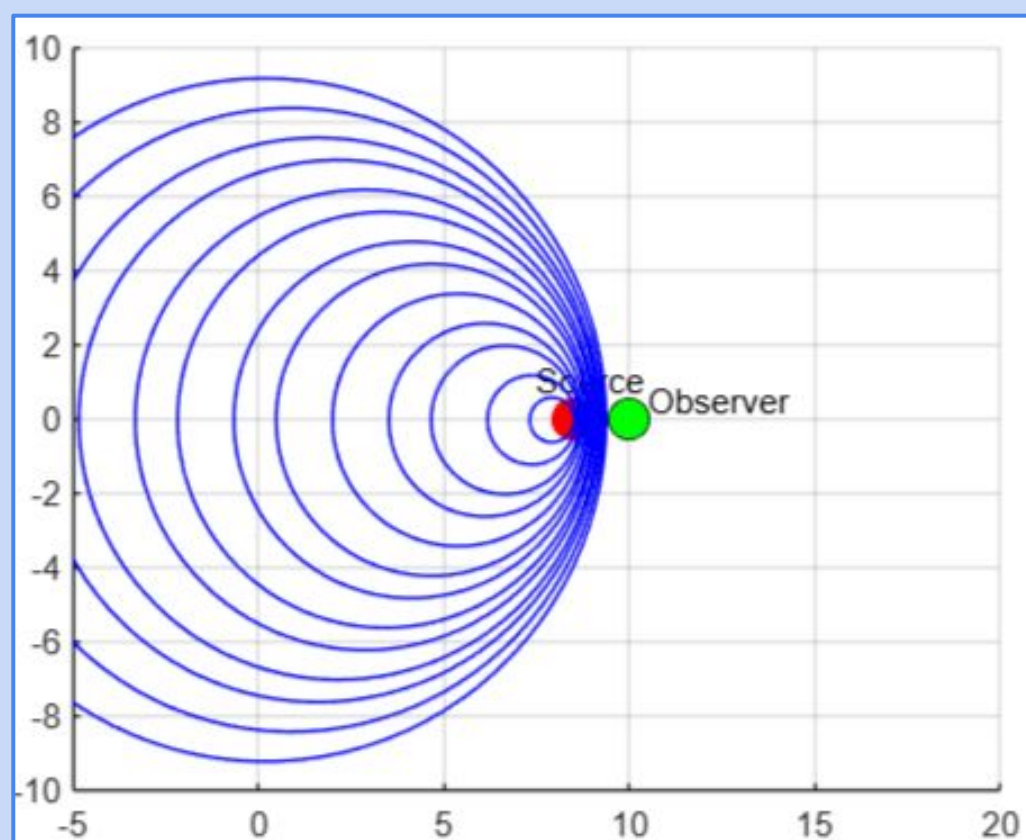


Figure 4. Representation of higher frequencies

ACKNOWLEDGEMENTS

This work is part of the INNOVA project "Integration of scientific computing in physics education (INCENFIS) (ref 344).