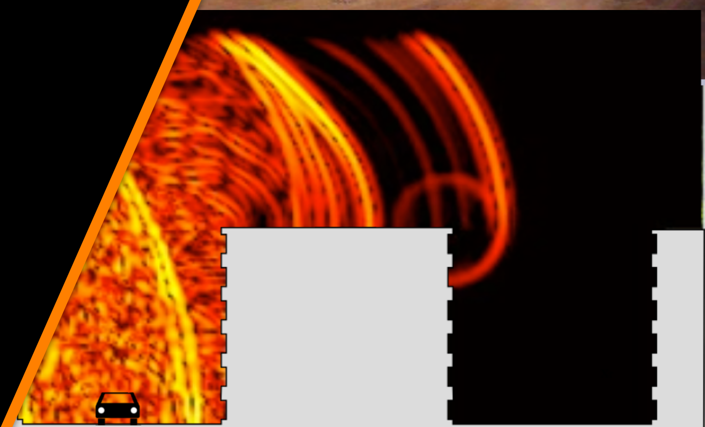
Architectural Acoustics

Week 2: Fundamentals of Acoustics
Lecture F.3



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- Impedance
- Resonance

- Fourier Transform
- Impulse response and Transfer function

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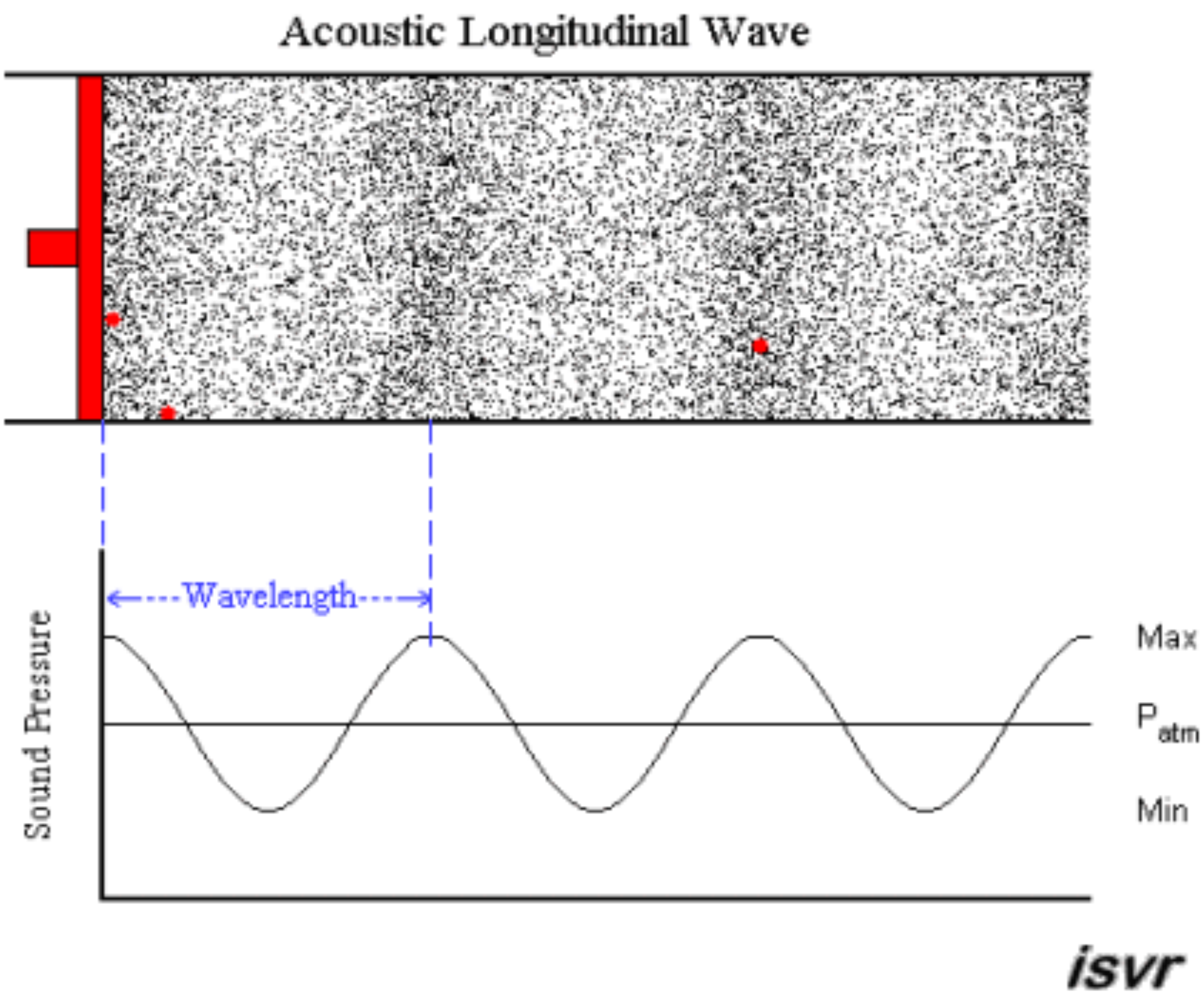
- Harmonic waves
- Intensity

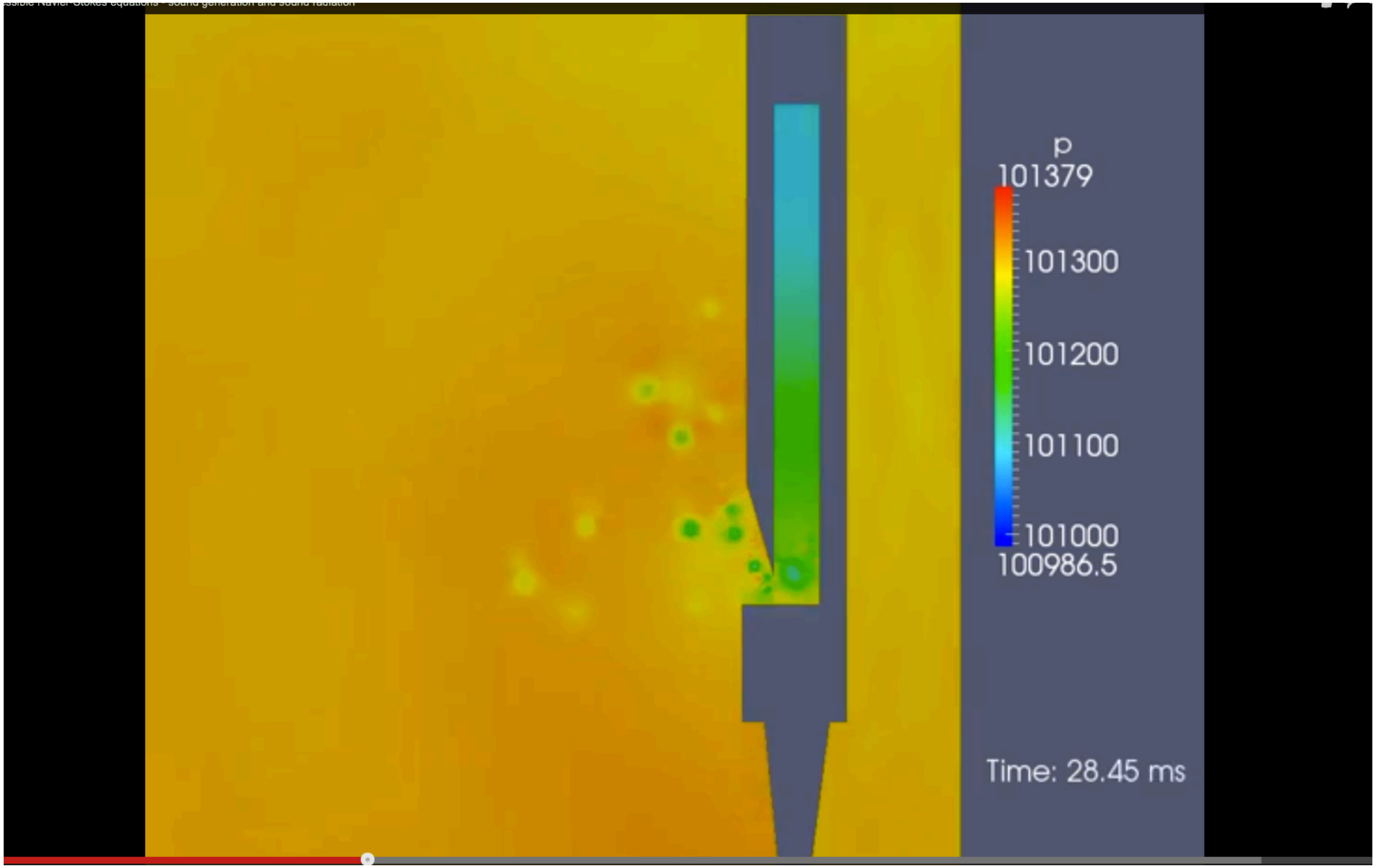
- Sound pressure level
- Wave equation in solids
- Quiz!

Acoustic waves in fluids



http://resource.isvr.soton.ac.uk/spcg/tutorial/tutorial/Tutorial_files/Web-basics-nature.htm

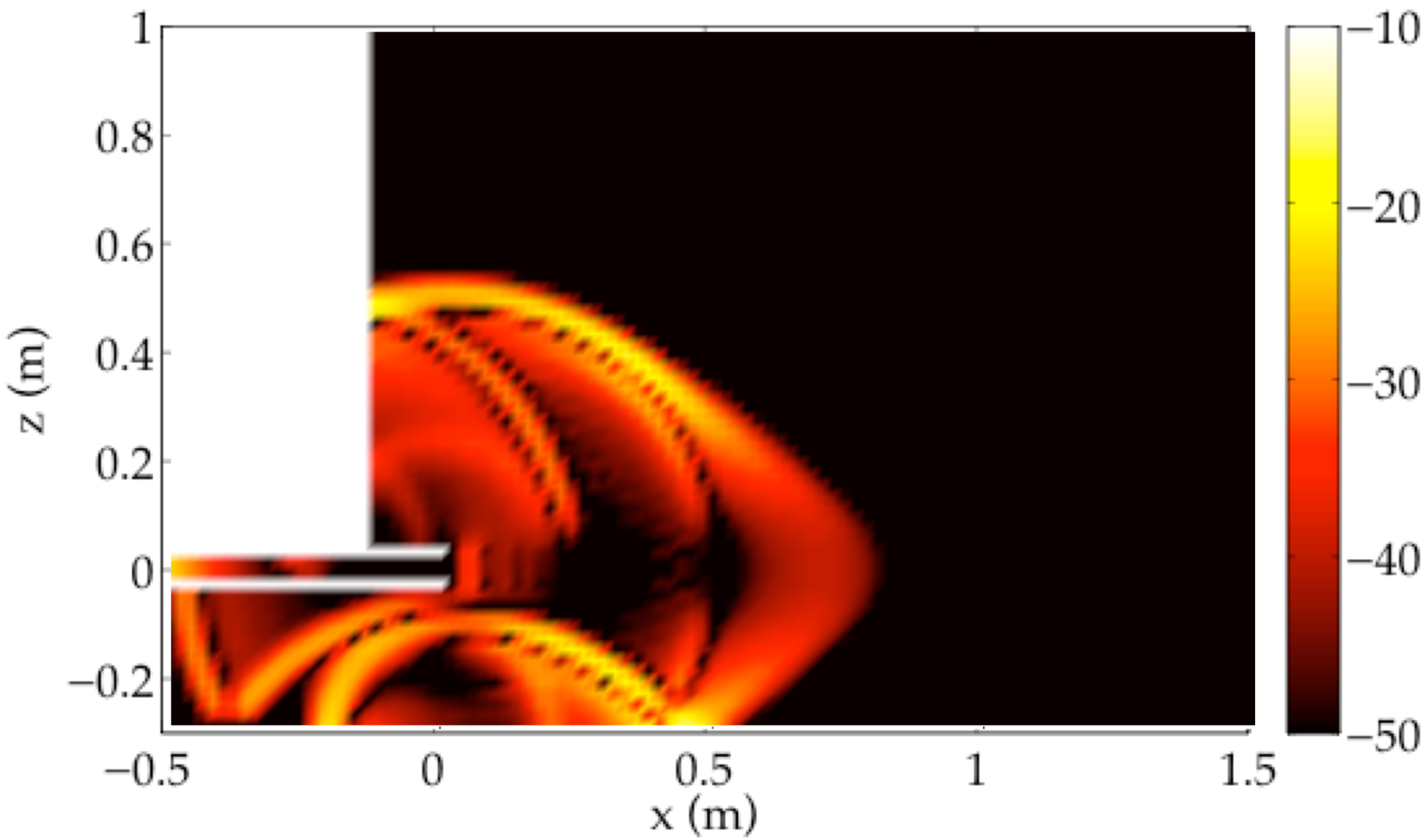
Acoustic waves in fluids



http://www.stat.physik.uni-potsdam.de/~jost/

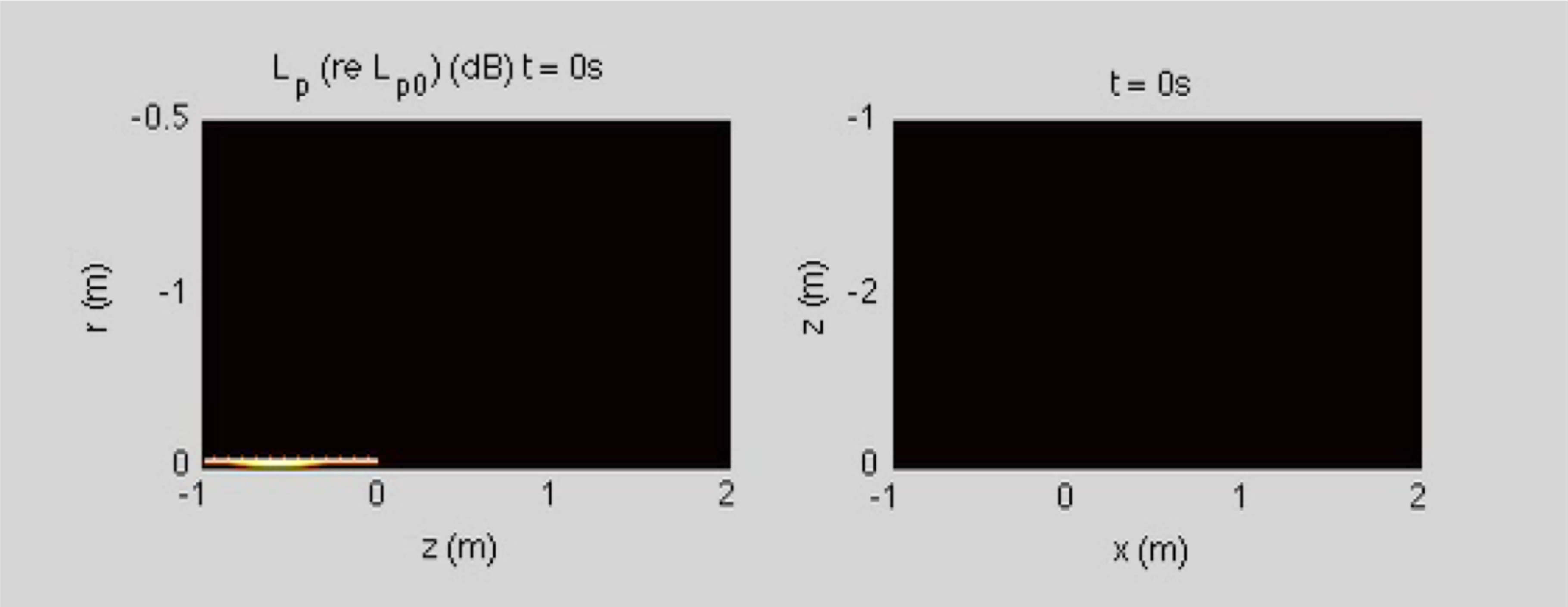
https://www.youtube.com/watch?v=AcM3OSeM7uk&fs=1&hl=en_US&rel=0

Acoustics and fluid flow



Own work

Acoustics and fluid flow

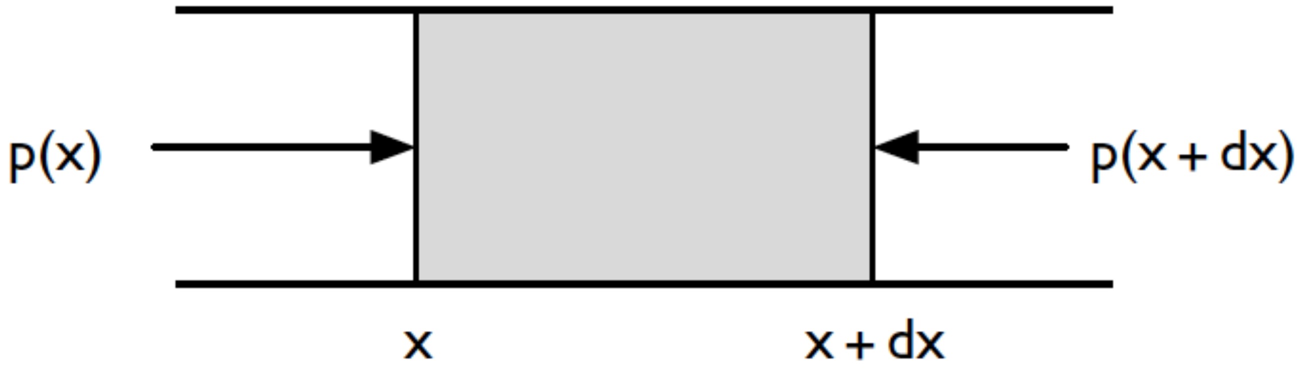


Own work

1D Wave Equation in fluids (as air)

http://www.haines.com.au

Balances to be respected



1) Force balance (Newton's second law, *F =ma*)

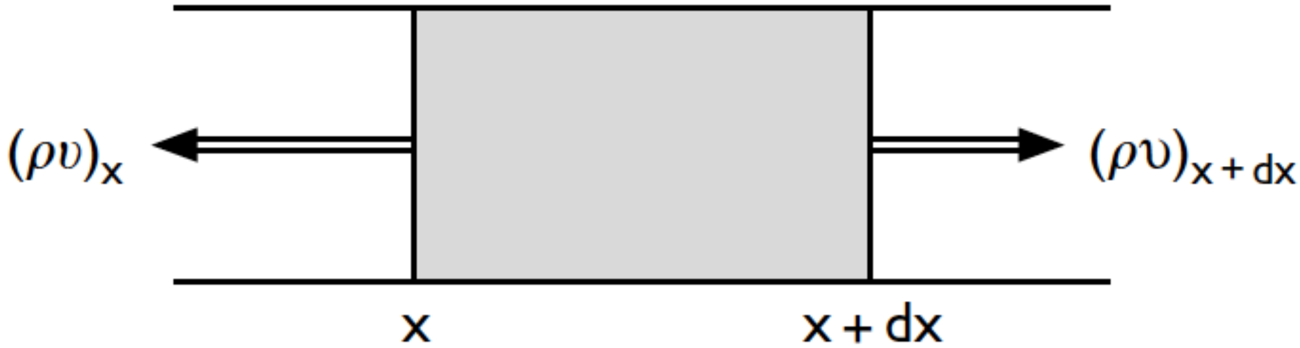
$$\frac{\partial p}{\partial x} = -\rho_0 \frac{\partial v_x}{\partial t}$$

v_x = x-component of acoustic particle velocity

ρ_0 = ambient density

Kuttruff, H. (2007). *Acoustics: an introduction*. CRC Press.

Balances to be respected



2) Mass balance (net mass inflow = rate of change of density)

$$\rho_0 \frac{\partial v_x}{\partial x} = -\frac{\partial \rho}{\partial t}$$

Kuttruff, H. (2007). *Acoustics: an introduction*. CRC Press.

1D Wave Equation in fluids (as air)

Assumptions

- No viscous effects
- No mean flow effects
- Temperature fluctuations but no heat flow (adiabatic conditions)
- Amplitudes of acoustic variables are small (pressure amplitude < 1 Pa) such that linearization applies
- We consider the molecular macro scale, i.e. not at molecule level

- + relation between pressure and density $p = c^2\rho$

$$\frac{\partial^2 p}{\partial x^2} = \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2}$$

3D Wave Equation in fluids (as air)

$$\frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} \quad = \quad \Delta p \equiv \frac{\partial^2 p}{\partial x^2} + \frac{\partial^2 p}{\partial y^2} + \frac{\partial^2 p}{\partial z^2}$$

Harmonic waves: solution to 1D wave equation

$$p(x,t) \quad = \quad \hat{p}e^{j(\omega t - kx)}$$

$$k = \frac{\omega}{c}$$ wavenumber

$$v_x(x,t) \quad = \quad \hat{v}_x e^{j(\omega t - kx)}$$

Impedance of air

$$Z_0 \quad = \quad \rho_0 c = \frac{p}{v_x}$$

Propagation of a pressure disturbance

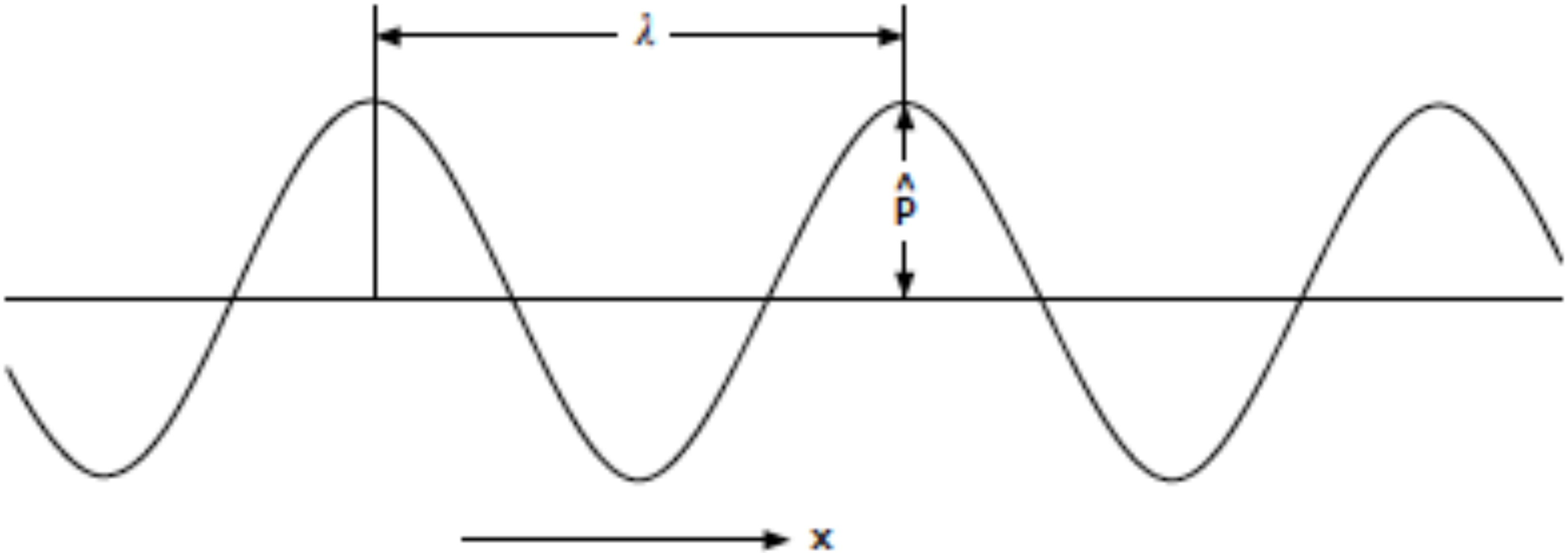


Figure 4.4 Spatial pressure distribution in a plane harmonic wave.

Kuttruff, H. (2007). *Acoustics: an introduction*. CRC Press.

Propagation of a pressure disturbance

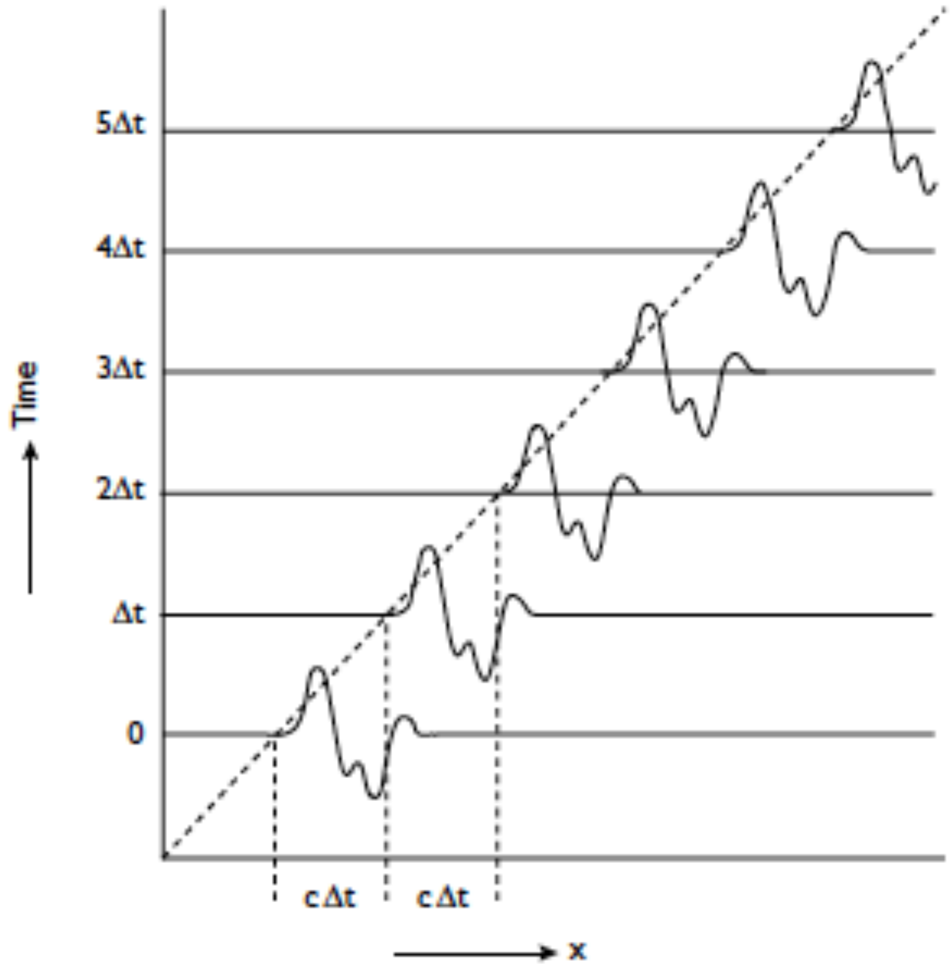


Figure 4.1 Propagation of a pressure disturbance.

Kuttruff, H. (2007). *Acoustics: an introduction*. CRC Press.

3D propagation

$$p(x,y,z,t) \quad = \quad \hat{p}e^{j[\omega t - k(x cos\alpha + y cos\beta + z cos\gamma)]} = \hat{p}e^{j(\omega t - \vec{k}\vec{r})}$$

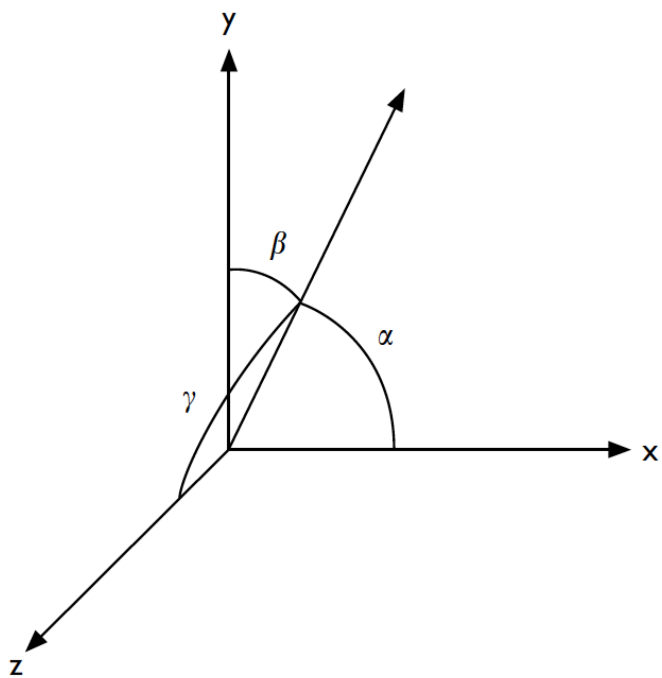
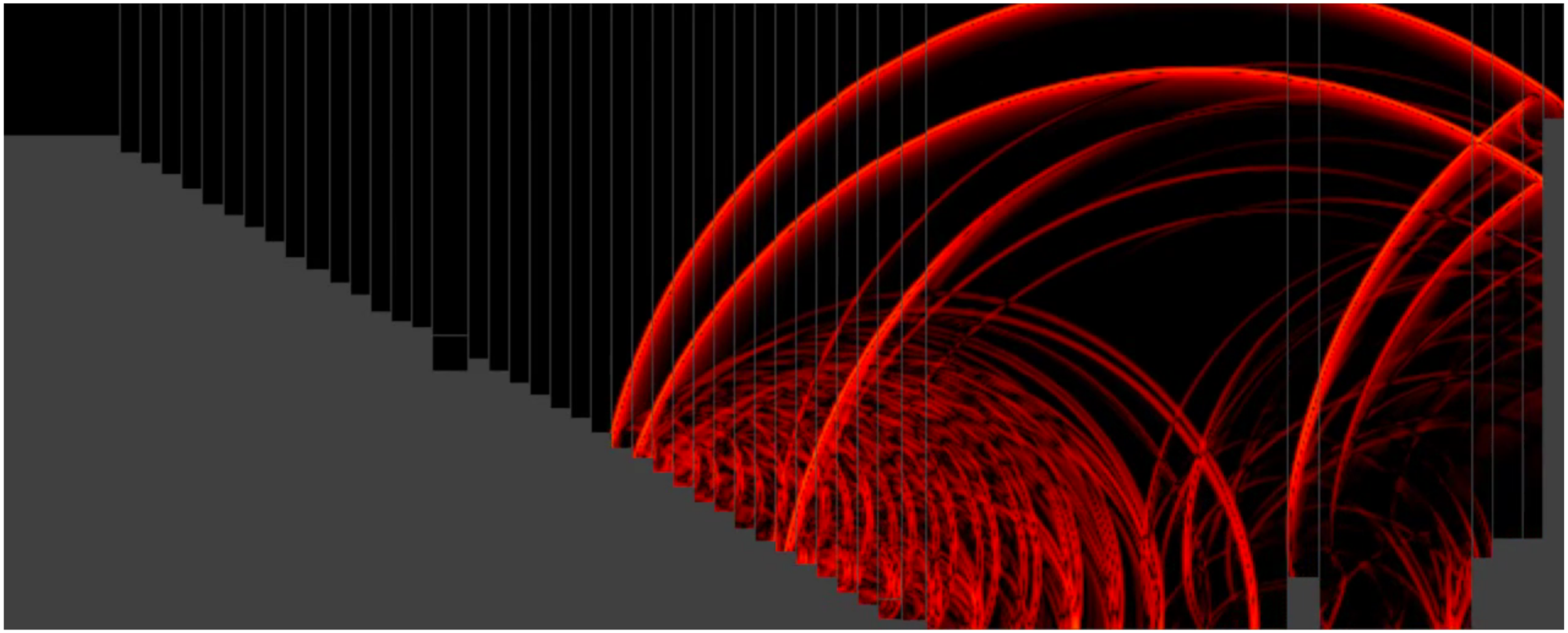


Figure 4.5 Definition of angles α, β and γ.

Kuttruff, H. (2007). *Acoustics: an introduction*. CRC Press.

Propagation of a pressure disturbance



www.openpstd.org

Acoustic intensity

Acoustic intensity *I* in W/m^2,
equivalent to irradiance (lighting) and heat flux (heat transport)

$$P_a = \iint_S \vec{I}_n dS$$

http://silent.se/

Acoustic intensity

Acoustic intensity *I* in W/m^2,
equivalent to irradiance (lighting) and heat flux (heat transport)

$$\vec{I} = \overline{p\vec{v}} = \frac{1}{2} Re\{p\vec{v}^*\}$$

$\vec{v}^*$ Complex conjugate of the particle velocity