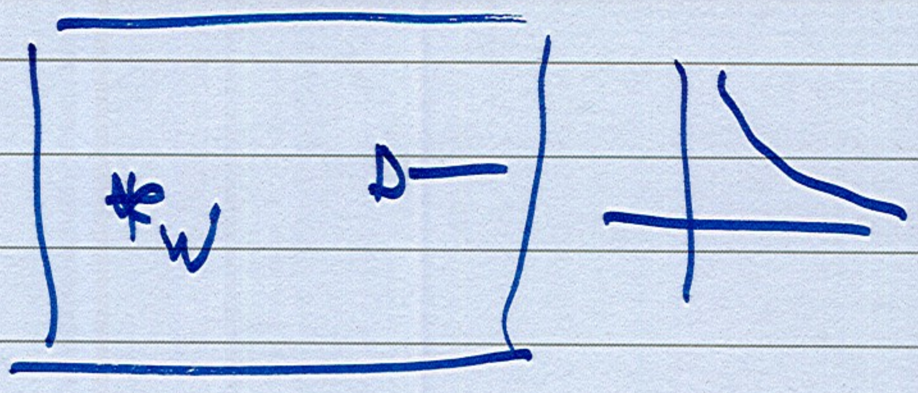
ME 513 Session 41 11/25/19

6.0 Room Acoustics

6.1 Introduction

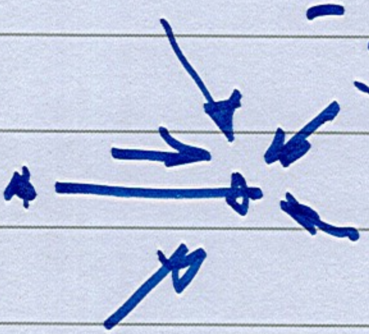
$$T \propto \frac{V}{A}$$

Energy Acoustics – high frequency



Reverberation

- sensation created by the superposition of <u>many</u> reflections



- long rev time - direct sound is reinforced by many reflections
  - level increases - benefit

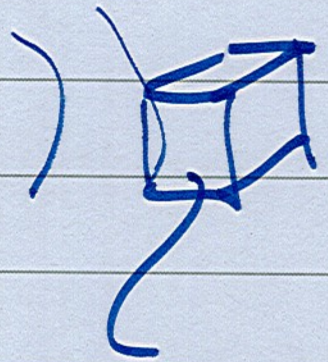
- rev time is too long
  - intelligibility is reduced.
  - speech "masks" itself

short rev time
- clarity - low sound levels

long rev time - lack of clarity, high levels

6.2 Energy Density

Sound propagates past a point in space



- fluid moves locally.
- " expands & contracts

- Kinetic
- potential energy

fluid element of fixed mass

(i) Kinetic Energy

$$E_k = \frac{1}{2}\rho_0 \underbrace{u^2}_{\text{particle speed}} \underbrace{V_0}_{\text{volume}}$$

(ii) Potential Energy

- energy associated with a change in volume

$$E_p = -\int_{V_0}^{V} p\,dV = \frac{1}{2}\frac{p^2}{\rho_0 c^2} V_0$$

E_p increases as work is performed on the element

(iii) Total Energy in Volume V_0

$$E = E_k + E_p$$

$$= \frac{1}{2}\rho_0\left(u^2 + \frac{p^2}{(\rho_0 c)^2}\right)V_0$$

u = instantaneous total real particle speed

p = " " " sound pressure

(iv) Energy Density

$$\mathcal{E}_i = \frac{E}{V_0}$$ instantaneous energy density

Time-averaged energy density

$$\underset{\approx}{E} = \langle \mathcal{E}_i \rangle = \frac{1}{T}\int_0^T \mathcal{E}_i \, dt$$

integral is performed over 1 or a few cycles of sound

Time average is over a very short interval so that $\mathcal{E}$ is itself a function of time

rate of change of $\mathcal{E}$ is very slow compared $\mathcal{E}_i$

<u>microflown</u>

$$E = \frac{1}{2}\rho_0\left(u^2 + \frac{p^2}{(\rho_0 c)^2}\right)V_0$$

for a plane harmonic wave

$$\bar{p} = \pm \rho_0 c \, \bar{u}$$

$$\varepsilon_i = \rho_0 u^2 \quad \text{or} \quad \frac{p^2}{\rho_0 c^2}$$

when the sound field is harmonic

$$p = P e^{j\omega t} \qquad u = U e^{j\omega t}$$

Time averaged energy density

$$\mathcal{E} = \frac{1}{2}\frac{|P|^2}{\rho_0 c^2} = \frac{1}{2}\rho_0 |u|^2$$

mean square pressure

- These relations are true for plane waves
- here we are assuming the sound field is diffuse
- plane waves traveling in all directions simultaneously

- each of the plane wave components is randomly phased

- when randomly signals are added

$$P^2_{total} = P_1^2 + P_2^2 + P_3^3 + \ldots\ldots$$

$(P_1 + P_2)^2$

because cross-terms are zero due to a lack of correlation

$$\varepsilon_t = \frac{1}{2}\frac{P_t^2}{\rho_0 c^2}$$

total mean square pressure at a point in ~~the~~ a ~~diff~~ diffuse sound field

relation between total mean square pressure & total energy density

- when the sound fields consists of a superposition of randomly phased plane waves

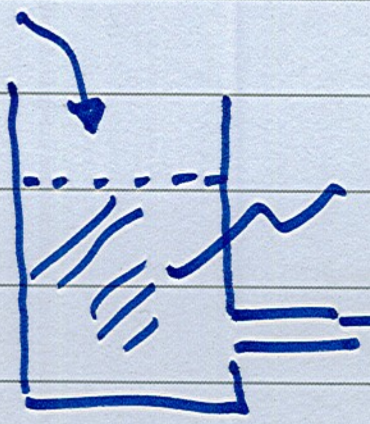
6.3 Energy Model for Sound in a Room

Sound source is turned

- due to reflections, energy density in the space increases until rate of energy absorption at the walls

=

rate of energy input



Π

rate of energy delivery to the space
- sound power of the source

Rate at which energy is delivered

Π = Rate at which energy is stored in the space + Rate at which energy is lost by absorption

(sound field)

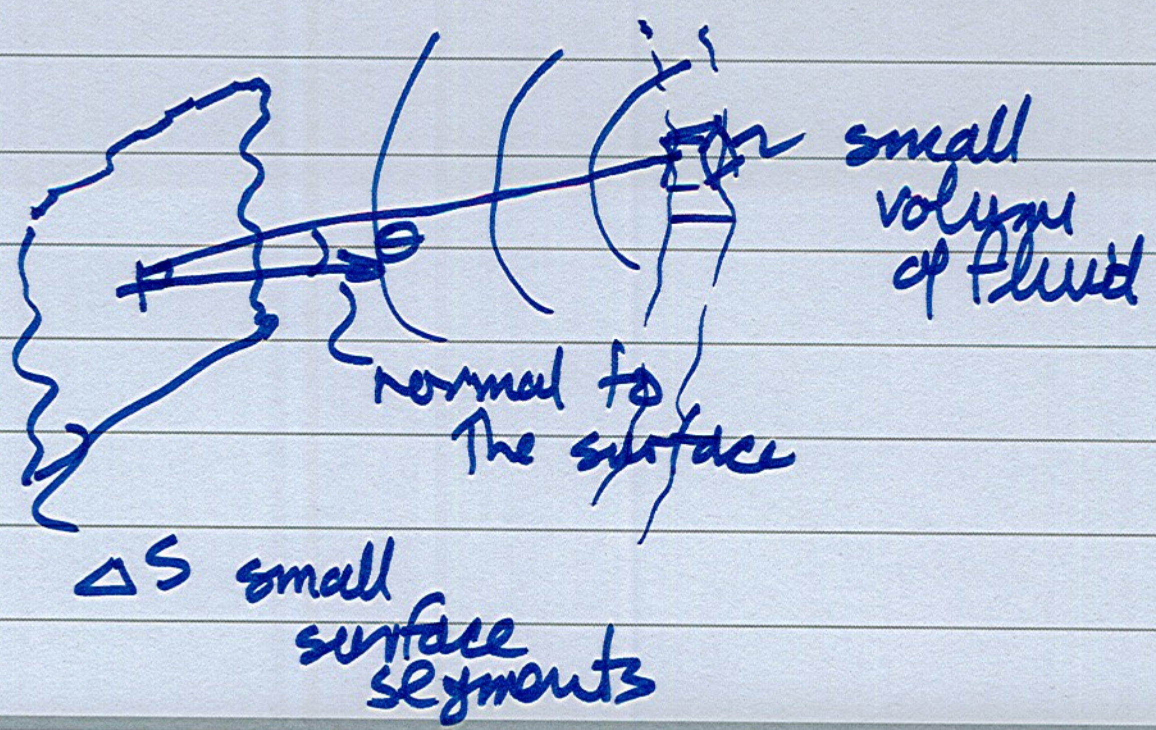
$$\Pi = V\frac{d\mathcal{E}}{dt} + \text{rate of energy loss}$$

Π: sound power of source

V: room volume

$\mathcal{E}$: space and short-time averaged energy density in the room last term = rate at which energy arrives at the surface × absorption at the surface

Relate energy density $\longrightarrow$ rate of arrival at the walls



$$\left(\frac{\Delta E}{\Delta t}\right) = \frac{\varepsilon c \,\Delta S}{4}$$

rate at which energy falls on are ΔS

$\div \Delta S$ let $\Delta t \to 0$

$\to$ unit area

$$\frac{dE}{dt} = \frac{\varepsilon c}{4}$$

Rate at which energy is absorbed at the wall

$\frac{\varepsilon c}{4} A$ ~ total room absorption m^2