THE THREE ACOUSTICAL TOOLS

ARCH 426

LECTURE 4

Architectural Department

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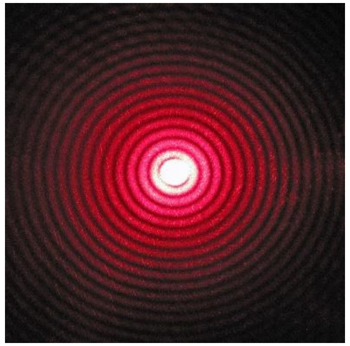
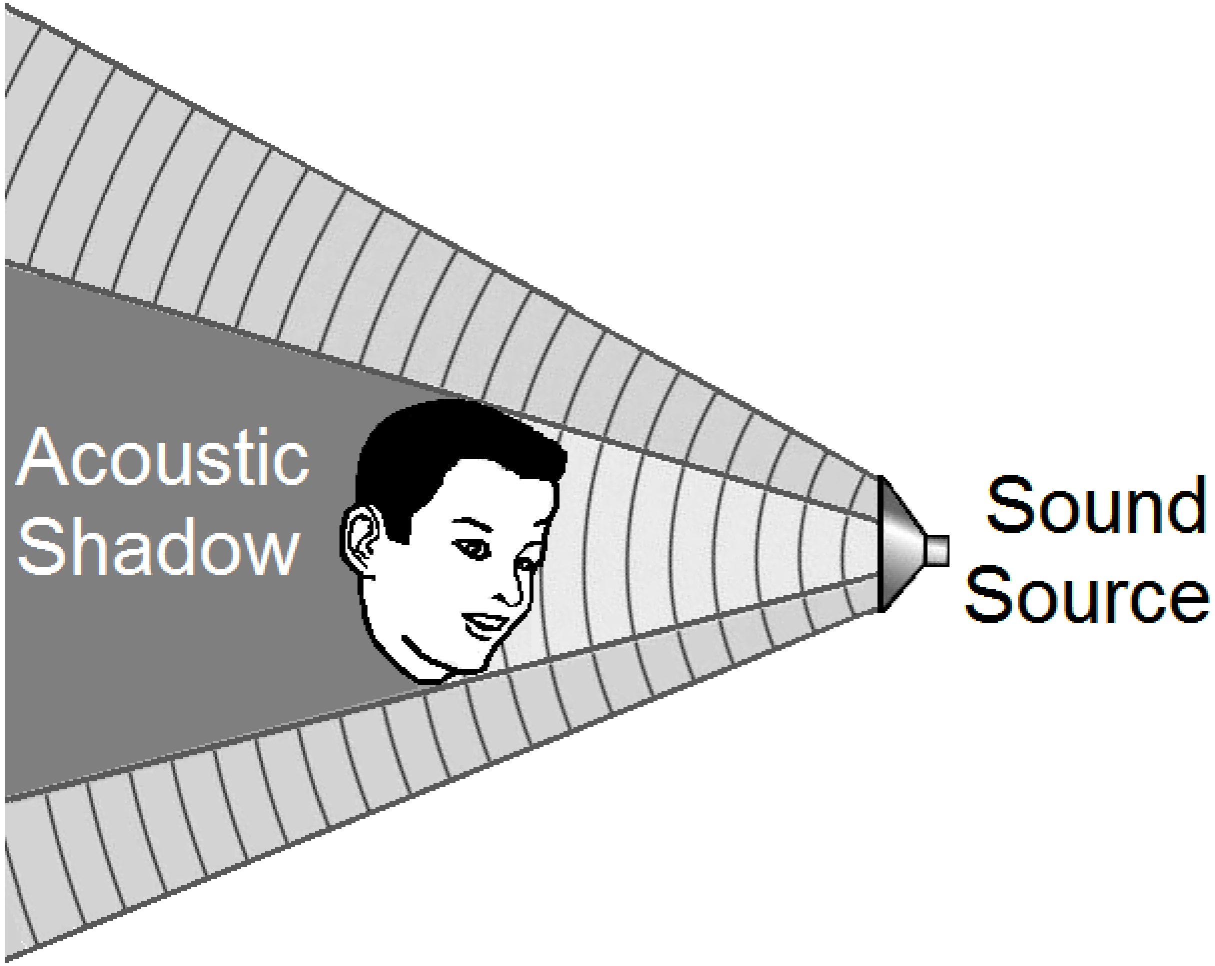
Acoustic Shadows



- Acoustic Shadows:
- A. Acoustic shadowing occurs when objects block the direct sound path between a sound source, and one or more listeners.
- 1. This subject comes into play more often than might be imagined. The most common examples are seen in large assembly areas that have columns, truss beams, and/or large lighting pendants or chandeliers.
- 2. This scenario is easily demonstrated and understood by using this simple test: If a listener cannot see all of the nearest loudspeaker or sound source, some or most of the *HF ray content will be blocked*. This condition is what creates an *acoustical shadow*.


Acoustic
Shadow
Sound
Source

B. The specific calculations needed to quantify the problem are too complex for this lecture therefore let's stick with these basic concepts:

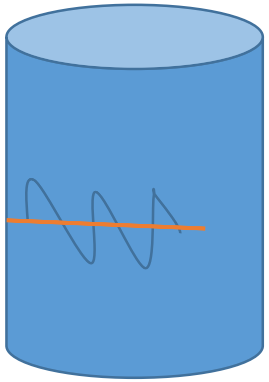
1. *The largest dimension of an obstruction is not necessarily the most "significant" dimension. The most significant dimension is the one obstructing sound from getting to one or more listeners.*

a. Example: For any given seat, the significant dimension of a **12" round column**, which is **15' tall, is almost alwalys12", not 15'.**

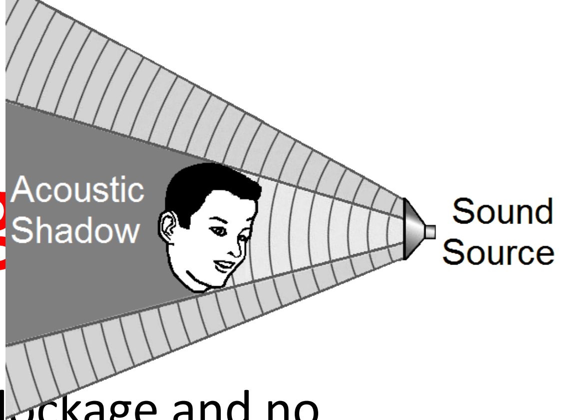
2. There are three qualities related to acoustic shadowing - **Full blockage, partial blockage and no blockage.**

a. **Full blockage:** If the most significant dimension of the blocking structure is equal to, or greater than, two times the wavelength dimension, most or all sound at those frequencies will be blocked.

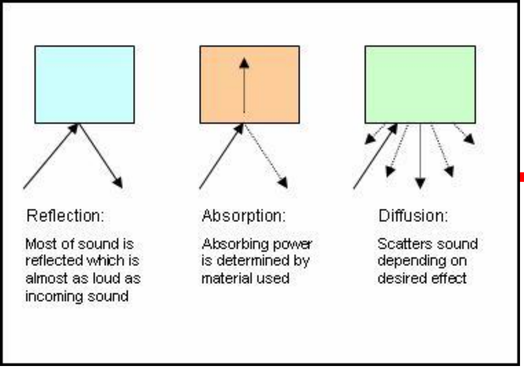
$D_{sig.} > 2\lambda$



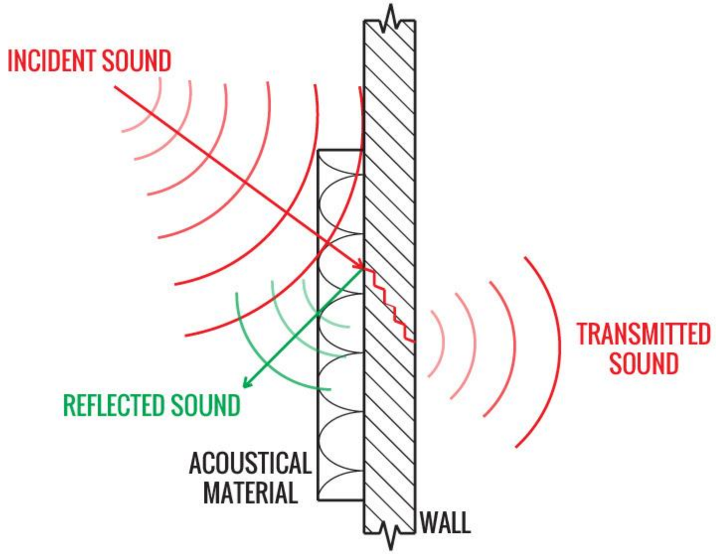
qualities related to acoustic shadowing



- There are three qualities related to acoustic shadowing - Full blockage, partial blockage and no blockage.
- a. **Full blockage:** If the most significant dimension of the blocking structure is equal to, or greater than, two times the wavelength dimension, most or all sound at those frequencies will be blocked.
- b**. Partial blockage (technically known as the "diffraction zone"):** When the most significant dimension is between one-quarter and two times the wavelength dimension, those frequencies will be partially blocked or diffracted.
- 1) The diffraction zone includes those wavelengths that are able to partially wrap around the obstruction in question, but without full power and fidelity. These frequencies may be audible, but will be distorted in time and energy relative to the unblocked sound in the same general area.
- c**. No blockage:** When the most significant dimension is smaller than one-quarter the size of the wavelength dimensions in question, then no significant blockage will occur.
- **The grand takeaway: There should never be an object that blocks the line of sight between any listener position, and the sound source or loudspeaker that is providing direct coverage to those seats or positions.**



THREE ACOUSTICAL TOOLS



- 5.1 The three acoustical "tools" are: **absorption, reflec** Technically, these are not actual tools, but rather *they* *acoustical properties and interactive behavior of variou* These three words translate into materials and application techniques that can be used to manage how sound behaves in an enclosed space.
- 5.2 **Absorption:** This tool is used to ***soak up sound***. It describes the action that happens when sound waves strike an absorbent wall, panel, boundary or barrier of some type. If the surface is a soft and/or porous material, some of the ***HF ray*** frequencies will become **absorbed or trapped** inside the fibers, pores or pockets of that material or structure.
- A. Most materials that absorb sound are only partially effective. Each type of material has a different absorption coefficient, which is a fancy way of saying the material is able to absorb more, or less, sound at various frequencies.

THE THREE ACOUSTICAL TOOLS

- B. Materials and techniques that are most effective at **absorbing *HF rays*,** are generally **least effective at absorbing *LF waves***. The inverse relationship is also true.
- C. Mineral wool, or spun glass insulation, is a very useful absorption tool when properly specified and installed.
- 1. R-11, R-19 and R-30 batt insulation are effective, especially in the *HF Ray* range of frequencies. However, these materials deliver little or **no acoustical benefit if fully enclosed in a wall, or placed above a hard-lid ceiling**.
- 2. When specified as a sound absorber, these insulation materials must be exposed, directly or indirectly, to the air and sound within the room.
- 3. **Indirect exposure is effective when open vaults, cavities, soffits and traps are created in a room**. In these areas, batt insulation can be used to line the walls, floor and/or ceiling areas as necessary.
- 4. **The soft, fuzzy side of the insulation should always be mounted outward, so it is exposed to the air as much as possible**, and not facing the structure to which it is attached.
- D. **Semi-rigid fiberglass panels are very effective sound absorbers too**.
- 1. These products are typically specified with a density of either 3pcf, or 6-7pcf. Other densities exist, but are less commonly used.
- a. **AC duct liner is an example of the 3pcf material**.
- b. **Fabric-wrapped wall panels, sometimes referred to as "sound soak" panels, are usually constructed from the 6-7pcf fiberglass boards**.

- E. Not all "insulation" works as an absorber.
- 1. In the construction trade, the term insulation can describe two different materials: one is useful to the acoustician, and one is not.
- 2. Closed-cell, Extruded Polystyrene (XPS), rigid foam insulation should never be specified or used as a sound absorber. This rigid foam material will absorb little or no sound, and is therefore useless as an absorption tool.
- F. *LF wave* frequencies can be absorbed too, but not easily by using soft/porous materials alone. This is true because the size and depth requirements needed for effective absorption are generally unavailable or aesthetically unacceptable.
- G. There are *LF wave*-range absorption materials, devices and techniques. One method is to construct an assembly of materials that create a "limp mass" structure. A limp mass assembly, or structure, consists of materials that have the following properties: size, weight, and a freedom of movement.
- 1. Sufficient size is required to catch or collect the long wavelengths of sound. Minimum size requirements are generally based on quarter-wavelength dimensions.
- 2. Weight (mass) is required to give the long sound waves something substantial to push against. Thin, lightweight materials don't work well.
- 3. Freedom of movement allows the mass to vibrate easily when pushed by the *LF waves*.

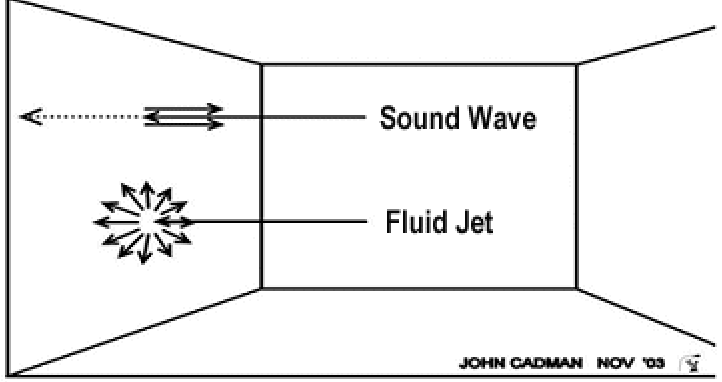
Perforation

- H. *LF wave* absorbers are typically damped-vibration panels; not designed to sustain or reinforce the waves that strike the surface.
- 1. When properly assembled, the vibration of the flexible panel converts *LF wave* energy into heat, via the friction that exists between the panel and its mounting attachments.
- 2. Additional energy loss occurs through the mechanical strain and deformation of the panel.
- I. Perforated panels are another excellent choice to consider when a hard, smooth, flat and/or curved surface is desired, along with some amount of absorption.
- 1. Perforated (perf) panels offer a combination of architectural, aesthetic and acoustical properties that are hard to ignore.
- a. **Perforated, curved-wall (or ceiling) finishes offer a unique combination of all three acoustical tools: absorption, reflection and diffusion**.
- 2. Manufactured perf panels are commonly available, and can be used as a non-structural finish material, which can be applied to ceilings and/or walls.
- 3. There is a nice variety of base materials, hole sizes, and hole shapes and patterns to choose from. Most panel types can be painted, or wrapped in acoustically-transparent fabric, as needed to best correlate with other room finishes.
- 4. Perf panels are available in a variety of material compositions, including: metal, polypropylene, fiberboard, and plasterboard.
- 5. **Perf panels have a specification labeled "% Open Area". From the most basic perspective, this number indicates how much sound will be absorbed, versus how much will be reflected or diffused. The higher the % Open Area, the greater the absorption. 20% - 40% open area is the typical range in this application**.
- 6. For proper performance, there is one detail to keep in mind: perf panels should always be mounted with airspace behind them, and the airspace should be lined or filled with mineral wool or spun glass insulation.
- a. Use these values as initial airspace guidelines: 2" = bare minimum. 4" = nominal. 6" or more, optimal.
- b. The greater the airspace depth behind a perf panel, the greater the absorption performance in the *LF wave* range.
- 7. In most cases, a perforated metal roof deck is a much

Perforation

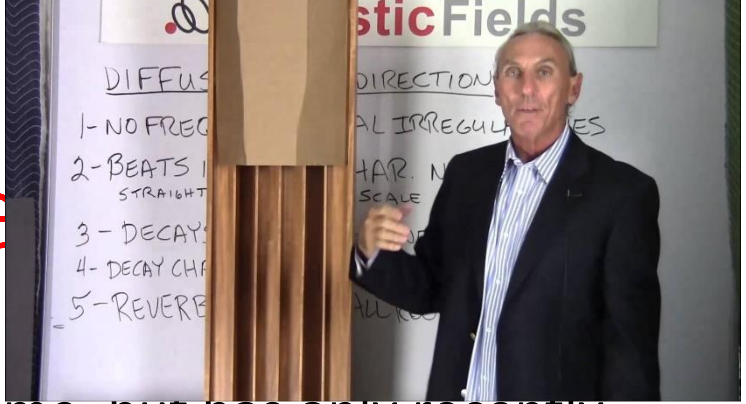
- . In most cases, a perforated metal roof deck is a much better solution than a standard, metal roof deck.
- a. Be sure to specify a sound absorbing filler material, not XPS-type rigid foam (thermal only) filler.
- J. Mounting locations, and material quantities (square footage), are the remaining keys to the successful use of absorptive materials.
- K. Air is also an effective *HF ray* absorber, but we won't discuss this in detail quite yet. Acoustics 101 for Architects Page 13 of 49 First Edition GraceNote Design Group © 2013 All Rights Reserved Revision 1.3.1
- L. One of the keys to the effectiveness of all absorption products is the thickness of the materials used. Thicker materials absorb more sound, but more is not always the goal.

Reflection:



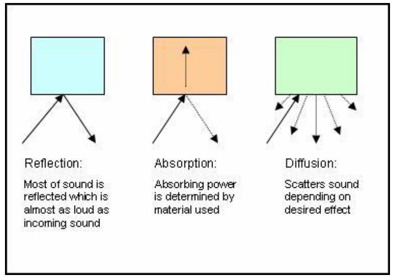
- 5.3 Reflection: Acoustically-reflective materials are probably the most widely used surface type. These materials are very commonly applied in modern construction, and are often the least expensive to purchase and install.
- A. Reflective surface materials are generally smooth and rigid. Concrete, tile, glass, wood, metal, and sheetrock are common examples.
- B. When exposed to sound, the classic Law of Reflection applies here: The angle of incidence is equal to the angle of reflection.
- 1. If you shine a flashlight at a mirror, or throw a golf ball against a concrete wall, you will get a reflection or bounce that is similar to what happens when sound bounces off a smooth, reflective surface.
- 2. These are sometimes described as "specular" reflections.
- C. When *HF rays* strike a reflective surface, the sound bounces off with nearly the same energy that it had before it struck the surface.
- D. To be highly effective at reflecting *LF wave* frequencies, finish materials must also be very-rigidly mounted.
- 1. Common construction methods are generally insufficient if effective *LF wave* reflections are required.
- 2. Think about designs that require double or triple layers of sheetrock. Such wall densities are usually specified to create an acoustical environment that requires efficient and supportive *LF wave* reflections.
- E. In some situations reflective finishes can be an effective acoustical tool. However, in many applications, they create more problems than they solve.

Diffusion : sound waves being e



- 5.4 Diffusion: Diffusion has existed since the beginning of time, but has only recently been identified and classified as an effective, quantifiable, acoustic tool.
- A. Diffusion transforms a singular, specular reflection, into hundreds, if not thousands of mini-reflections.
- B. To visualize this, imagine sound waves being exploded, and evenly scattered in many directions, after they strike a boundary.
- 1. Another visualization is to imagine a stream of water, from a squirt gun, striking a screen door. A narrow stream of water comes out of the nozzle, but a much broader, "scattered" spray of water is what is seen after the water passes through the screen.
- 2. Diffused sound waves don't go through a wall or barrier, they bounce back into the room after they have been exploded into many smaller waves, each having less pressure or energy than the original wave.
- 3. Much of the scattered sound energy is still "alive", and actively moving through the room. However, significant amounts of energy also get trapped in the complex geometry of the diffusive boundary, and are thereby absorbed.

Diffusion : sound waves being exploded



- C. *HF ray* diffusion is accomplished by deploying highly-complex geometrical shapes across one or many areas of interest.
- 1. While the total square footage of treatment may be moderately large, the individual cavity dimensions are usually quite small; typically measured in inches.
- 2. Round columns, and other convex structural features, make excellent *HF ray* diffusers too. This is not true of concave structures. Convex features scatter sound; concave features "focus" sound.
- 3. Architectural features that focus sound are rarely desirable.
- D. *LF wave* diffusion is accomplished by deploying large, moderately-complex geometrical shapes in one or more areas of interest.
- 1. The wavelength of a 100 Hz signal (baritone voice) is a little over 11’. A low bass guitar note (50 Hz) is double that wavelength. Because the wavelengths are so long in this region, *LF wave* diffusion requires treatment materials that are many times larger than what are needed for *HF ray* diffusion.
- 2. It's not always necessary to construct full-wavelength *LF wave* diffusers. To be at least moderately effective, only one-quarter of the target wavelength is needed.
- 3. A structure that is at least 5.5’, in its smallest dimension, can provide useful diffusion for frequencies of 50 Hz and above.
- 4. For most public facilities, large building features or structures are often the only practical application of *LF wave* diffusion. For some rooms, large ceiling clouds can serve this purpose. In others, balconies, pews, stairways and stages can all contribute to *LF wave* diffusion.
- E. Diffusion is a very effective tool when properly applied. It can also be more expensive to implement than either of the other two treatment tools

5.5 The Square Footage Challenge:

A. Regardless of the acoustical tools or materials used, the true effectiveness of the various treatments is based on the total square footage of each treatment, and the location(s) in which it is placed.

B. The formulas used in calculating a room's reverberation time rely heavily on the total square footage of each finish material applied.

1. When a facility is built without a specific AA plan, the base-line acoustical characteristics will be defined by the room's dimensions, geometry, and the sound absorbing-, reflecting- and/or diffusing-properties of the construction materials and furnishings. Typically, these are materials such as: carpet, drapes, sheetrock, glass, padded or un-padded chairs, steel, wood, tile, and concrete. All are architecturally-driven decisions.

a. The acoustical properties of each material listed above is different. Though some might be quite similar, some are very different.

b. The greater the total square footage for each material, the greater that material will influence the overall reverberation time in the room

c. By pure random accident, it is possible to build a venue that is too reverberant, too "dead", "dry" or non-reverberant, or something in between.

2. For any reason, if additional acoustic treatment is required, and the ratio of treated to untreated footage is too large (large areas untreated : small areas treated = a large ratio), the treatment will be ineffective, and potentially a waste of money.

a. Rule-of-thumb: To be statistically significant, any generalized acoustic treatment must represent at least 10% of the total surface area of the room. Yes, there are exceptions

- C. Added or specialized acoustic treatment(s) should be considered under these conditions:
- 1. The whole room needs to be adjusted to a more appropriate Reverberation Time (T60), "Room Tone", or "Time Slope". (See Sections 11.3 and 11.4 for more on T60, Room Tone and Time Slope).
- a. This is the scenario under which the 10% rule applies.
- 2. Acoustical zones or spot treatments are required.
- a. There are situations that may require a small, dedicated, acoustical zone that differs from the overall room requirement. A choir loft or drum booth are two possible examples.
- b. There are also conditions that call for a spot treatment of absorption or diffusion material, in order to improve a small problem, in an otherwise well behaved room.
- c. The 10% rule does not necessarily apply under these conditions.
- 3. Appropriate calculations can be run by any competent acoustician. However, it is important to note that acoustical calculations are just estimates. They are only valid when specific conditions, parameters and assumptions are being considered.

Location, location, location.

- D. Location, location, location.
- 1. If a venue requires additional, overall acoustic treatment(s), the results will benefit greatly from the proper distribution of the various treatment materials. Bunching the materials together on one wall, or in one confined area, is usually not productive, recommended, nor cost effective.

Loudspeakers: it manages sound radiation, minimize unusable sound broadcasted in a room.

- 5.6 Please understand that loudspeakers are not one of the acoustical tools listed above.
- A. With the exception of the electronic, variable acoustic systems outlined in Section 15 below, no loudspeaker, nor collection of loudspeakers, can be used to "improve" the acoustics of a room.
- 1. No electronic system can actively defeat, reduce, or remove the negative effects of excess reverberation, echo, or bad acoustics in general. Acoustics 101 for Architects Page 16 of 49 First Edition GraceNote Design Group © 2013 All Rights Reserved Revision 1.3.1
- 2. The best that loudspeakers can do is minimize the amount of unusable sound they broadcast into a room. This is accomplished through accurate selection and placement of all loudspeakers, and properly managing their sound radiation.