Acoustical Society of America
Architectural Acoustics; Theme Park Acoustics
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Theme park attractions are on the cutting edge, some might say the bleeding edge, of entertainment technology. Many of the innovations that appear in other entertainment venues first appear in theme parks. This is not only because the theme parks use the latest technology but because they can afford to provide the highest show quality since it is on a relatively small scale. Theme parks only have to provide one theater or one attraction which features a new technology.

All who worked on these projects I am sure will agree that there were enormous challenges involved. The types of problems go well beyond the normal acoustical problems which you might expect from any building. The difficulty with these types of applications is that first of all there is a tremendous amount of human traffic and any materials that are used are subject to incredible abuse. The typical animated figures in a ride is inspected every night to see whether it needs a change of clothes. Anything within reach of people will be destroyed on a regular basis and most things that are within projectile range will undergo periodic damage. Secondly there are problems of safety, especially where you have ride vehicles. There is a tremendous effort expended in keeping people from hurting themselves. You have the problem of people who will get out of vehicles or maintenance people who have to be protected from hurting themselves by vehicles, turntables or whatever. An additional problem is that anything that is difficult to maintain, hard to access, or generally a nuisance will be quickly discarded by the maintenance personnel. Thus box tops for enclosures or anything that is a trouble will find itself no longer in use.

The ultimate problem perhaps in any project of this type is that it is financially a zero sum game. Every dollar that goes into acoustical treatment must be weighed against the additional revenue that it will produce. Time and time again I was asked what is the value in terms of attendance with a dollar spent on acoustics or sound?

The final problem was tied up with the overwhelming scope of the projects. These are billion dollar projects, which had to be built in essentially two years although planning had been underway for several years, the main thrust has been in the last two years. Disney to take an example had committed to opening the park on a given day and had sacrificed enormously to achieve that end, both in the work that had been done, the extra money that has been spent in order to meet the deadline and the things that had been left out in the rush to get everything built.

The range of acoustical problems encountered ran from the mundane to the impossible. The overall noise level criterion was set for all guest areas in EPCOT at an NC 35. This was a compromise value between a lower criterion that was considered more desirable for theaters and a higher criteria that was considered probably more practical for rides. Later the criterion for rides was raised to an NC 45. Reverberation tines in the show spaces depended on the size of the room and what could be achieved in the size of the individual theaters. In general we were trying to achieve a reverberation times below a second at 70% of the theater capacity and typically about .8 seconds at full capacity in the mid frequencies.

The acoustical challenges in developing theme parks fall into general categories: sound system design, noise control, and reverberation control. Although there is not time to do an exhaustive survey of each of these areas, I will try to hit some of the highlights of what we have learned over 30+ years of working in theme park projects and to emphasize the creative side of engineering. The acoustical challenges in developing theme parks fall into general categories: sound system design, noise control, and reverberation control. Although there is not time to do an exhaustive survey of each of these areas, I will try to hit some of the highlights of what we have learned over 30+ years of working in theme park projects and to emphasize the creative side of engineering,

Show Creation

The shows are created by very talented writers and artists. These people may base their concepts on a movie, book, or simply from their imagination. As the show develops a series of drawings is prepared, which illustrate the story and what the writer wants the audience to see. From these story boards the technical team can begin to figure out how to portray the vision of the creative team. I will use an example from Ghostbusters which was developed by Landmark Entertainment for the Universal Studios Park in Florida.

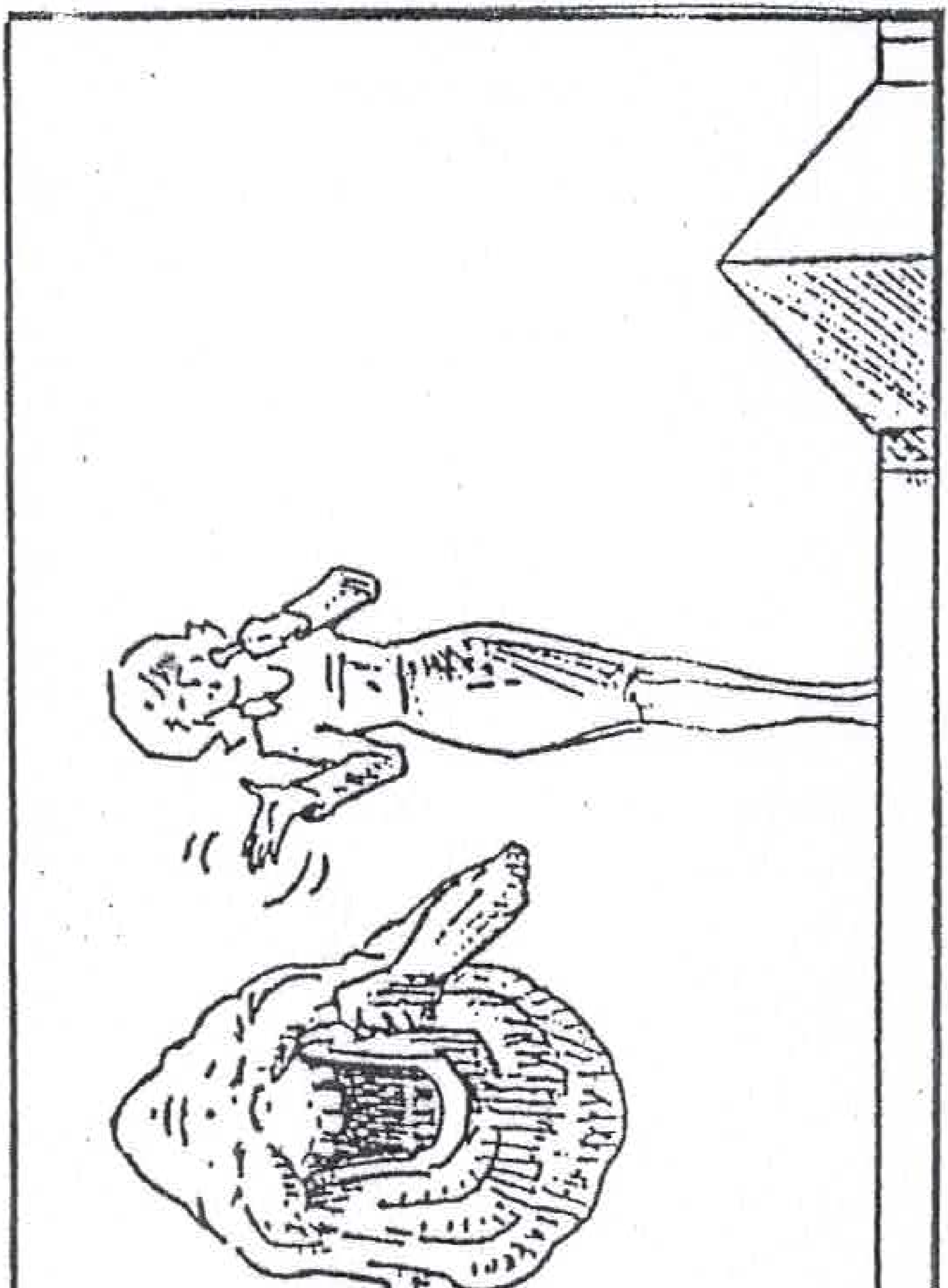
Slide 1

The show featured live actors along with ghost effects on a traditional stage. The challenge was how to get this effect to work. I will leave it to you to think about this problem as I discuss other elements of Theme Park design. We will return to this effect later in the talk. Note that the story board is only a rudimentary drawing of the scene. It features a live hostess with a microphone so some of the design elements are included. The ghost is in mid-air and must appear and disappear magically. This is about the level of detail that the technical team starts with.

In the Universal Park we did the acoustics, sound system design, and designed and manufactured the electronics that interfaced to the show control computers. So let us look at the elements that we could control.

Sound System Design

Sound system design is one of the most interesting areas and one of the few areas where engineers can control the sources directly. The first problem is to maintain the illusion that the sound is coming from the show element. This is the so-called imaging problem, The Haas effect must be used whereby the sound which arrives at the listener first establishes the apparent direction of the source. In the most straightforward types of theaters, similar to traditional movie houses, the sound emanates either from loudspeakers located behind a perforated film screen or in the case of rear projection above the screen. As the characters move across the screen, the sound can be panned to maintain the apparent image. Front speakers are augmented by surround speakers. In today's movie theaters speaker positions have been standardized into a front left, center, right, and various surround configurations. In theme parks where there is a show computer system, there is the possibility of controlling many individual speakers. For example, in the Puroland Theme Park



in Tokyo the Time Machine of Dreams theater designed about twenty years ago contains individually controllable surround and overhead speakers so that sounds can come from any direction and move in any direction. This speaker density and sophistication of control is beyond that in most cinemas and heightens the source direction illusion.

Theme parks also feature non-traditional theaters. An example of this might be the Back-to-the-Future ride at Universal Studios where the guests are seated in a vehicle mounted on a motion simulator within a large semi-spherical screen. Here we were able to position loudspeakers behind the perforated metal projection screen near where effects would appear in the film. Enough speakers were included so that right-left as well as an up-down control could be achieved through panning.

Additional speakers were placed near the ride vehicle for augmentation of bass effects such as explosions. Bass speakers, originally built into the ride vehicle, proved to be too heavy. Since bass is non-directional, the directional the sound could come from the behind-screen speakers and be timed so as to arrive simultaneously at the listener.

A second example of a non-traditional theater was the Alien Theater at Disney World in Florida. Here the illusion was that an alien was loose in the darkened theater. Each guest was given the experience that the alien was located directly behind him. The effect was produced using binaural speakers mounted beneath the seats and connected to the headrests through tubes. Digital equalization was used to remove the tube resonances. The object was to have the sound appear to come from the position of the alien in front of the guest and to then move to behind the guest using the transition between the speaker locations. The effect was carried out and is quite realistic. This system was designed by Drew Daniels when he was at Disney Imagineering.

Traditional dark rides are another theme park staple. Here the guest is transported through a darkened space to experience the adventure. Audio imaging on traditional dark rides such as ET's Adventure, King Kong, and Energy Pavilion is usually brought about by positioning speakers close to, or in the case of Kong, within the figure producing the sound. In dark rides much of the challenge is to ensure scene-to-scene isolation so that the audio from one scene does not bleed into the adjacent scene. This is carried out using separating walls between scenes and careful positioning and control of the speakers. In ET where the guests are transported on a flying bicycle, most of the speakers were placed overhead along the line of the ride track. In order to isolate the audio from one vehicle to another, speakers were only turned on when the vehicle was directly below them leaving speakers between one vehicle and the next turned off. This not only increased the vehicle-to-vehicle isolation but also reduced the reverberant field energy in the space, which improved intelligibility. Here again a show control computer which knows where each vehicle is located is essential.

Visual Trickery

The maintenance of an audio image requires not only audio but also visual trickery. Speakers are hidden by placing them in set pieces. Typically a set piece can be built out of perforated metal, which is then themed to look like a show element. In the case of large animatronic figures, loudspeakers can be placed within the figure, for example, in the chest and head of King Kong. This allows the audio directional cues to come straight from the horse's (or ape's) mouth.

Control Systems

Control systems in theme parks provide a great deal of flexibility in maintaining .imagery that is not possible in conventional theaters. An example is the King Kong ride at Universal Studios Florida, where an overhead tram is moving through a New York neighborhood. When the guests first approach King Kong, he is not facing them us so the loudspeakers in his body are not pointed in an appropriate direction. Thus, separate speakers must be provided for the long throw vehicle approach which then, by using VCA control, are merged into the speakers emanating from Kong himself. Since the body loudspeakers alone were not loud enough, additional sources were built into the sets on either side of the figure. As the vehicle moves, the sound must smoothly transition from one loudspeaker set to another so that a constant level and coverage are maintained.

In the Kong ride in Florida there was also a helicopter fly-by. Here the sound had to appear to emanate from the helicopter even while it is circling the tram. This required two sets of horns pointed at right angles mounted in the helicopter which were panned to appropriate levels as the helicopter rotated.

Noise Control

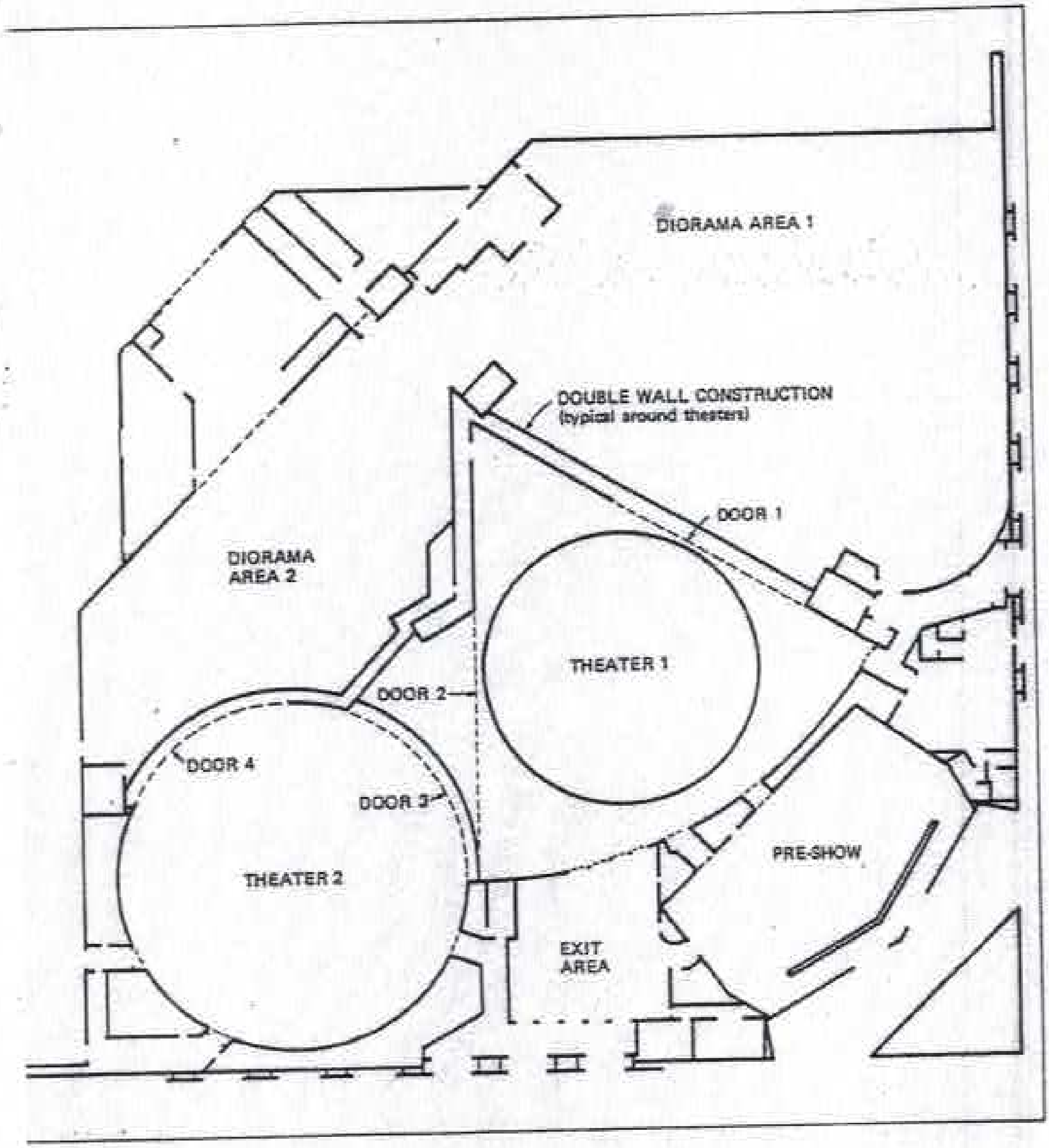
The second major feature of acoustical engineering in theme parks is noise control. Much of the engineering is straightforward mechanical and acoustical design involving standard techniques. The acoustical design must be visually and technically consistent with the shows. A good example is the Energy Pavilion at Epcot. In this pavilion there are two theaters, both with a projection screen, one of which is a Circlevision Theater and two dioramas featuring dinosaurs.

Slide 2

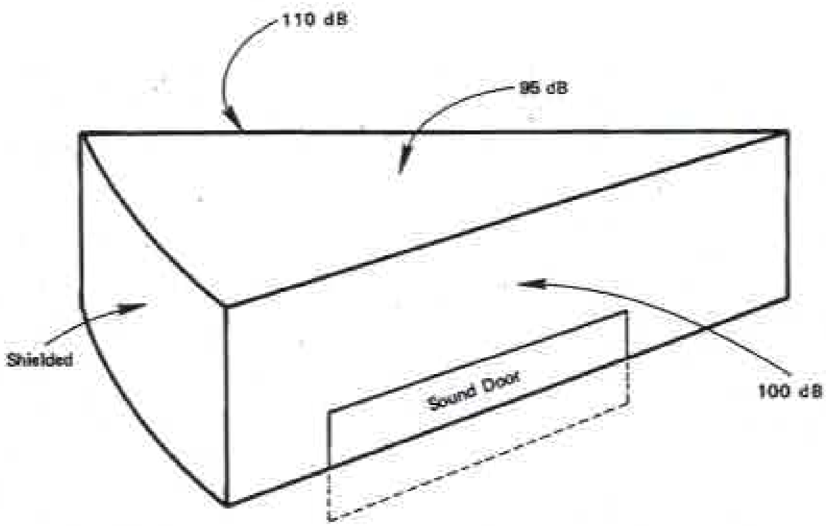
In one of the theaters there was a film of the take-off noise from the space shuttle at 110 dB at 100 Hz, which needed to be isolated from the adjacent theater. The guests were seated on large ride vehicles that were computer controlled and followed wire guides imbedded in the floor.

Slide 3

The ride vehicles drove three abreast through door openings between the theaters. The doors separating the theaters had to provide both the acoustical isolation and be able to be withdrawn so that the 25,000-pound vehicles could drive over them. The door itself was approximately 90 feet long by 10 feet high with the result that there could be no compression seals associated with the doors since the force would have overwhelmed the lift motors. Due to the weight of the doors, they had to be carefully counterbalanced so that the total weight lifted by the motors was small.



.gure 2. ENERGY PAVILION PLAN SHOWING SOUND DOORS



ENERGY PAVILION - THEATER I

Assumed Sound Field Distribution
Levels at 100 Hz

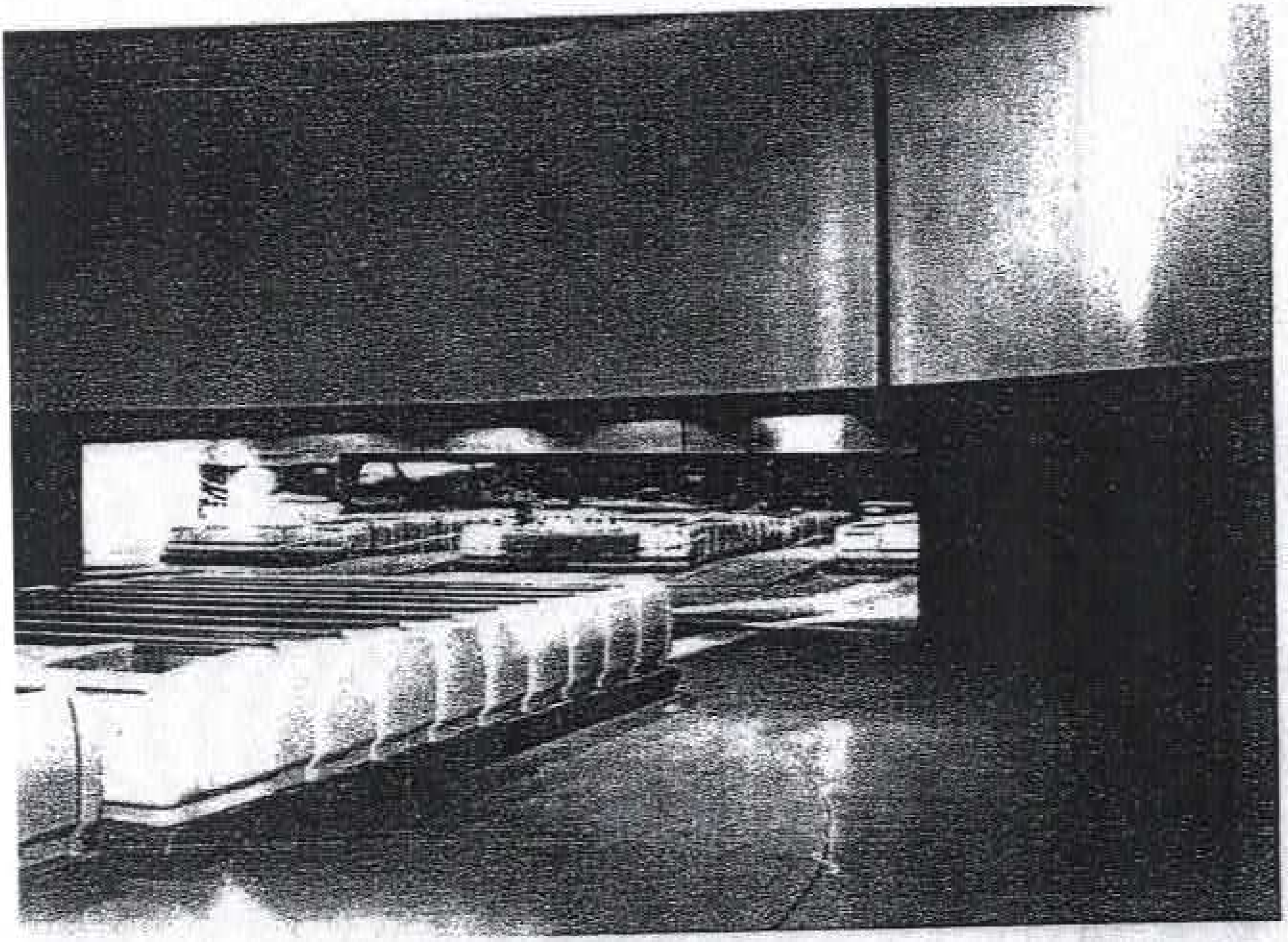


Figure 7. The Six Vehicle Transit from Scene-to-Scene.
Three Abreast

Slide 4

The doors themselves were quite large as can be seen in the photograph of the factory floor where they were constructed. The next slide shows a plan view of the side seals between the doors and the adjacent walls.

Slide 5

Side and bottom seals were designed as labyrinths and at the top there was a saw-toothed seal made of two strips of heavy closed-cell foam about 16 inches thick. This material was used because it would provide a gradual mating seal, and if the seal was imperfect, the labyrinth would still block the sound from passing through.

Slide 6

The next slide shows a section of the door showing the top and bottom seals.

Slide 7

Within each theater in the Energy Pavilion were large rotating turntables. These were supported on multiple air casters. These are bags, which are located beneath a circular steel plate under the

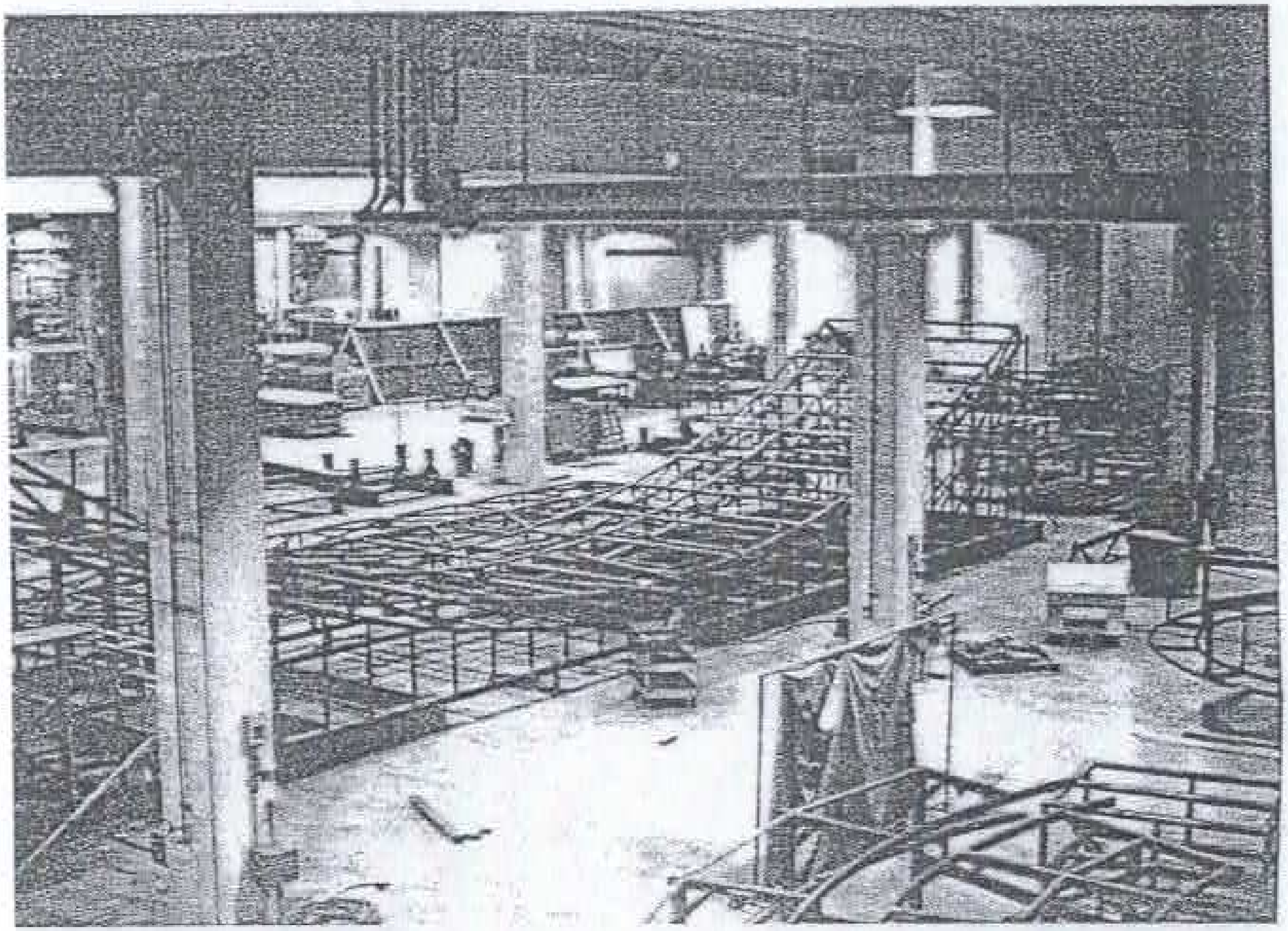
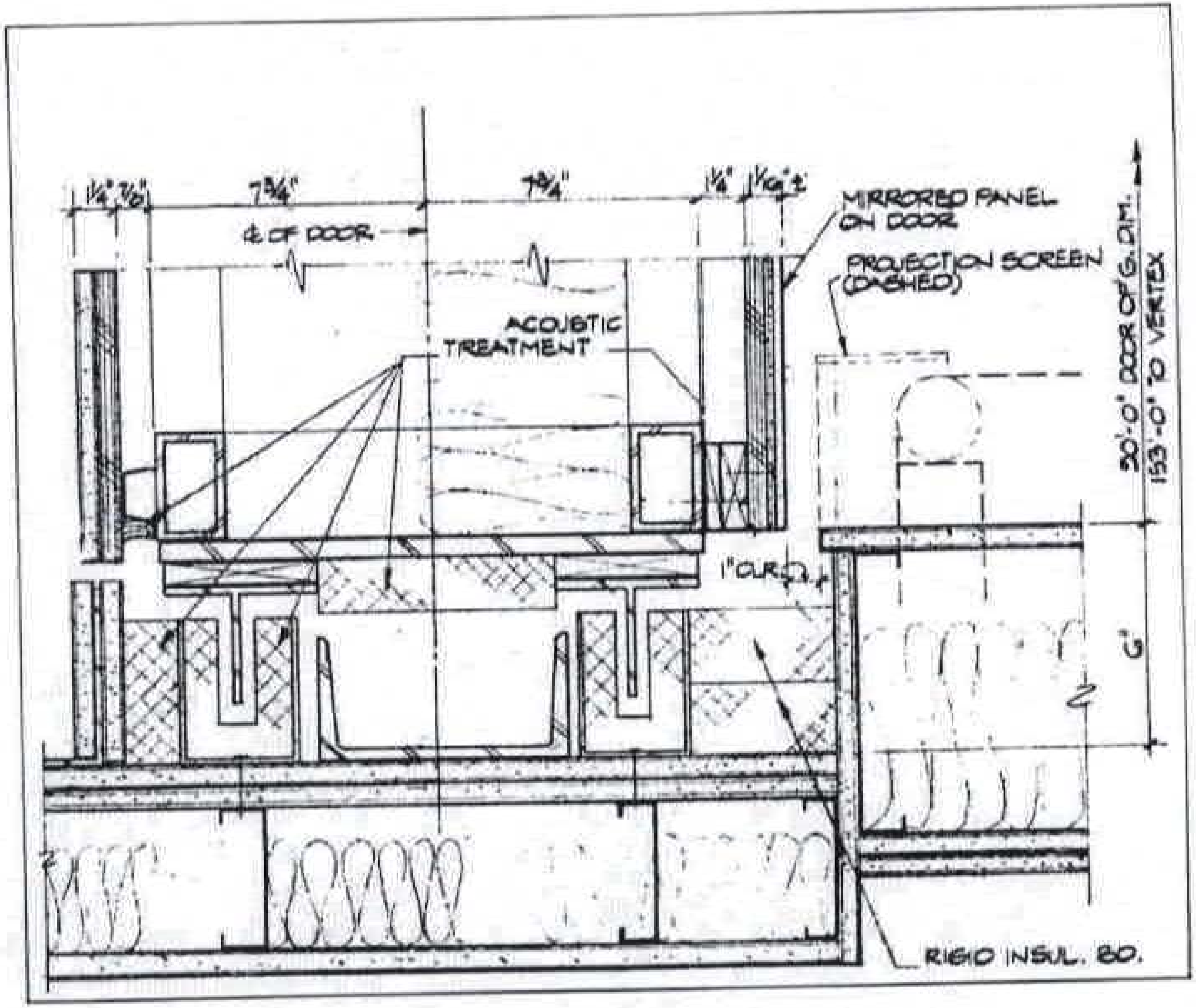
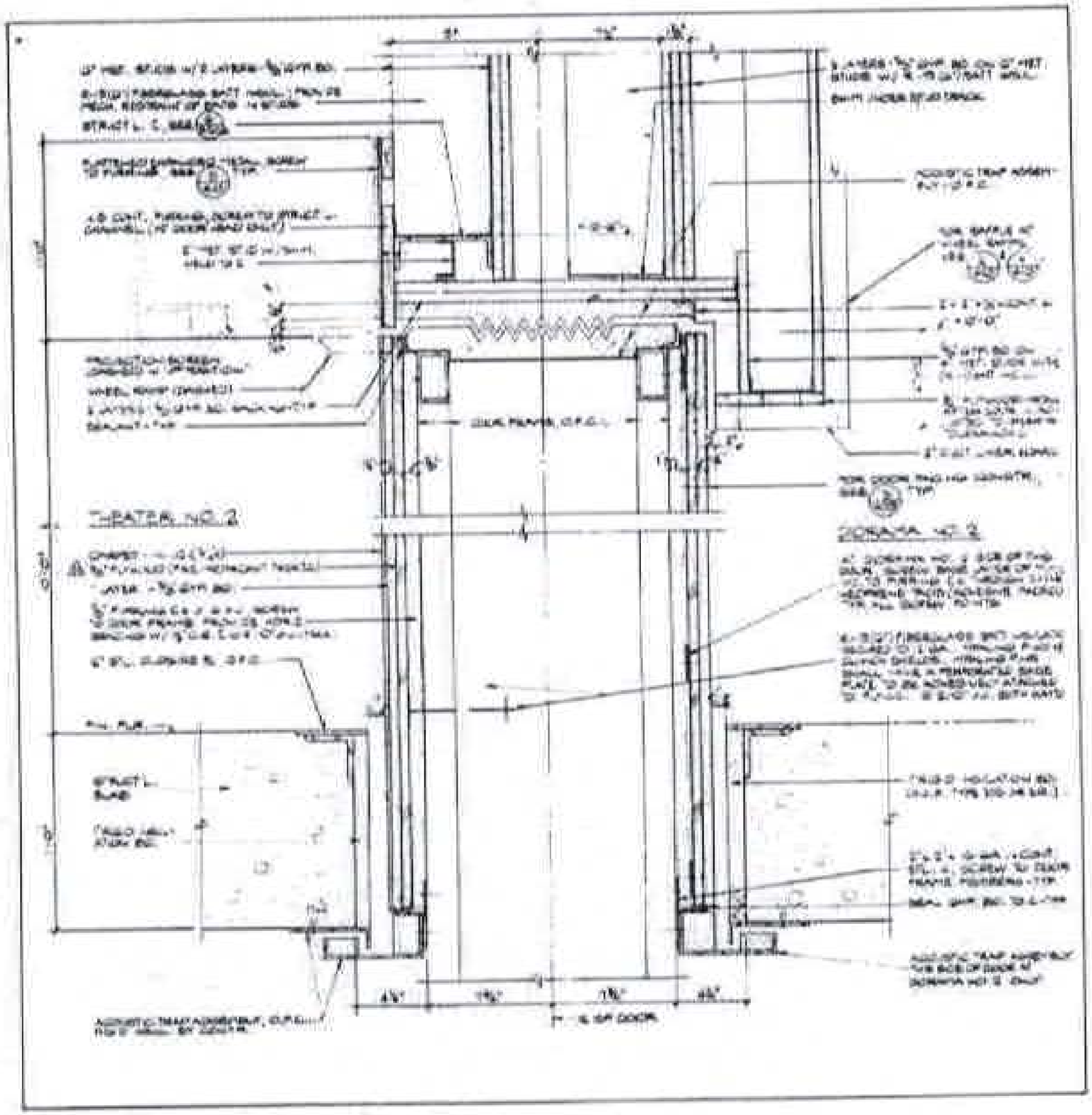


Figure 8. Building of Door Frames for Energy Pavilion



ENERGY PAVILION SOUND DOORS / LABYRINTH SEAL DESIGN



ENERGY PAVILION SOUND DOORS / SECTION THROUGH DOOR NO. 4

turntable. The bags have small holes near their center and air flows through those holes and proceeds outward towards the outside of the bag. This provides a low friction air cushion to support the weight of the turntable and the vehicles when it rotates.

Slide 8

As it turned out, if the bags were under-loaded or tilted at a very shallow angle, and the openings in the air bag vibrated and chopped the air flow producing a very efficient siren. This resulted in noise levels as high as 110 dBA at 5 feet. A similar effect could be initiated when the bags moved over small pockets of debris or indentations in the floor. The only solution that was found was to carefully control the flatness and smoothness of the floor. A specification was developed, which maintained a floor flatness of 1/4 inch in 90 feet and the resulting smoothness eliminated the problem. The final floors were made of steel plates bolted to the slab with welded edges, which were then ground to the required smoothness.

Slide 9

Sometimes there are unusual solutions, which are somewhat technical nature. In. the Energy Pavilion the large ride vehicles were electronically driven from batteries located on board. These batteries had to be recharged. during the ride while the vehicles were sitting on the turntables. In order to do this inductive coupling plates were used, that consisted of parallel flat plates located beneath the vehicle charged through a current loop. The current loop also generated a magnitostriction that in turn generated noise levels higher than were acceptable. A detailed analysis was undertaken to treat this noise which was about 56 dBA and centered around 120 Hz. Since the noise level was linearly dependent on magnetic flux density and the flux density on the conduction medium area, it turned out that the most expedient way to solve the problem was to redesign the interior pole pieces by increasing the cross-sectional area of the steel cores.

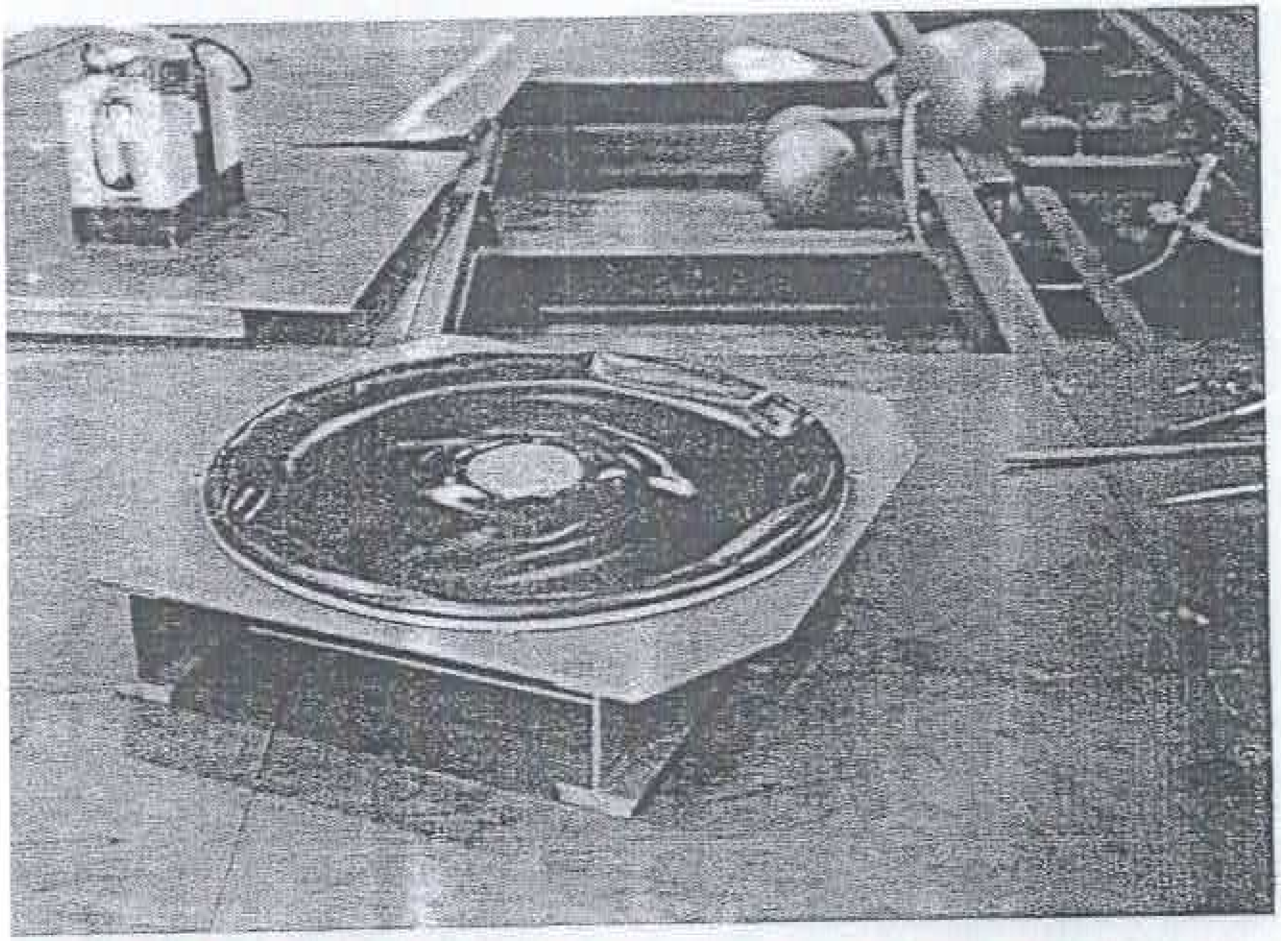
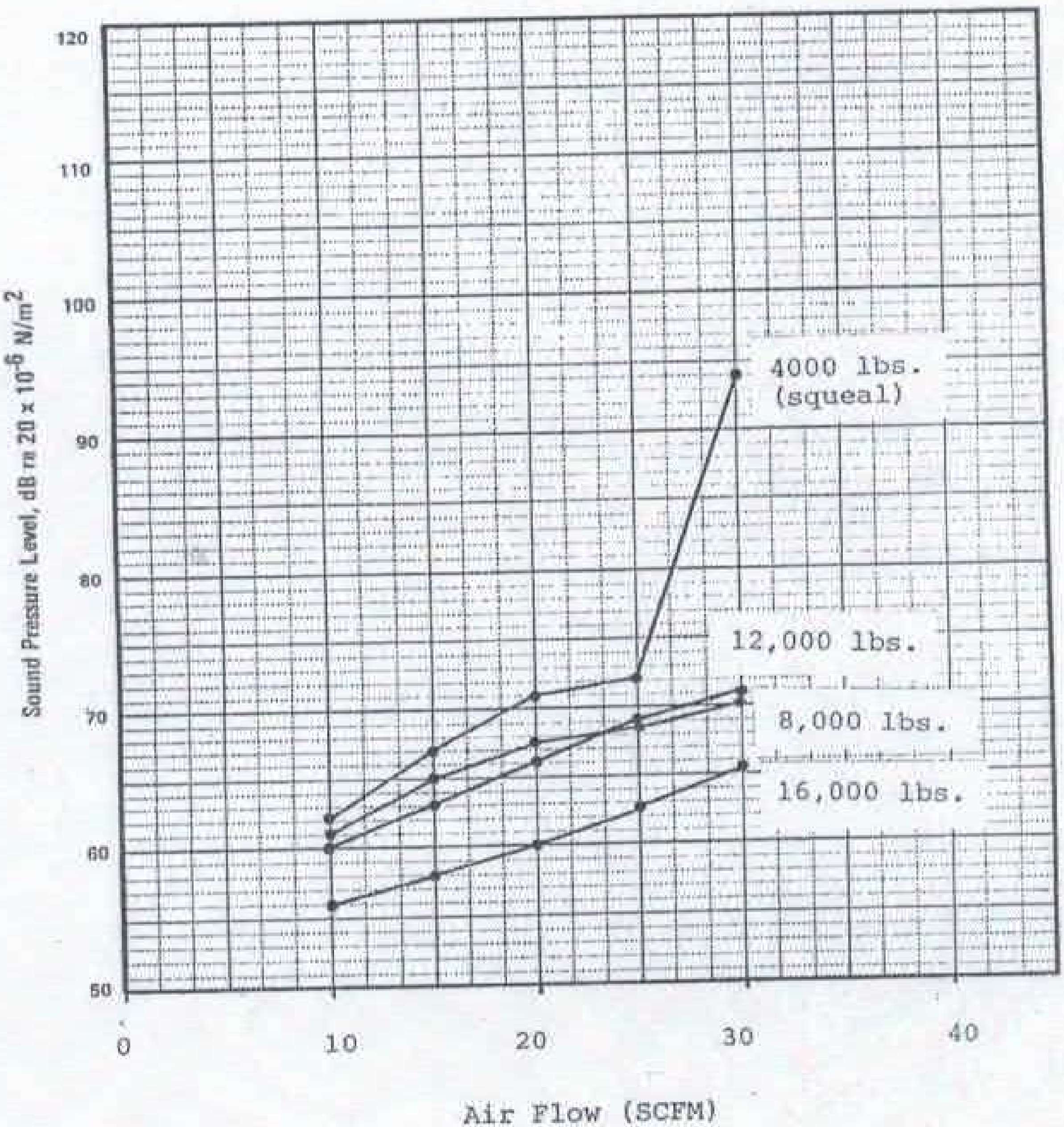


Figure 14. An Air Bearing Which Supports the Energy Pavilion Turntable.



Sound Pressure Level, dB re 20 x 10^-6 N/m^2
120
110
100
90
80
70
60
50
0
10
20
30
40
Air Flow (SCFM)
4000 lbs.
(squeal)
12,000 lbs.
8,000 lbs.
16,000 lbs.

Slide 10 & 11

It is interesting since flux density is one of the few functions which are linear with sound level and a considerable decrease in noise was achieved using this technique. The levels are currently at around 40 dBA from this mechanism and are not a problem.

Specialized Noise Control Problems

A number of specialized problems occur in theme park acoustics. The animated figures and large props require analog hydraulic actuators. Here an analog motion is one that can be controlled at any point along the path. Some of these props can be of substantial size. In the American Adventure Pavilion in Epcot, for example, the main theater lifts are about the size of a couple of locomotives side by side. Hydraulic systems are a particular challenge since they involve high-pressure oil and are often attached to lightweight set pieces which are driven like loudspeakers. We found that the inclusion of hydraulic pulse dampeners close to the pumps was a highly successful solution to the hydraulic problem since the actuators themselves are relatively quiet.

Pneumatic motors are used for digital motion. This is one which goes from one point to another without the ability to control it in between. A good example might be the Small World figures in Disneyland. Here air from the actuators can produce a noticeable puffing sound when they are discharged, .Small porous blow-off silencers have been used for control, and we found that the addition of about 6 inches of air hose before the silencer yields an additional 5 to 10 dB of attenuation. The hose being flexible tends to spread out the pulse so that it is not as high in amplitude when it reaches the silencer,

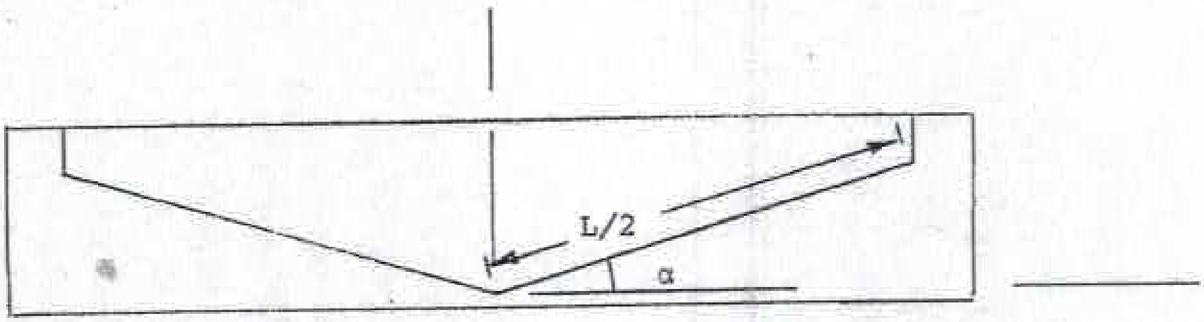
Roll-back preventer on ride vehicles have been a traditional challenge. These are devices which prevent the vehicles from rolling back down a slope if the ride system should stop. In Splash Mountain roll-back preventers originally generated levels above 90 dBA at the guest, Modifications were made to change the drive mechanism in Florida to a chain-type drive, which

4.0 Theoretical Conclusions

The principal mechanism of sound generation seems to be repeated spontaneous magnetostriction due to the periodic reversal of a magnetic field which is well above the saturation point of the metal. A brief theoretical derivation is included below.

Figure 4

Cross Section of Magnetic Coupler Showing Pole Piece



Length of Plate = 5' = 1.5 m

Width of Plate = 2' = .6 m

Thickness of plate = 1.5"

Estimate of Angle α of pole piece = 5°

Estimate of Field Strength = 1 k Oe

Saturation magnetostriction

$$\frac{\Delta L}{L} = \lambda = \text{Linear strain at saturation} \cong 19.5\times10^{-6} \text{ for iron*}$$

Forced change in length from an applied field above saturation

$$\frac{\partial\lambda}{\partial H} \cong 1.9\times10^{-10} \text{ for iron**}$$

* Morrish, The Physical Principals of Magnetism

**Magnetic Properties of Metals and Alloys, Bozorth Editor.

Thus for a field of 1 k Oe the change in length in the y direction will be

$$\Delta L_y = (\frac{L}{2})(\lambda)(\sin\alpha) + (\frac{\partial\lambda}{\partial H})(H)(\frac{L}{2})(\sin\alpha)$$

$$\Delta L_y = (\frac{.6}{2})(19.5\times10^{-6})(.09)+(1.9\times10^{-10})(.09)(10^3)(\frac{.6}{2})$$

$$\Delta L_y = 5.3\times10^{-7} \text{ meters}$$

For a sinusoidal driving force the velocity at 120 Hz

$$v = j\omega x$$

$$|v_y| = (120)(5.3\times10^{-7})(2\pi) = 4\times10^{-4} \frac{\text{meters}}{\text{second}}$$

Sound radiated from a flat plate

$$L_W = L_V + 10 \log(\frac{S}{S_o}) + 10 \log \sigma$$

L_W = Sound power level

$L_V = 20 \log \frac{\tilde{v}}{\tilde{v}_o}$ where $\tilde{v}$ = rms velocity, $\tilde{v}_o = 5\times10^{-8} \frac{\text{meter}}{\text{second}}$

σ = Radiation efficiency = 1 for plates above critical frequency

S = Area of plate .6x1.5 = .9 m^2

S_o= 1 meter^2

for this plate

$$L_W = 20 \log \frac{(.707)(4\times10^{-4})}{5\times10-8} + 10 \log .9$$

$$L_W = 74.6 \text{ dB}$$

Sound pressure level at 5 feet

$$L_p = L_W + 10 \log \left(\frac{Q}{4\pi r^2}\right) + 10.45$$

Assume $Q = 1$

$L_p = 60$ dB

Measured $L_p = 56$ dB so the order of magnitude is about right.

had an integral roll-back prevention system. In Tokyo Disneyland a series of very small spring loaded catches were developed that reduced the noise level to below the ride criteria.

Unusual noise sources sometimes appear. In Puroland in Tokyo a problem arose in a pre-show where there was a 20-foot high waterfall, When the waterfall was running, it generated a noise which was about 75 dBA., so loud that the show could not be understood, We developed a waterfall silencer in order to treat the problem consisting of several layers of wire mesh mat which was located below the floor out of the guests' view so that the impact of the falling water could be reduced. We achieved about a 20 dB reduction in this way.

In water rides where there are changes in elevation where falling water noise is also a problem. In Splash Mountain Tokyo 'we worked to develop bypass pipes to take the water from underneath a trough and deliver it to a lower level also below the surface of the water essentially creating a bypass loop around the natural waterfall. Waterfalls were simulated by letting a small amount of water run over a themed surface which greatly reduced the overall noise.

Reverberation Control

One of the last areas of interest I want to talk about today is reverberation. Obviously both for interior acoustical considerations and also for scene-to-scene isolation, it is important for adjacent areas in dark rides and other similar venues to have acoustical treatments on the surfaces. This in some cases comes into direct conflict with the show requirement that the surfaces appear to be themed. Thus, the solution must be a merger of the two concerns, that is, themed acoustical materials. Traditional acoustical materials such as fiberglass boards are used wherever possible. These can be placed. behind perforated metal or other exposed surfaces or left exposed. In some cases, such as Mexico Pavilion at Epeot, blackout fiberglass boards were attached to the ceiling which was in that case to be a night sky. Joints between the boards were covered with a cloth that was then spray painted dark blue to provide a monolithic surface. Effects such as a sky or other features could be painted directly on these boards so long as sufficient non-painted surface was left. to be absorptive. Curved surfaces were constructed from two layers of 1/8-inch thick pressed fiberglass board which were painted out.

Slide 13

In other cases absorption was built directly into set pieces. Again, in 'Mexico Pavilion sets were constructed of Tectum, and stucco was simulated by using a trowelled acoustical plaster applied directly on the Tectum. This yielded a set which appeared to be white adobe but was highly absorptive.

Many sets in theme parks appear to be rock. Areas that have a high percentage of rock work, such as those in. Splash Mountain, presented a difficult problem. Here we worked with Pyrok, a manufacturer of absorbing plaster, and Disney to develop products and trowelling techniques to allow rock work to be sculpted. The result was highly successful and has become a standard Disney technique for building rockwork.

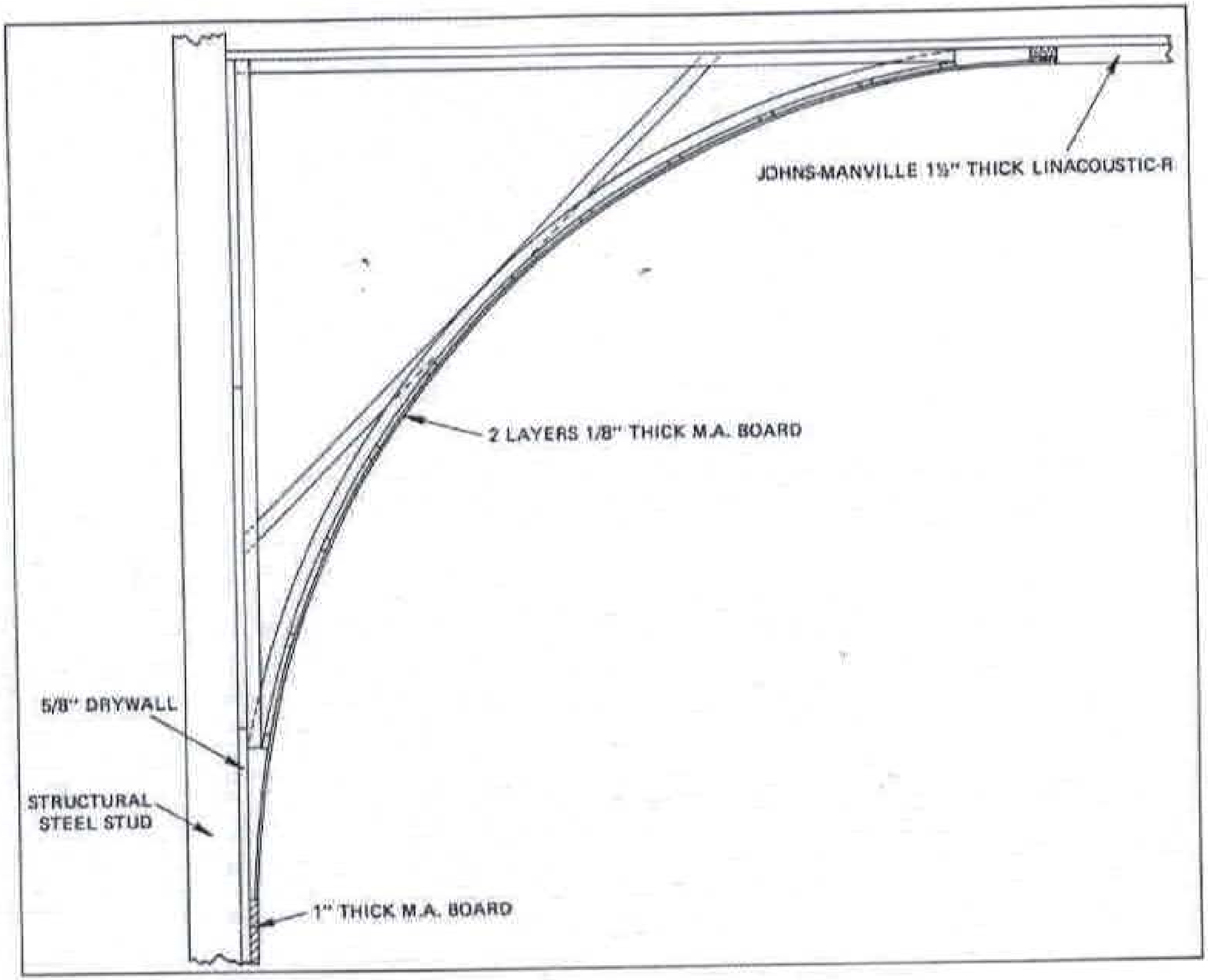
Ghostbusters

We can return to the example I left you with at the beginning of the talk, the Ghostbusters Theater at Universal Studios Florida.

Slide 14

The slide shows the solution to the appearance of ghosts beside the hostess using a heavy sheet of coated glass which can be reflective if the area it reflects is properly lit. The viewer sees both the objects behind the glass as well as superimposed reflected objects. This is called a Pepper's ghost effect. The main show effect was an image of ghosts mirrored off of a large glass plate placed between the audience and the actors. The audience sees not only the actors but also the reflection of the ghosts located on a balcony above the audience so the impression is that the ghosts are on stage beside the actors.

The glass window blocks the sound coming from the actors, presenting another challenge by making it impossible for sound to he transmitted directly from the actors to the audience. A complicated system of point source and delayed ceiling loudspeakers above the audience was developed whereby reflected sound off the glass panel and was augmented by sixteen



MEXICO PAVILION PLAZA AREA / ABSORBANT COVE DESIGN

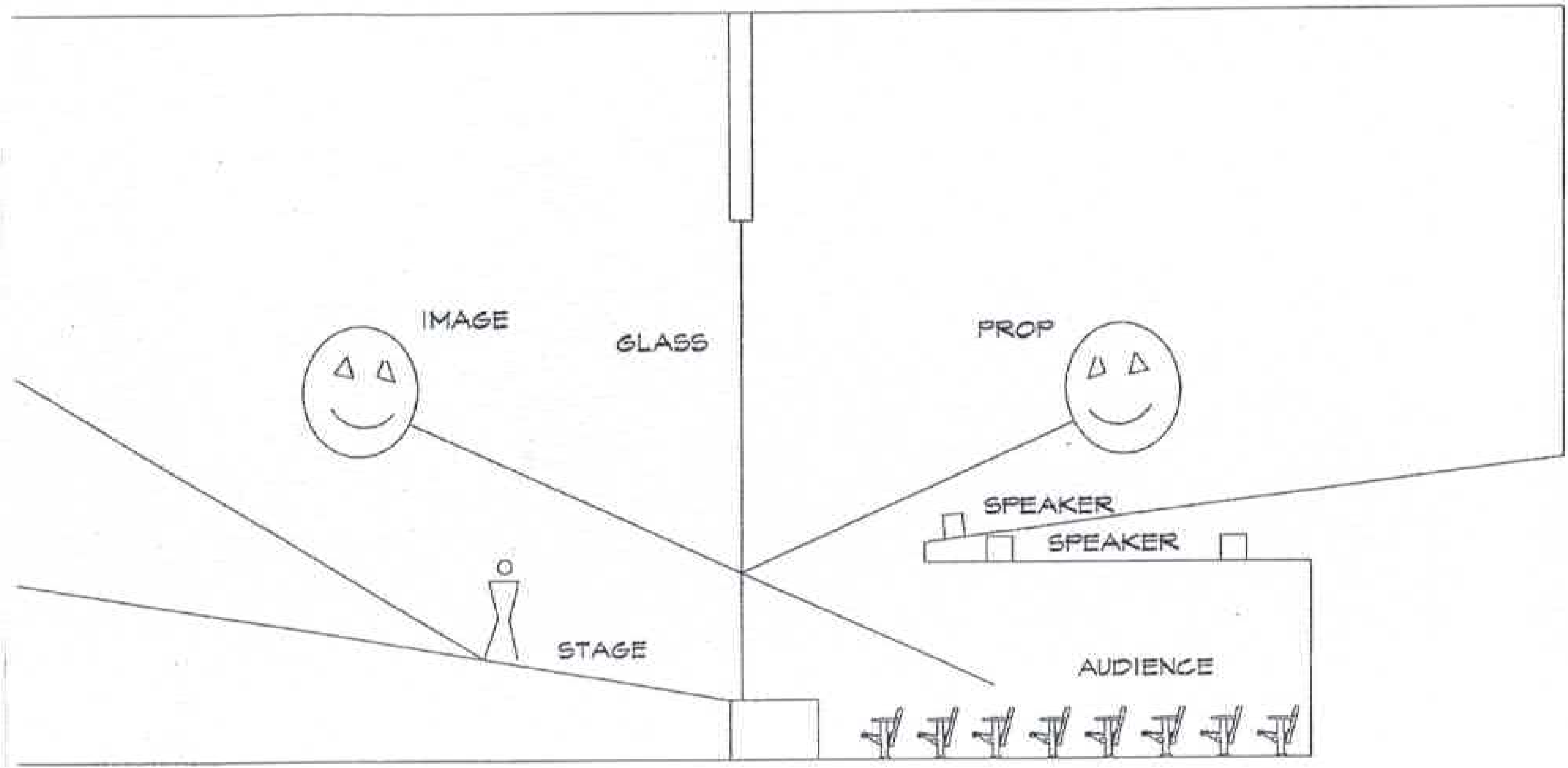
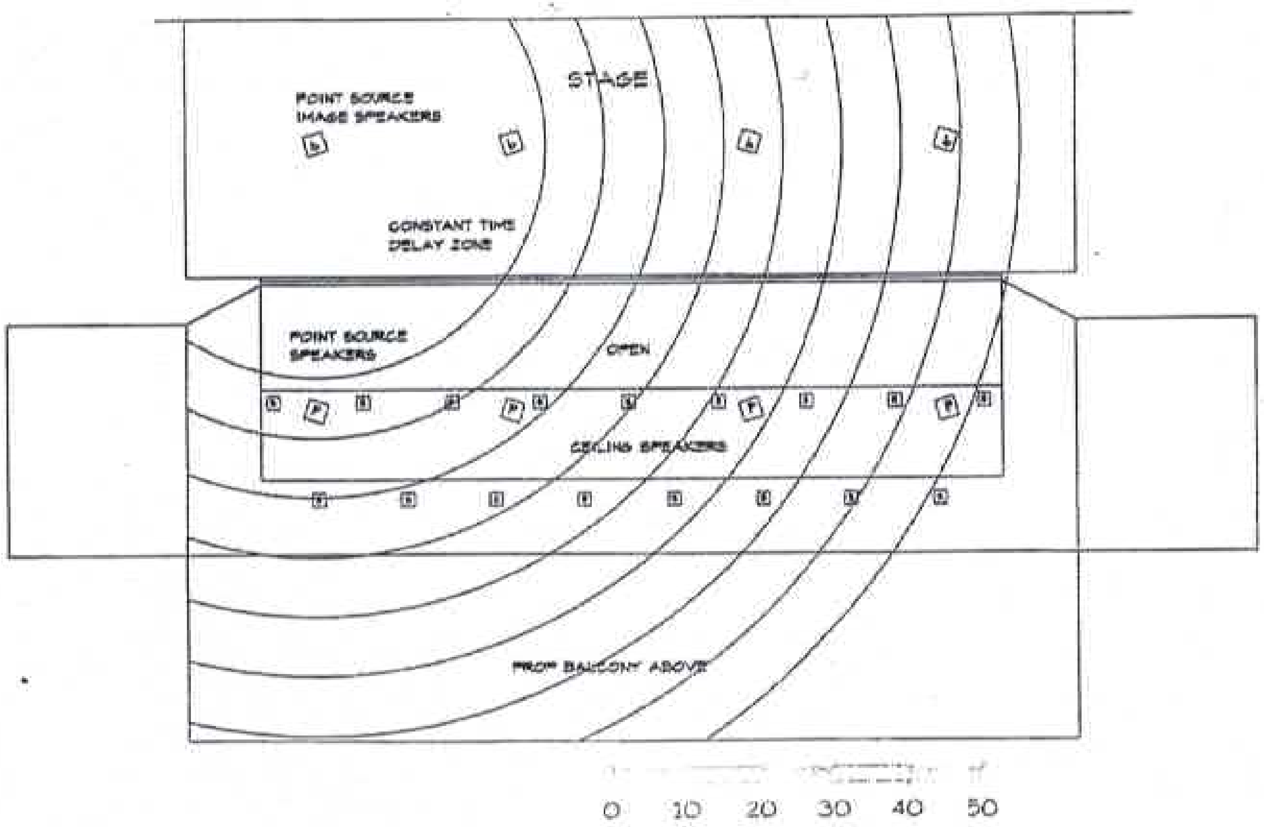


IMAGE
GLASS
PROP
SPEAKER
SPEAKER
STAGE
AUDIENCE



STAGE
POINT SOURCE
IMAGE SPEAKERS
CONSTANT TIME
DELAY ZONE
POINT SOURCE
SPEAKERS
OPEN
CEILING SPEAKERS
0 10 20 30 40 50

loudspeakers located in the ceiling above the audience. The time delays required to do the overhead loudspeakers were quite complicated and a detailed explanation would take too long. However, for each point source speaker located on the balcony above the guests, there was a unique set of time delays associated with each overhead speaker. As actors moved across the stage, the sound was panned between the point source loudspeakers to maintain the spatial illusion. The overhead loudspeakers were delayed to maintain the effect.

Summary

The gratifying part of helping to develop the engineering side of theme park acoustics is that it has now become relatively standard practice for the major theme park builders to use acoustical engineers and engineering as part of their construction process. We have come from a time when acoustical treatments were actively opposed to one where it which is included as a standard feature. The reason is that acoustical engineers have helped develop techniques which integrate the acoustical treatments into the themed environment so that we do not intrude on the guests' overall experience.

CREATIVITY IN THEME PARK ACOUSTICS

SOUND SYSTEM DESIGN

Audio Imaging

- Traditional Movie Theaters (Hitchcock, Imagination Theater)
- Nontraditional Theaters (Back to the Future, Alien, Ghostbusters)
- Traditional Rides (ET Adventure, King Kong, Energy Pavilion)
- Nontraditional Rides (Splash Mountain, Indiana Jones)

Visual Trickery

- Haas Effect
- Point Source Placement (King Kong)

Control

- Zone Isolation (ET Adventure)
- Directional Control (King Kong)

NOISE CONTROL

Enclosures

- Large Enclosures (Energy Pavilion)
- Continuous Enclosures (Horizon Pavilion)

Specialized Problems

- Hydraulics (Pulse Dampeners)
- Pneumatics (Discharge Silencers)
- Roll Back Preventers (Small Levers)
- Waterfalls (Silencers, Bypass Loops)
- Charging Plates (Magnetostriction)
- Ride Vehicles (Wheels, Structural Modifications)
- Air Casters (Floor Flatness)

REVERBERATION CONTROL

Absorptive Materials

- Surface Treatments (Fiberglass Boards, Curved Surfaces)
- Rockwork (Absorptive Plaster)
- Set Pieces (Absorptive Setwork)