Multipurpose Auditorium

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Physics 498 POM

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1. Purpose

A major problem when constructing an auditorium is deciding what its primary function must be. The acoustics for an orchestra hall vary greatly from those for a proscenium theatre or a large lecture hall. However, many institutions, such as high schools and small colleges, only have space and money for once of these arrangements. As a result, the good acoustics for some arrangements is often sacrificed. However, auditoriums can be designed to provide good acoustics for many different types of performances. To illustrate this, the multipurpose auditorium was designed. The goal was to design an auditorium that would have excellent acoustics for a variety of purposes, specifically orchestra, drama, and lectures.

2. Theoretical Background

The acoustics of a room is usually a subjective quality. Concertgoers describe a hall as “live” or “dead” and talk about the “shimmer” of the strings. Theatre patrons are primarily concerned with how well they can understand the speakers. There are a few quantitative measures of the acoustics of a room.

2.1 Reverberation Time

The most important of these parameters is reverberation time. Reverberation time is defined as the time it takes for an impulse of sound in a room to decay 60 dB, or one millionth of the original level. This value is affected by most everything in the room, including room volume, absorption of room materials, diffusion from surfaces, and room temperature and pressure. An estimate of reverberation time is given by the Sabine Equation:

$$T = 0.049\left(\frac{V}{A}\right),$$

where T is the reverberation time, V is the room volume in ft^3, and A is the effective area of absorption, given by

$$A = \sum_{n=1}^{N} S_n a_n \ ,$$

where S is the area in ft^2 and a is the absorption coefficient of all N surfaces in the room. This equation assumes that the room is not too oddly shaped (e.g., a tunnel) so that the sound energy can spread out easily throughout the room. The equation also does not take into account the effects of room atmosphere on sound. This equation is purely empirical, using data collected in the late 1800s. The measurements of reverberation time were taken at 512 Hz, which limits the description of the reverberation of the room to this single frequency.

A more accurate estimate of reverberation time is found by using ray tracing with acoustics modeling software. A model of the room is created, giving each surface its absorption and diffusivity coefficients, and sound sources are placed in the room. The ray tracing technique involves following rays shot out from the source in different directions. When a ray encounters a surface, its intensity is reduced according to the absorption coefficients, and it goes in a new direction according to the diffusivity of the surface. If this process is done with thousands of waves at each octave band, an accurate estimate of the sound levels at each location in the room can be calculated, based on how many rays of each intensity reach a particular audience area. The most common measure of reverberation time for these programs is T-30, which is calculated from the slope of a best fit curve for the sound levels and times as the sound decays from -5 to -35 dB. This tends to be more accurate that the Sabine equation because it takes into account not only the absorption of the surfaces, but also the diffusivity, the specific shape of the room, and the locations of the sources and audience. Also, the reverberation time can be calculated at many different octave bands, which is a more telling measure of the sound of the room.

2.2 Speech Intelligibility

While the reverberation time is the most important factor in the acoustics of a room, speech intelligibility is also important, especially in dramas and lectures. One useful way of measuring speech intelligibility is by using D-50.

D-50 = $\dfrac{\int_0^{0.050s} p^2(t)dt}{\int_0^{\infty} p^2(t)dt}$, where p is the pressure level and t is time in seconds

This is a measure of the percent of the total sound energy arriving before 50 ms after the initial pulse of sound. The idea is that sound energy heard by the audience before 50 ms is beneficial to the understanding of speech in that it increases the volume of the words spoken. On the other hand, sound that comes after 50 ms is detrimental to speech comprehension, because it tends to muddy the sound and make it less clear. A high D-50 indicates that the audience will easily be able to understand speech. This parameter must be found using ray tracing software, as there is no simple equation to estimate this value like the Sabine equation.

2.3 Sound Coverage

A final desirable quality for an auditorium is even coverage of sound. There should be no seats in the audience where the sound level is significantly lower or higher than the rest of the audience. Problems can be predicted and adjusted using ray tracing software before the auditorium is built. Sound pressure levels can be mapped over the audience area to see if there are any spots with more than a few dB difference. These mappings typically output specific sound pressure levels, but these are not as important as the even coverage, as sound amplification can always be used.

3. Desired Qualities

With the parameters defined, it is necessary to determine what the best acoustic measurements are. While the optimal acoustic parameters will vary depending on the preferences of the listener, some spaces have been judged consistently as among the best in the world.

3.1 Boston Symphony Hall

Symphony Hall in Boston is usually considered the best orchestra hall acoustically in the United States. It was built in 1900 with acoustical consulting by Wallace Sabine, who come up with the Sabine equation a few years earlier. Soloists enjoy the intimacy of the response of the hall, and music critics say the music heard is clean and clear. Boston Symphony Hall was the model for the concert hall setup of the multipurpose auditorium. Its relatively simple, rectangular shape also makes adjustments easier to make, which will be important in the multipurpose auditorium. The goal of the orchestral setup of the multipurpose auditorium was to match the acoustics of Boston Symphony Hall by mimicking its dimensions closely.

Boston Symphony Hall has a reverberation time of 1.8 seconds when fully occupied. This measurement is an average of ones at 500 and 1000 Hz. While this is slightly shorter than average halls of the same size, many critics think that this is what gives the hall its superior quality over even the best concert halls, such as the Grosser Musikvereinssaal in Vienna. It contains 2631 seats, with 1486 on the main level and 598 and 547 on the two balconies. For the multipurpose auditorium, the top balcony and the side portions of the lower balcony were eliminated. Most of the materials from the Boston hall were used, including the plaster walls and wood floors.

3.2 Royal Shakespeare Theatre

With the primary setup for the multipurpose auditorium established, adjustments must be made to make the space appropriate for other uses. For drama, a good model for suitable acoustics is the Royal Shakespeare Theatre in Stratford-upon-Avon. It would be difficult to mimic the shape of this theatre by modifying the orchestral setup of the multipurpose auditorium, because this theatre is fan shaped instead of rectangular. However, the acoustical measurements can be used as a guide for what the acoustics of the drama setup of the multipurpose auditorium should be. Royal Shakespeare Theatre has a reverberation time of 1.0 seconds and a capacity of 1459 over three levels. The portion of early energy from a centrally located source is about 72% on average and ranges from 60 to 80%, depending on the location of the measurement in the theatre. The dimensions of the fly space were used as a model for the multipurpose auditorium.

3.3 Classroom Acoustics

For the lecture hall setup of the multipurpose auditorium, the drama setup can be altered to include a chalkboard, podium, and other teaching aids. However, the acoustics must also change. The American National Standards Institute recommends a maximum reverberation time of 0.7 seconds for classrooms between 10,000 and 20,000 ft^3. It also recommends in Standard S12.60 for Classroom Acoustics that the background noise in a classroom should not exceed 35 dB. While the volume of the multipurpose auditorium will greatly exceed 20,000 ft^3, 0.7 seconds is a good standard for good speech intelligibility in a lecture hall setup. The multipurpose auditorium also will not have much background noise, as the background noise requirements for a quality orchestral performance space will be below 35 dB. A performance space will usually have a remotely located HVAC system, which is the main source of background noise for classrooms.

4. Auditorium Design

After the criteria for all three setups of the multipurpose auditorium were established, design began. A number of initial sketches were made, primarily concerning the method of reducing the volume of the space so as to decrease reverberation time. Next, the design was put into AutoCAD 2005 so as to have a three dimensional representation of the auditorium. The exact dimensions of everything in the auditorium were finalized and entered into CATT-Acoustic, an acoustics modeling program that uses the ray tracing technique.

4.1 Initial Design

The most critical problem with varying the acoustics of the multipurpose auditorium was determining how to change the reverberation time of the room. Many modern auditoria use absorptive hanging curtains in the audience area to fine-tune this parameter, but a large volume change is needed to alter the reverberation time by more than a few tenths of a second. The solution was to install a retractable ceiling above the audience. This ceiling would cut off the balcony as well as about a third of the volume of the audience area, significantly reducing the volume of the room. The bottom of the ceiling would be made of absorptive ceiling panels, which would prevent too many detrimental reflections off of the ceiling. Since the ceiling would cut off the balcony, it would reduce the capacity of the house, but since the majority of the seats are on the main floor this would not make too much of a difference.

The second major problem was designing an orchestra shell which would cut off the fly space and its absorptive curtains. The goal was to have as much of the sound energy as possible be directed towards the audience. The solution was to make the sound shell span the width of the stage and reach to the top of the stage opening so as to minimize the amount of energy lost into the fly space. The elliptical shape prevents the sound from being focused at one point in the audience, a common problem with parabolic and circular reflectors, and also allows the shell to reduce the depth of the stage to the minimum necessary for an orchestra performance. The shell was designed to be made of a highly reflective material such as sealed plywood.

The final problem was finding a way to further reduce the volume of the room to reduce the reverberation time for the lecture setup. This was solved by having a movable heavy curtain between the two sections of the main floor. A curtain was used because it would not reflect sound back onto the audience, as this would inhibit speech intelligibility. This will cut down the audience area substantially, but even the largest lectures rarely exceed 500 students, which will be the approximate capacity of this setup.

4.2 AutoCAD Modeling

The initial model of the multipurpose auditorium was made in AutoCAD 2005. First, the major dimensions of Boston Symphony Hall were used to form a basic outline of the auditorium. The balconies and stage were left out. The stage and fly space were made by adjusting the dimensions of those of the Royal Shakespeare Theatre to make them fit with the walls already in place. With all of the permanent walls in place, the movable ceiling and curtain were added on different layers so they could be turned on and off to see the different setups. Finally, the sound shell was added so the elliptical shape met with the walls and opening of the stage.

4.3 CATT-Acoustic Modeling

After a demo version of CATT-Acoustic was obtained, the next step was to transfer the AutoCAD model to the acoustic software. In the full version of CATT-Acoustic there is a module that will convert AutoCAD files to the CATT-Acoustic format, but unfortunately this is not part of the demo version, so the model of the multipurpose auditorium had to be manually put into the program. To do this, all of the vertices of all of the planes that make up the room were given coordinates taken from the AutoCAD model. Then, the planes were defined by connecting the vertices. Absorption coefficients and colors were assigned to each surface to facilitate ray tracing and three-dimensional modeling of the auditorium. The absorption coefficients of each surface were defined in percents across six octaves, from 125 Hz to 4 kHz. For instance, audience areas were modeled as fully occupied, upholstered seats, with <60 74 88 96 93 85> as the percent of absorption for the <125 250 500 1k 2k 4k> Hz frequencies. After all of the surfaces were added, initial computations were made using the software.

4.4 Initial Results and Troubleshooting

There were a few problems with the first design of the multipurpose auditorium. First of all, the reverberation times for all setups were too long. The reverberation time was shortened to an acceptable level for the orchestra setup by adding a curtain on the back wall. This absorbs some sound without eliminating any of the important direct sound or early reflections. A balcony was also added, which reduced the reverberation time while increasing the capacity of the house. The reverberation time of the lecture setup was also improved somewhat, but it was still too long. This problem was solved with the realization that there were no curtains hanging in the fly space. Three curtains were added in the fly space, and their added absorption reduced the reverberation time to the desired value range, while not affecting that of the orchestra setup because the orchestra shell cut off the fly space. Small hanging curtains near the side walls were added to further reduce the reverberation time if needed in any setup. A large problem occurred with the lecture setup. When the hanging curtain was added in the center of the auditorium, the reverberation time increased instead of decreasing. This problem was eventually solved by adding transparency coefficients to the curtain. This allowed some of the sound energy to pass through the curtain to the unused portion of the auditorium, reducing the total sound energy in the lecture portion and reducing the reverberation time to an appropriate length.

5. Results

The results of the multipurpose auditorium were calculated using the CATT-Acoustic software. The numbers were compared to the two model performance spaces as well as the ANSI standard.

The audience capacity was calculated by dividing the audience area by the average area per seat, usually taken to be about 0.5 m^2, or 5.38 ft^2. The area of the two front audience areas is 1200 ft^2 each, of the two back areas 1500 ft^2 each, and of the balcony area 1950 ft^2. For the orchestra setup, which uses all of these areas, this gives a capacity of

$$Capacity = \frac{1200\,ft^2 * 2 + 1500\,ft^2 * 2 + 1950\,ft^2}{5.38\,ft^2 / seat} = 1366 \text{ seats}$$

Similarly, the capacity of the drama setup is 1004 seats, and the lecture setup can hold up to 446 people. These numbers are in the range of the desired capacity at the beginning of the project.

5.1 Orchestra Setup and Boston Symphony Hall

The only acoustical statistic that could be found for Boston Symphony Hall was reverberation time, 1.8 seconds. This was found by averaging the reverberation times at 500 and 1000 Hz. If this is done for the multipurpose auditorium, the result is 2.0 seconds, slightly longer, but still in the range of a premiere concert venue. Since the majority of the dimensions of the multipurpose auditorium were taken from Boston Symphony Hall, the two spaces should sound approximately the same. The multipurpose auditorium holds less people than Boston Symphony Hall, with 1366 seats in the multipurpose auditorium compared to 2084 for the first two levels for the Boston hall. This is because of the removal of the side balconies from the Boston design and the widening of the aisles. If this is too few seats for the intended owners, a second balcony could be added above the existing one in the plan, adding about 300-400 extra seats. The orchestra setup of the multipurpose auditorium is a good replica of Boston Symphony Hall, with similar acoustic properties.

5.2 Drama Setup and Royal Shakespeare Theatre

While the drama setup is merely a modification of the orchestra setup and quite a different shape from most drama spaces, their acoustical properties are comparable. Royal Shakespeare Theatre in Stratford-on-Avon has a reverberation time of 1.0 seconds. The drama setup of the multipurpose auditorium also has a reverberation time of 1.0 seconds. The Royal Shakespeare Theatre has about 72% early sound energy on average.

CATT-Acoustic estimates the D-50 of the multipurpose auditorium to be about 95%. This is much higher, which might indicate that the lecture setup will sound somewhat dryer than the Royal Shakespeare Theatre. This could be altered by removing some of the absorptive material in the audience area, but this would increase the reverberation time also. A model would have to be constructed to determine the extent of the early energy fraction problem. A mapping of sound pressure levels over the audience area shows that there is even coverage of sound across all of the seats. The 1004 seats are slightly fewer than the 1459 for the theatre in Stratford, but should be ample for the needs of the intended owners.

5.3 Lecture Setup and ANSI Standard S12.60

The lecture setup as similar acoustic properties to the drama setup of the multipurpose auditorium. It has the same even coverage of sound as the drama setup, and the added curtain lowers the reverberation time to about 0.7 seconds. This is within the maximum reverberation time defined by ANSI Standard S12.60, especially considering the volume and capacity of the hall. The D-50 of the lecture setup is about 98%, which still might be too dry for a lecture, but this can again be altered somewhat. The capacity of 446 should be enough for almost all lectures, and the students will be able to understand the speech better than in most other lecture halls.

5.4 Errors with CATT-Acoustic Demo

There are a few problems that are the result of using the demo version of CATT-Acoustic. First of all, there was no way to convert the AutoCAD model to the CATT-Acoustic format. This did not affect the prediction of acoustic properties. A large problem is that the demo version limits the number of rays used in the ray tracing technique to 1000 per octave. This limits the accuracy of all of the measurements because fewer rays mean odd reflections and slight disturbances in a few waves can change the measurements drastically. For a room about the size of the multipurpose auditorium, about 10 to 100 times this number of rays should be used at each octave for an accurate prediction. This limitation might have added to the early sound energy fraction discrepancy.

6. Conclusions

The multipurpose auditorium was intended for use in a small college or high school with limited space and money, but a need for many different performance types. To facilitate this, the auditorium was designed so it could be altered for orchestra, drama, and lecture functions. The three setups were modeled after premiere performance venues, including the Royal Shakespeare Theatre and Boston Symphony Hall. The hall was designed in AutoCAD 2005 and CATT-Acoustic software. The results, found using CATT-Acoustic, are quite impressive. The orchestra setup has acoustic properties closely resembling this of Boston Symphony Hall. The drama setup has properties close to the Royal Shakespeare Theatre, with discrepancies in the percent of early energy. The lecture setup meets ANSI Standard S12.60 with a low reverberation time and even coverage of sound. Limitations in the demo version of CATT-Acoustic may have caused errors in some calculations. In all, this was a worthwhile project with many challenges but a very rewarding result.

7. References

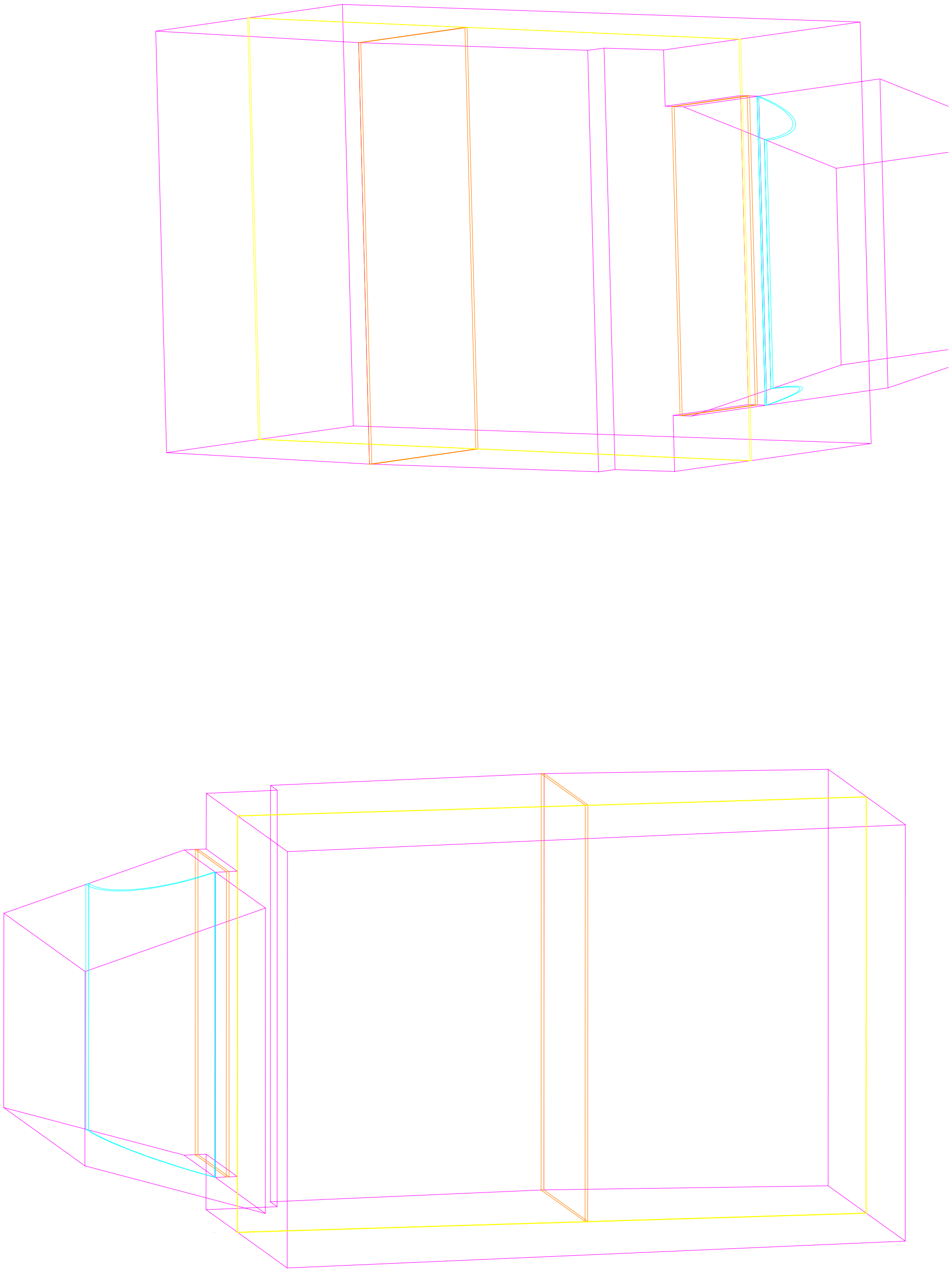
Barron, Michael. Auditorium Acoustics and Architectural Design. London: Routledge, 1998.

Beranek, Leo L. Music, Acoustics & Architecture. New York: John Wiley & Sons, Inc., 1962.

Dalenbäck, Bengt-Inge. CATT-Acoustic v8.0c (build 7.01) (Limited demo/evaluation version). 2005.

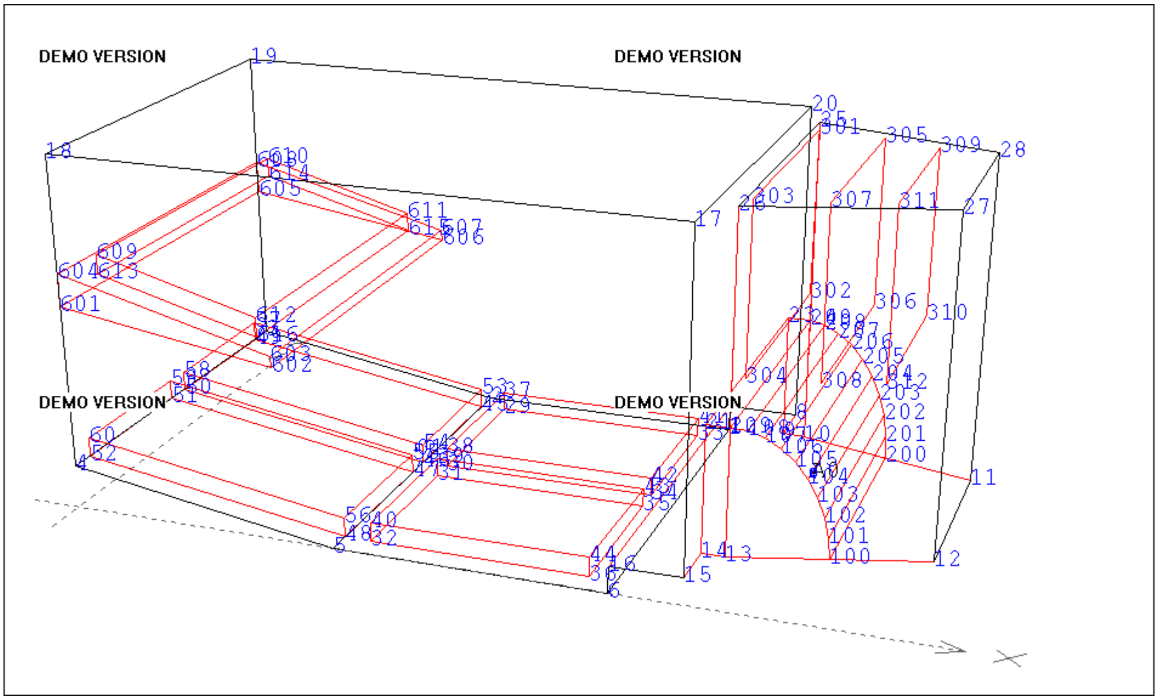
Associated Productions of Texas Communications. “Absorption Coefficients of Building Materials and Finishes”. http://www.aptcommunications.com/abcoef.htm

AutoCAD 2005 Screenshots

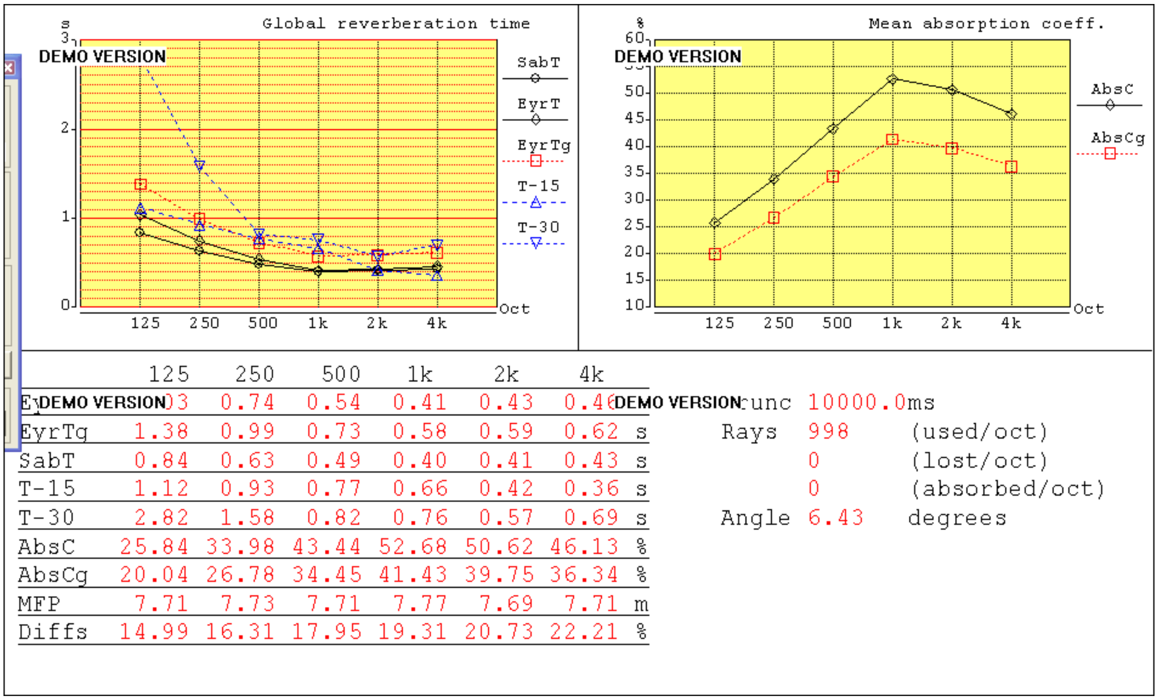


Model in AutoCAD with permanent walls (pink), movable ceiling (yellow), movable curtain (orange), and orchestra shell (blue)

<u>CATT-Acoustic Screenshots</u>



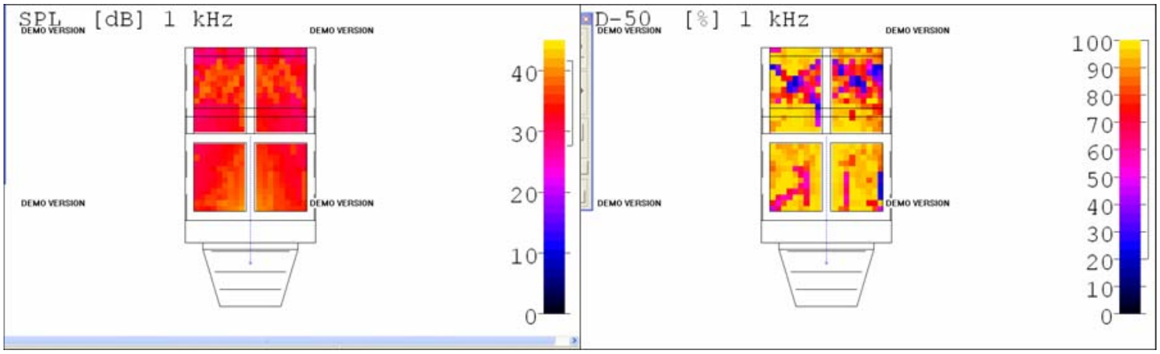
Labeled vertices defining planes



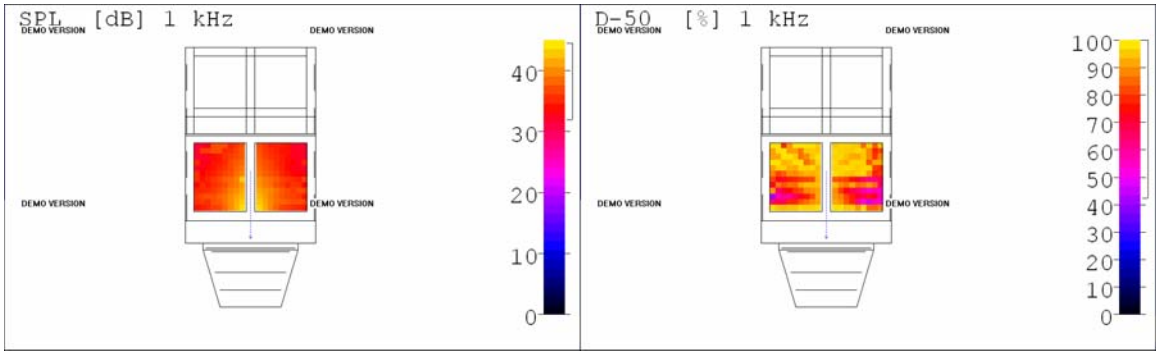
```
              125    250    500    1k     2k     4k
E DEMO VERSION)3   0.74   0.54   0.41   0.43   0.46DEMO VERSION:unc  10000.0ms
EyrTg      1.38   0.99   0.73   0.58   0.59   0.62  s     Rays  998     (used/oct)
SabT       0.84   0.63   0.49   0.40   0.41   0.43  s           0       (lost/oct)
T-15       1.12   0.93   0.77   0.66   0.42   0.36  s           0       (absorbed/oct)
T-30       2.82   1.58   0.82   0.76   0.57   0.69  s     Angle 6.43    degrees
AbsC      25.84  33.98  43.44  52.68  50.62  46.13  %
AbsCg     20.04  26.78  34.45  41.43  39.75  36.34  %
MFP        7.71   7.73   7.71   7.77   7.69   7.71  m
Diffs     14.99  16.31  17.95  19.31  20.73  22.21  %
```

Output of reverberation time and other parameters across octave bands

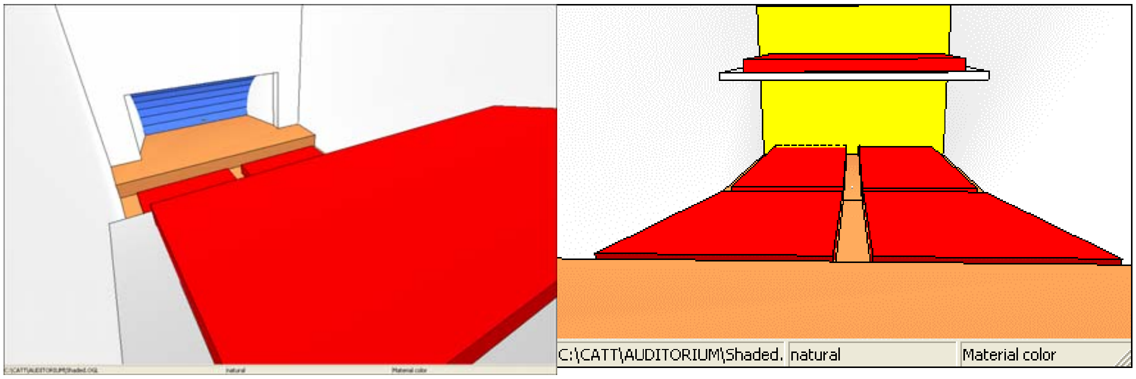
CATT-Acoustic Screenshots



SPL and D-50 mappings at 1 kHz for drama setup

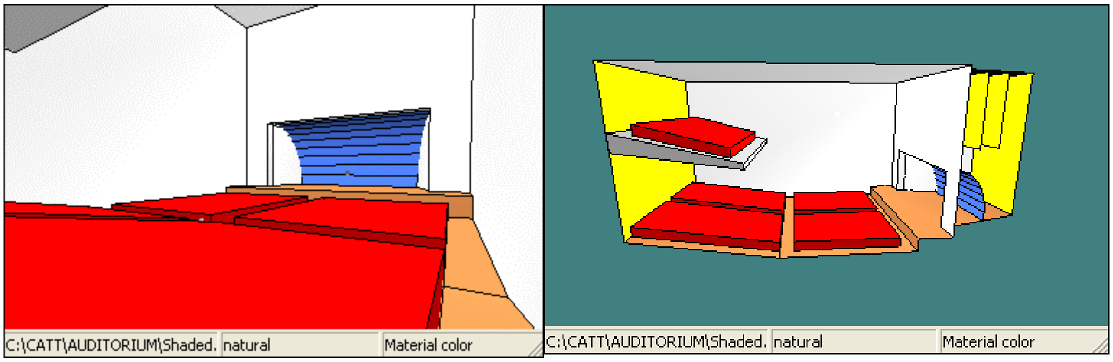


SPL and D-50 mappings at 1 kHz for lecture setup

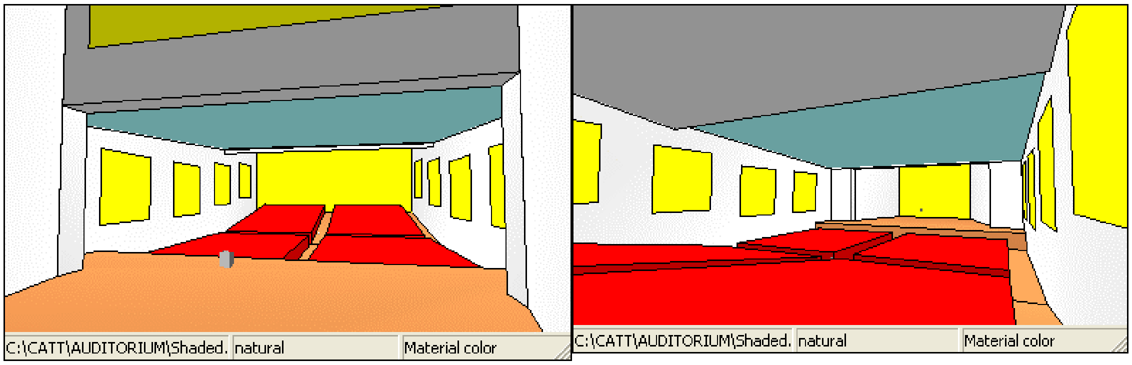


3-D rendering of orchestra setup

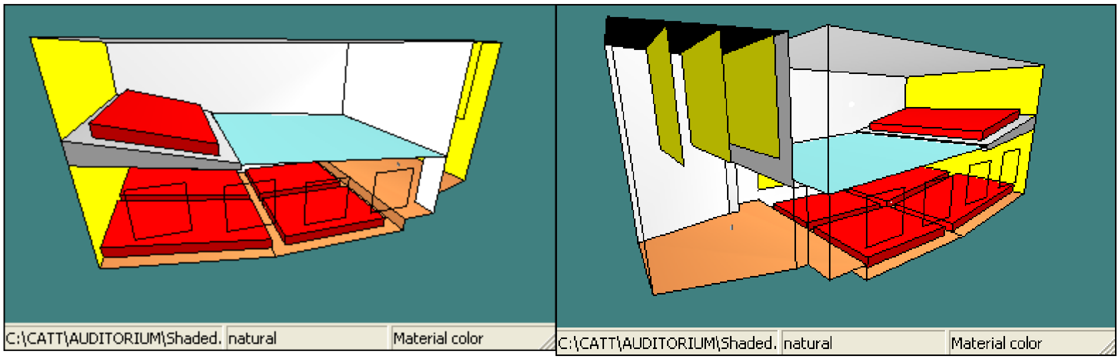
CATT-Acoustic Screenshots



3-D rendering of orchestra setup

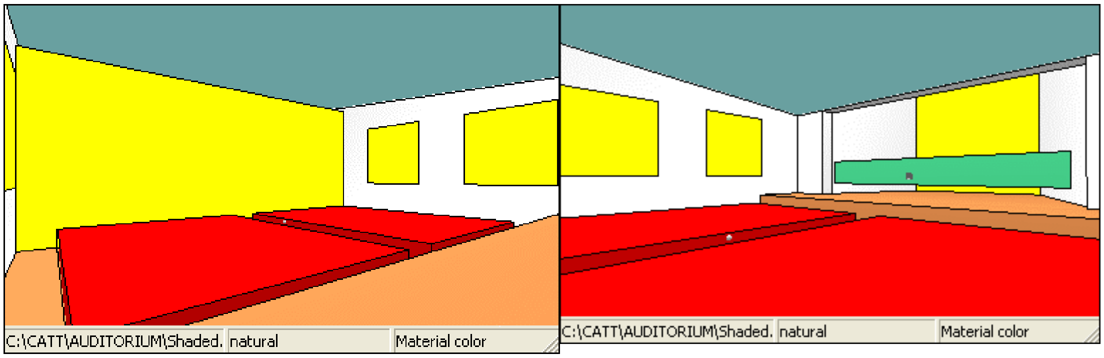


3-D rendering of drama setup

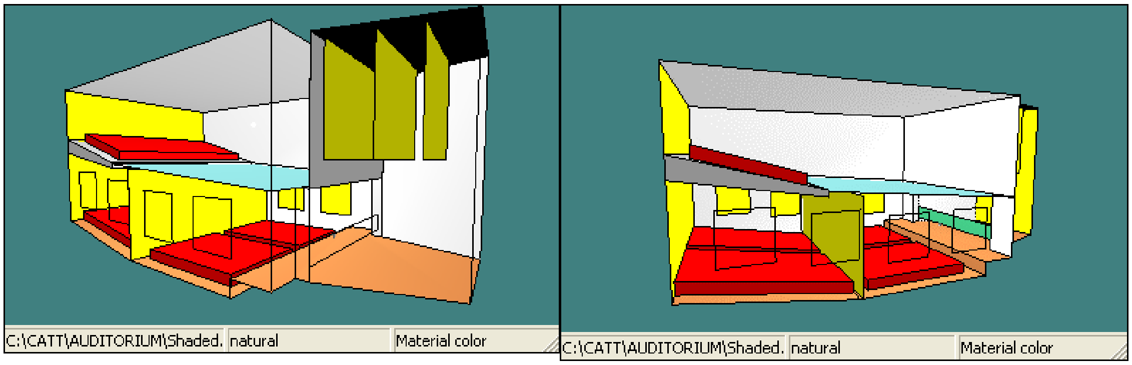


3-D rendering of drama setup

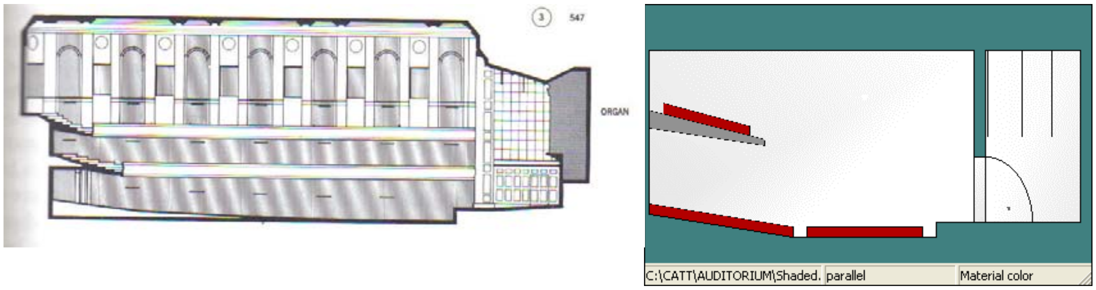
CATT-Acoustic Screenshots



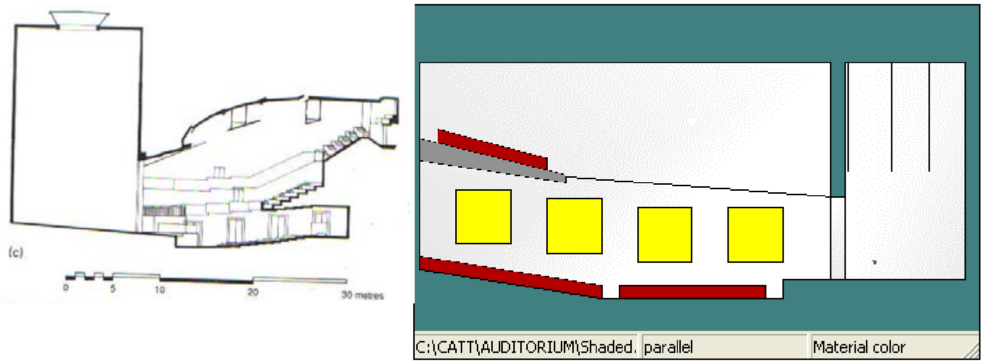
3-D rendering of lecture setup



3-D rendering of lecture setup



Comparison of orchestra setup with Boston Symphony Hall



Comparison of drama setup with Royal Shakespeare Theatre

CATT-Acoustic Files – Master.geo

```
;Auditorium - Tyler Dare
;MASTER.GEO

scale 0.3048 0.3048 0.3048
;Changes units from feet to meters

GETGLOBAL SETUP = 1-Orchestra  2-Drama  3-Lecture

INCLUDE BALCONY

IF SETUP = 1 THEN
INCLUDE SHELL
ENDIF

IF SETUP = 2 THEN
INCLUDE CEILING
INCLUDE PANELS
ENDIF

IF SETUP = 3 THEN
INCLUDE CEILING
INCLUDE CHALKBOARD
INCLUDE PANELS
INCLUDE SEPARATOR
ENDIF

;absorption and scattering coefficients 125Hz to 4kHz [%], RGB-color
;ABS audience = <40 50 60 70 80 80> L <30 40 50 60 70 80> { 255 0 0 }

;Foor - wood on joists
ABS wood     = <15 11 10  7  6  7> L <30 30 30 30 30 30> { 194 120 65 }

ABS d = <50 50 50 50 50 50>

;Audience seats - fully occupied, fabric upholstered
ABS aud = <60 74 88 96 93 85> L <30 40 50 60 70 80> { 255 0 0 }

;Walls - plaster on lath
ABS plaster = < 2 3 4 5 4 3 > {210 210 210}

;Ceiling - Acoustic ceiling tiles
ABS ceiling = <70 66 72 92 88 75> {150 230 230}

;Flyspace - high absorption from hanging curtains
ABS Flyspace = <90 90 90 90 90 90> {0 0 0}

;ABS Shell = <28 22 17 9 10 11> {60 97 196}

;Curtain - high absorption on back wall
ABS curtain = < 14 35 55 72 70 65 > {255 255 0}
ABS curtain1 = < 14/12 35/15 55/18 72/10 70/6 65/5 > {255 255 0}


CORNERS
```

```
;Permanent walls
01        100       75        0
02        50        75        0
03        0         75        8
04        0         0         8
05        50        0         0
06        100       0         0
07        100       75        5
08        113       75        5
09        113       65        5
10        117       65        5
11        150       55        5
12        150       20        5
13        117       10        5
14        113       10        5
15        113       0         5
16        100       0         5
17        113       0         65
18        0         0         65
19        0         75        65
20        113       75        65
21        113       10        28
22        117       10        28
23        113       65        28
24        117       65        28
25        117       65        65
26        117       10        65
27        150       20        65
28        150       55        65


;Front audience
29        55        70        0
30        55        40        0
31        55        35        0
32        55        5         0
33        95        70        0
34        95        40        0
35        95        35        0
36        95        5         0
37        55        70        3.5
38        55        40        3.5
39        55        35        3.5
40        55        5         3.5
41        95        70        3.5
42        95        40        3.5
43        95        35        3.5
44        95        5         3.5

;Rear audience
45        50        70        0
46        50        40        0
47        50        35        0
48        50        5         0
49        0         70        8
50        0         40        8
```

```
51      0       35      8
52      0       5       8
53      50      70      3.5
54      50      40      3.5
55      50      35      3.5
56      50      5       3.5
57      0       70      11.5
58      0       40      11.5
59      0       35      11.5
60      0       5       11.5

;Curtains
301     118     60      65
302     118     60      35
303     118     15      65
304     118     15      35
305     130     58      65
306     130     58      35
307     130     17      65
308     130     17      35
309     140     55      65
310     140     55      35
311     140     20      65
312     140     20      35


PLANES

;Permanent walls
[01 Floor / 01 02 05 06 / wood]
[02 Slope Floor / 02 03 04 05 / wood]
[03 Back Wall / 19 18 04 03 / curtain]
[04 Audience Ceiling / 20 17 18 19 / plaster]
[05 Audience Front Wall / 17 20 08 09 23 21 14 15 / plaster]
[06 Stage Floor / 07 16 15 14 13 12 11 10 09 08 / wood]
[07 Apron Front / 16 07 01 06 / wood]
[08 Separator Top / 24 22 21 23 / plaster]
[09 Separator SL Side / 21 22 13 14 / plaster]
[10 Separator SR Side / 24 23 09 10 / plaster]
[11 Aud SL Wall / 18 17 15 16 06 05 04 / plaster]
[12 Aud SR Wall / 20 19 03 02 01 07 08 / plaster]
[13 Stage SL Wall / 26 27 12 13 / plaster]
[14 Stage SR Wall / 28 25 10 11 / plaster]
[15 Stage Back Wall / 27 28 11 12 / curtain]
[16 Fly Ceiling / 28 27 26 25 / flyspace]
[17 Separator Back / 25 26 22 24 / plaster]

;Front audience area
[18 SL Aud Top \ 43 44 40 39 \ aud]
[19 SL L Side \ 40 44 36 32 \ aud]
[20 SL R Side / 39 43 35 31 / aud]
[21 SL Front / 43 44 36 35 / aud]
[22 SL Back / 40 39 31 32 / aud]
[23 SR Aud Top / 42 41 37 38 / aud]
[24 SR L Side / 42 38 30 34 / aud]
[25 SR R Side / 41 33 29 37 / aud]
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```
[26 SR Front / 41 42 34 33 / aud]
[27 SR Back \ 37 38 30 29 \ aud]

;Rear audience area
[28 Rear SL Aud Top /60 56 55 59 / aud]
[29 Rear SL L Side / 56 60 52 48 / aud]
[30 Rear SL R Side \ 55 59 51 47 \ aud]
[31 Rear SL Front / 55 56 48 47 / aud]
[32 Rear SL Back / 60 59 51 52 / aud]
[33 Rear SR Aud Top / 54 53 57 58 / aud]
[34 Rear SR L Side / 54 58 50 46 / aud]
[35 Rear SR R Side / 53 45 49 57 / aud]
[36 Rear SR Front / 45 53 54 46 / aud]
[37 Rear SR Back \ 57 58 50 49 \ aud]

;Curtains
[*3 D 60 Stage Curtain / 4 4 4 4 / 301 302 304 303 / curtain]
```

CATT-Acoustic Files – Balcony.geo

```
scale 0.3048 0.3048 0.3048

CORNERS

;Balcony Structure

601     0       0       38
602     40      0       32
603     40      0       34
604     0       0       44
605     0       75      38
606     40      75      32
607     40      75      34
608     0       75      44

;Audience Area

609     5       5       46.5
610     5       70      46.5
611     35      70      38.5
612     35      5       38.5

613     5       5       43
614     5       70      43
615     35      70      35
616     35      5       35

PLANES

;Balcony Structure

[100 Balcony Top / 608 604 603 607 / plaster]
[101 Balcony SL Side / 601 602 603 604 / plaster]
```

```
[102 Balcony SR Side / 608 607 606 605 / plaster]
[103 Balcony Underside / 605 606 602 601 / plaster]
[104 Balcony Front / 603 602 606 607 / plaster]

[105 Balcony Aud Top / 609 612 611 610 / aud]
[106 Balcony Aud Front / 612 616 615 611 / aud]
[107 Balcony Aud SR Side / 610 611 615 614 / aud]
[108 Balcony Aud SL Side \ 609 612 616 613 \ aud]
[109 Balcony Aud Back / 609 610 614 613 / aud]
```

CATT-Acoustic Files – Ceiling.geo

```
scale 0.3048 0.3048 0.3048

CORNERS

;Movable Ceiling
61      113     0       28
62      113     75      28
63      40      75      33.5
64      40      0       33.5

PLANES;Movable Ceiling
[D 38 Movable Ceiling / 64 63 62 61 / ceiling]
```

CATT-Acoustic Files – Chalkboard.geo

```
scale 0.3048 0.3048 0.3048

ABS Chalkboard = <1 1 2 2 2 3> {50 150 100}

CORNERS

401     116     12      8
402     116     12      14
403     116     63      14
404     116     63      8

PLANES

[70 Chalkboard / 401 402 403 404 / chalkboard]
```

CATT-Acoustic Files – Panels.geo

```
scale 0.3048 0.3048 0.3048

CORNERS

;Panels
81      10      .5      15
82      10      .5      30
83      25      .5      30
```

```
84      25      .5      15

85      35      .5      12.5
86      35      .5      27.5
87      50      .5      27.5
88      50      .5      12.5

89      60      .5      10
90      60      .5      25
91      75      .5      25
92      75      .5      10

93      85      .5      10
94      85      .5      25
95      100     .5      25
96      100     .5      10

181     10      74.5    15
182     10      74.5    30
183     25      74.5    30
184     25      74.5    15

185     35      74.5    12.5
186     35      74.5    27.5
187     50      74.5    27.5
188     50      74.5    12.5

189     60      74.5    10
190     60      74.5    25
191     75      74.5    25
192     75      74.5    10

193     85      74.5    10
194     85      74.5    25
195     100     74.5    25
196     100     74.5    10

PLANES

;Panels
[50 Panel1 / 81 82 83 84 / curtain]
[51 Panel2 / 85 86 87 88 / curtain]
[52 Panel3 / 89 90 91 92 / curtain]
[53 Panel4 / 93 94 95 96 / curtain]

[54 Panel1 \ 181 182 183 184 \ curtain]
[55 Panel2 \ 185 186 187 188 \ curtain]
[56 Panel3 \ 189 190 191 192 \ curtain]
[57 Panel4 \ 193 194 195 196 \ curtain]
```

CATT-Acoustic Files – Separator.geo

```
scale 0.3048 0.3048 0.3048

CORNERS
```

```
;Movable Partition
501     51      0       0
502     51      75      0
503     51      75      31.61
504     51      0       31.61

PLANES

[D 90 Partition / 501 502 503 504 / curtain1]
```

CATT-Acoustic Files – Shell.geo

```
scale 0.3048 0.3048 0.3048

;Shell is made of 3/8" plywood
ABS Shell = <28 22 17 9 10 11> {60 97 196}

CORNERS
loop(100,angle,0,90,10,117+16.5*cos(angle),-5*angle/90+15,5+23*sin(angle))
loop(200,angle,0,90,10,117+16.5*cos(angle),5*angle/90+60,5+23*sin(angle))

PLANES
;Shell
[39 Shell 1 / 100 101 201 200 / shell]
[40 Shell 2 / 101 102 202 201 / shell]
[41 Shell 3 / 102 103 203 202 / shell]
[42 Shell 4 / 103 104 204 203 / shell]
[43 Shell 5 / 104 105 205 204 / shell]
[44 Shell 6 / 105 106 206 205 / shell]
[45 Shell 7 / 106 107 207 206 / shell]
[46 Shell 8 / 107 108 208 207 / shell]
[47 Shell 9 / 108 109 209 208 / shell]
```

CATT-Acoustic Files – SRC.LOC

```
scale 0.3048 0.3048 0.3048
SOURCEDEFS

IF SETUP = 1 THEN
a0 125 37.5 10 catt.sd1 50 37.5 3
ENDIF

IF SETUP = 2 THEN
a0 125 37.5 10 catt.sd1 50 37.5 3
ENDIF

IF SETUP = 3 THEN
a0 110 37.5 10 catt.sd1 70 37.5 3
ENDIF

Lp1m_a = Lp_voice_normal
Gain_a = <10 10 10 10 10 10>
```

```
Delay_e = 0
```

CATT-Acoustic Files – REC.LOC

```
Scale 0.3048 0.3048 0.3048
RECEIVERS

IF SETUP = 1 THEN
01      50      37.5    3.5
02      75      20      3.5
03      75      55      3.5
04      20      20      7.5
05      20      55      7.5
06      20      37.5    42.5
ENDIF

IF SETUP = 2 THEN
01      50      37.5    3.5
02      75      20      3.5
03      75      55      3.5
04      20      20      7.5
05      20      55      7.5
ENDIF

IF SETUP = 3 THEN
01      70      37.5    3.5
02      75      20      3.5
03      75      55      3.5
ENDIF
```