

Problem 1 - Modal Behaviour of a Cylindrical Room

The Matlab code for this problem is listed in Appendix 1.

Problem 1a

Table 1 lists the ten lowest resonance mode orders for the room and the respective frequency.

Index	Mode (n_x, n_θ, n_r)	Frequency [Hz]
0	0, 0, 0	0
1	1, 0, 0	17.2
2	0, 1, 0	33.5
3	2, 0, 0	34.3
4	1, 1, 0	37.6
5	2, 1, 0	48.0
6	3, 0, 0	51.5
7	0, 2, 0	55.6
8	1, 2, 0	58.2
9	3, 1, 0	61.4
10	2, 2, 0	65.3

Table 1: Resonant modes of the cylindrical room.

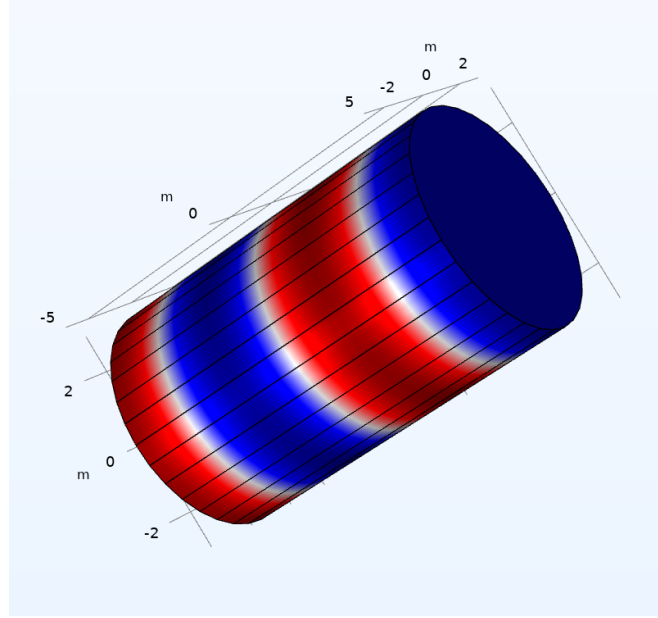
Problem 1b

The two closest modes are (3, 0, 0) and (0, 2, 0) with frequencies of 51.5 Hz and 55.6 Hz, respectively.

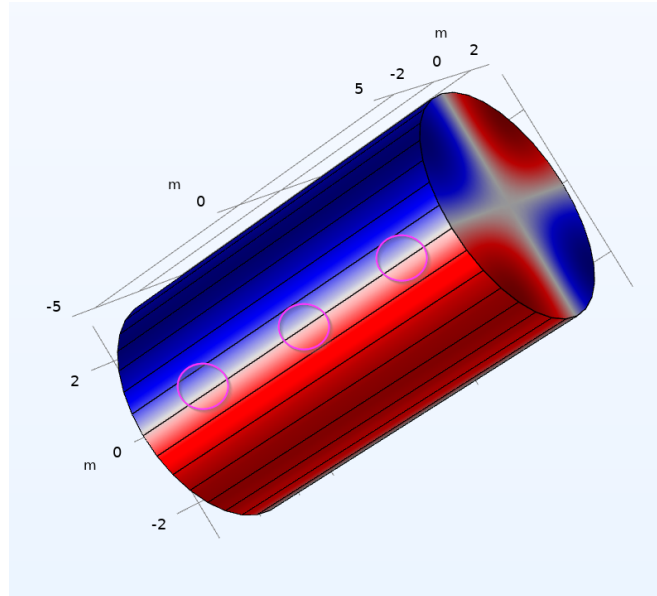
Problem 1c

Figure 1 illustrates the (3, 0, 0) and (0, 2, 0) modes. The white lines in each figure show the modal lines for that mode. **The machine can be placed where the modal lines for each mode overlap.** The figures were produced using the Room Eigenmode Simulator Version 1.1 software package.

The pink rings in Figure 1b indicate 3 possible places where the machine could be placed. These points coincide with the three modal planes shown in Figure 1a. Theoretically, there are an infinite number of places where the machine could be placed. However, placement would take into account practical considerations such as accessibility, etc.



(a) Mode (3, 0, 0)



(b) Mode (0, 2, 0)

Figure 1: Visualization of modes. (a.) Mode (3, 0, 0). (b.) Model (0, 2, 0). The pink circles in [1b](#) illustrate a few modal line intersections where the machine could be placed.

Problem 2 - Sabine Room

The Matlab code for this problem is listed in Appendix 2.

Problem 2a

The reverberant field sound pressure level is approximately 98.3 dB SPL.

Problem 2b

Figure 2 shows the direct, reverberant, and total sound pressure levels for a 25 mW, 125 Hz, broadband, omnidirectional source placed centrally in the room (i.e. the directivity factor is 1).

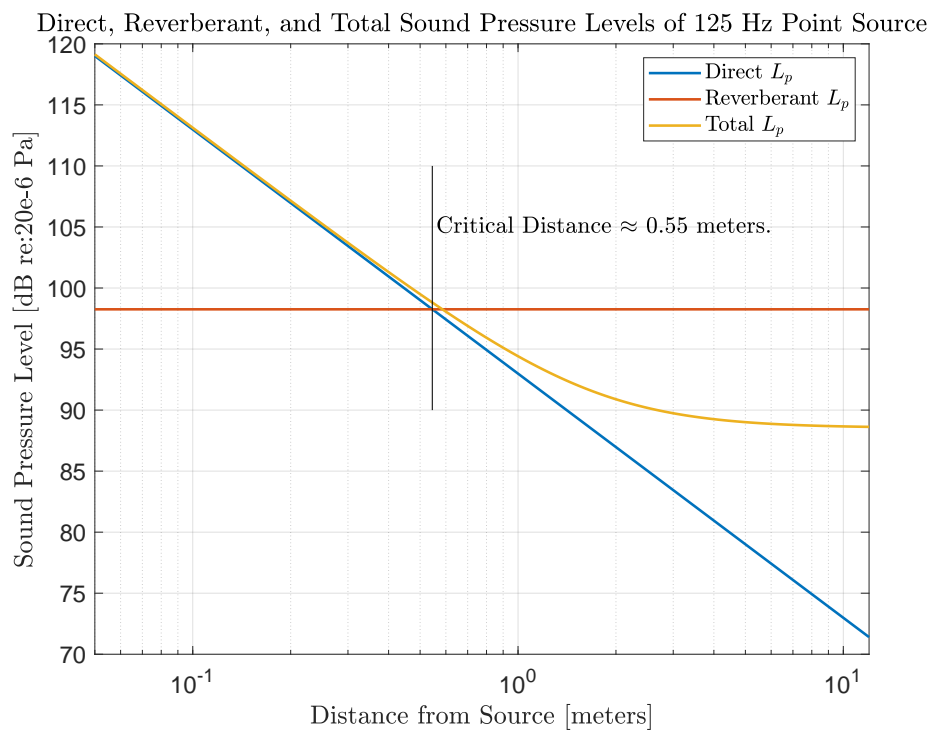


Figure 2: Sound levels for the room produced by a 25 mW, 125 Hz omnidirectional, broadband source.

Problem 3 - Transmission Loss Measurement

The Matlab code for this problem is listed in Appendix 3.

Figure 3 shows the average absorption per octave band based on the T60 data. The calibration plate isolates the receiver room and the absorption calculation does not consider the calibration plate.

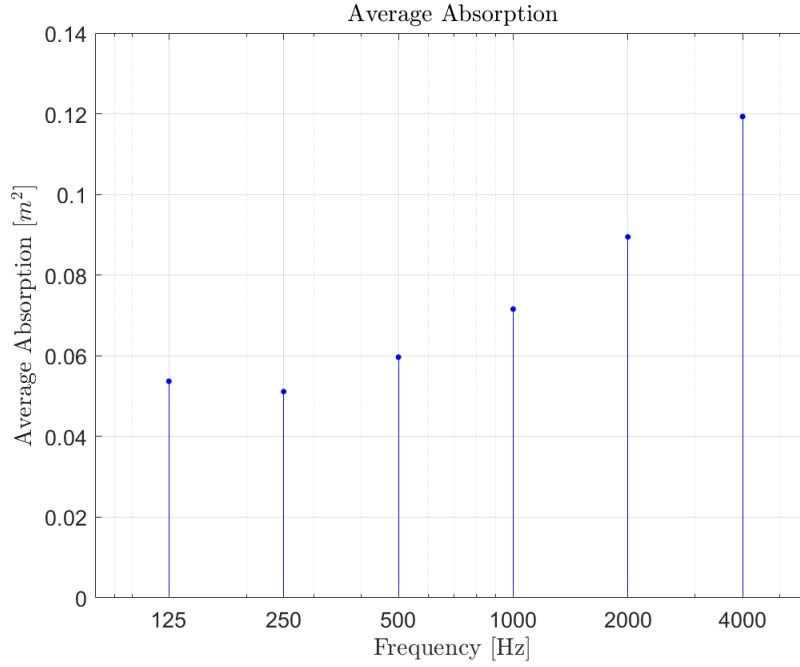


Figure 3: Average absorption per octave band.

Figure 4 shows the transmission loss per octave band.

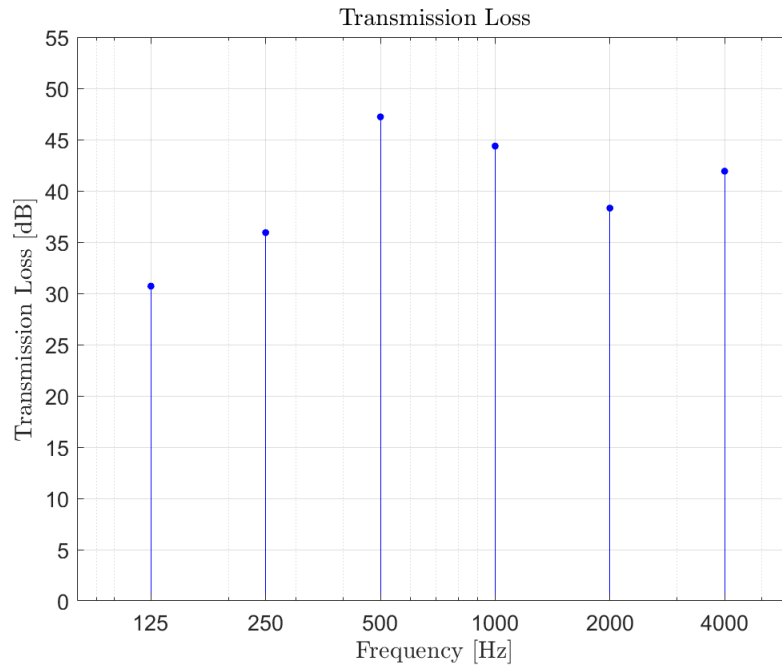


Figure 4: Transmission loss per octave band.

Problem 4 - Panel Transmission Loss

The Matlab code for this problem is listed in Appendix 4.

Problem 4a

The resonance frequency, f_0 , of the galvanized steel panel is 4 Hz or $22.6 \frac{\text{radians}}{\text{s}}$.

Problem 4b

i - Critical Frequency and Coincidence Frequency at 75°

The critical frequency is 10,216 Hz and the coincidence frequency at 75° is 10,494 Hz.

ii - Transmission Loss at Angle of Incidence of 75°

Figure 5 shows the transmission loss for an angle of incidence of 75° .

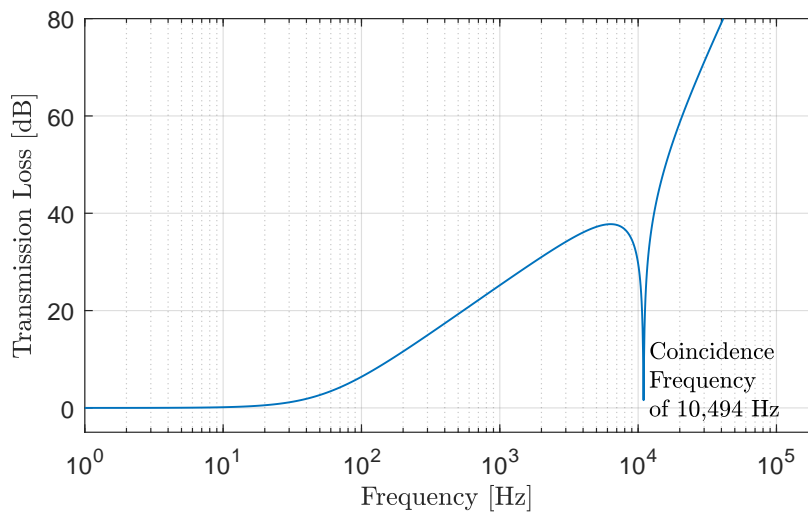


Figure 5: Flexible Panel Transmission Loss for a 75° Incidence Angle

iii - Transmission Loss for Angles of Incidence between $0-90^\circ$

Figure 6 shows the transmission loss angles of incidence from 0 to 90° in steps of 10° .

iv - Diffuse Transmission Loss

See the Matlab code in the Appendix 4

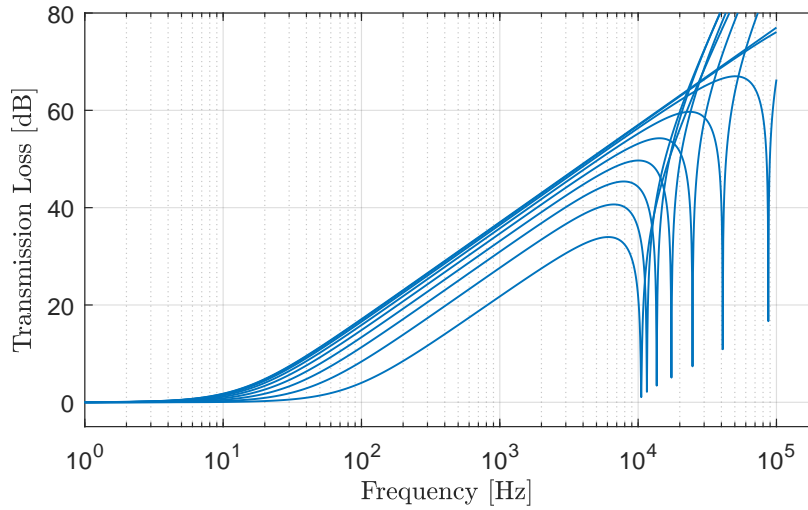


Figure 6: Flexible Panel Transmission Loss for angles of incidence between 0 and 90°.

Problem 4c

See the Matlab code in the Appendix 4

Problem 4d

Figure 7 shows the transmission loss angles of incidence from 0 to 90° in steps of 10°.

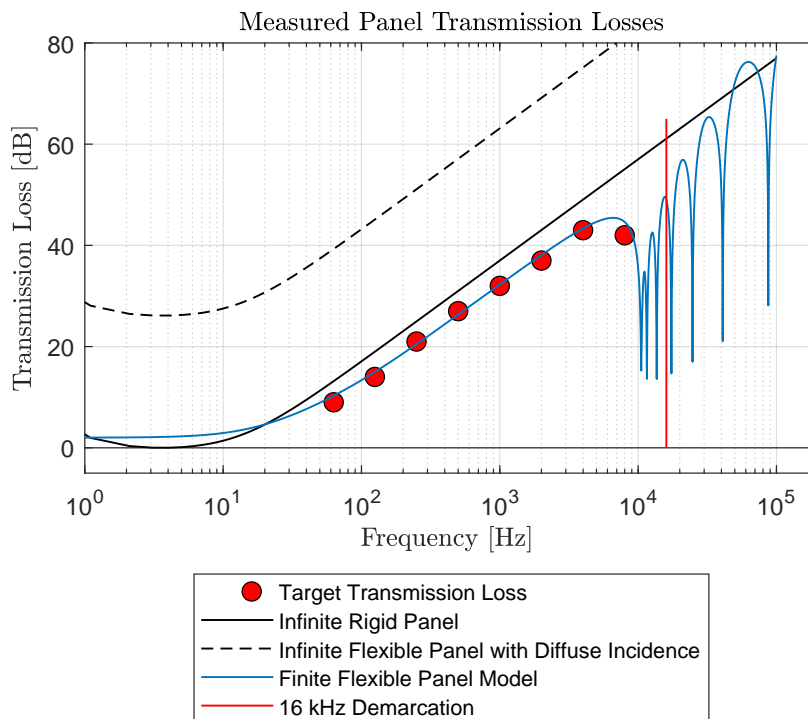


Figure 7: Measured data and the modeled responses.

The finite flexible panel appears to be the most appropriate model. As noted in class, the measured transmission loss at 8 kHz is smaller than the loss at 4 kHz. This indicates that the loss at 16 kHz should be less than the response of the infinite rigid panel at 16 kHz.

Problem 5 - Large Enclosure Design

The Matlab code for this problem is listed in Appendix 5.

My enclosure is a 2 m cube that sits on the ground (5 sides of enclosure material) over the machine. The machine is suspended above the pad (directivity factor of unity). It is assumed that there is no noise transmission through the ground.

Table 2 lists the target insertion losses, the calculated insertion losses for four materials, and the loss difference between the target and each type of material. A positive value indicates that the target insertion loss for the given octave band was not met.

Figure 8 shows calculated insertion loss differences for the data in Table 2.

Octave Band [Hz]	Target IL [dB]	QBV 2 [dB]	QBV 3 [dB]	HTL (100MM) [dB]	HTL 4 [dB]
250	44	28.0	19.7	10.6	5.6
500	54	26.7	22.2	6.6	-4.4
1,000	45	5.6	1.4	-15.4	-22.4
2,000	47	-8.4	-2.2	-18.4	-19.4
4,000	58	-2.4	5.7	-11.0	-13.0

Table 2: Calculated insertion losses for the 4 enclosure materials.

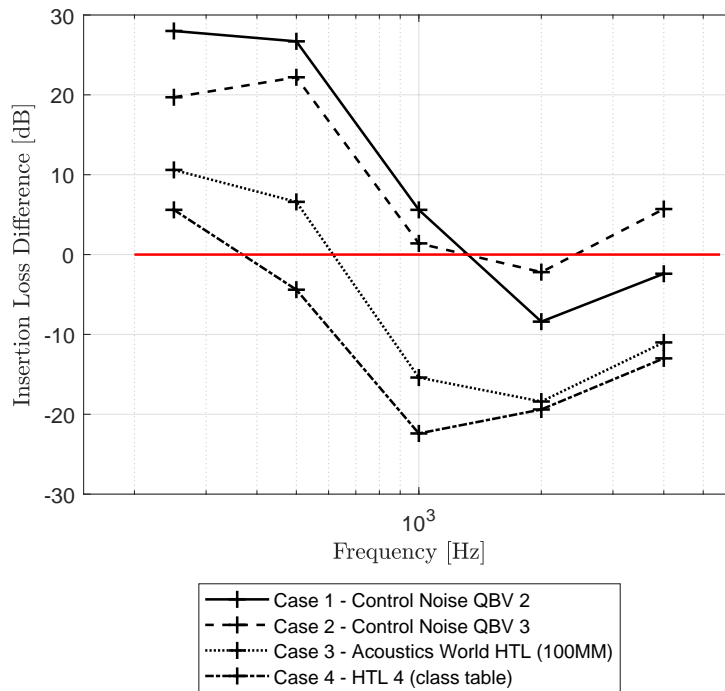


Figure 8: Insertion loss differences.

The most restrictive case given the 2 cubic-meter, 5-sided enclosure, is the HTL 4 material, Case 4, which was presented in class. The target insertion loss was reached by all of the octave bands except the 250 Hz band.

With the same enclosure dimensions and machine orientation, the HTL (100MM) material, Case 3, was found to be the second best material, not meeting the 250 Hz and 500 Hz targets. Figure 9 shows the transmission loss and absorption coefficient data for the material selected from Acoustics World.

The QBV-2 and QBV-3, Case 1 and Case 2, respectively, had the poorest performance. Figure 10 shows the transmission loss and absorption coefficient data for these material from Control Noise.

Using the HTL 4 material from class, a cube with 2 m sides appeared to produce the optimal insertion loss for the 250 Hz octave band. Making the size of the enclosure larger does not reduce this insertion loss and does not seem to be practical. A supplementary approach for this octave band should be considered.

NRC Rating								
Sound Absorption Coefficients (ASTM C423)								
Acoustic Panel Type	Panel Construction	125 Hz	250Hz	500Hz	1000 Hz	2000 Hz	4000 Hz	NRC
STL (100MM)	18 ga. solid / 22 ga. perforated	0.60	1.13	1.12	1.09	1.03	0.91	1.00
STL (100MM)	16 ga. solid / 22 ga. perforated	0.60	1.13	1.12	1.09	1.03	0.91	1.00
HTL (100MM)	16 ga. solid / 22 ga. perforated with HD Soundbloc Layer	0.60	1.13	1.12	1.09	1.03	0.91	1.00

STC Rating								
Sound Transmission Class								
Acoustic Panel Type	Panel Construction	125 Hz	250Hz	500Hz	1000 Hz	2000 Hz	4000 Hz	STC
STL (100MM)	18 ga. solid / 22 ga. perforated	21	28	39	48	56	58	40
STL (100MM)	16 ga. solid / 22 ga. perforated	24	32	41	51	60	66	43
HTL (100MM)	16 ga. solid / 22 ga. perforated with HD Soundbloc Layer	27	34	48	61	66	70	48

Figure 9: HTL (100MM) data from Acoustics World.

ACOUSTICAL DATA:

The **most effective** noise reduction products combine **both sound absorption and noise barrier properties**. Tested under strict compliance to appropriate ASTM standards, we offer the following results:

Sound Transmission Loss (dB) per Octave Band Frequency									
NetWell Model #	THK.	WT.	125	250	500	1000	2000	4000	STC
QBV-1	1"	1.3	11	16	24	30	35	35	27
QBV-2	2"	1.5	13	20	29	40	50	55	32
QBV-3	2.5"	2	19	25	33	46	53	58	37
QBS-1	2"	1.5	12	16	27	40	44	43	29
QBS-2	2"	2.5	19	22	28	40	56	61	33
Roof Panel	2"	2	18	24	28	37	45	46	31

Per ASTM E 90

Sound Absorption Data – Absorber Component Random Incident Sound Absorption Octave Band Center Frequencies (Hz)								
Product	THK.	125	250	500	1000	2000	4000	NRC
QBV-1	1"	.12	.47	.85	.84	.64	.62	.70
QBV-2	2"	.07	.27	.96	1.13	1.08	.99	.85
QBS-1 & 2	2"	.45	.96	.87	.66	.47	.30	.75
QB-4	4"	.21	.89	1.09	1.17	1.13	1.07	1.05

Per ASTM C 423

Flammability Ratings			
Product	Descriptor	Flame Spread	Smoke Developed
QBS-1	Vinyl faced 1" quilted fiberglass on both sides of a 1 lb. PSF non-reinforced loaded vinyl barrier septum	23	30
QBS-HT	Silicone faced 1" quilted fiberglass on both sides of a 1 lb. PSF non-reinforced noise barrier septum	4	19
QBV-2	Vinyl faced 2" quilt on one side of a 1 lb. reinforced loaded vinyl noise barrier	23	12
QBV-1	Vinyl faced 1" quilt on one side of a 1lb. reinforced loaded vinyl noise barrier	23	30

Above table shows flame spread and smoke developed ratings per ASTM Designation E84: Surface Burning Characteristics of Building Materials. Note: Class A rating applies to products with a flame spread index of 25 or less, and a smoke developed index of 450 or less. Additional products tested to ASTM E 162 and ASTM E 662, test reports available on request

Figure 10: QBV-2 and QBV-3 data from Control Noise.

Problem 6 - Close-fitting Enclosure Design

The Matlab code for this problem is listed in Appendix 6.

1 Appendix - Matlab Code for Problem 1

```
1
2
3
4 %% Synopsis
5
6 % Problem 1 – Modal Behaviour of a Cylindrical Room
7
8
9
10 %% Environment
11
12 close all; clear; clc;
13 % restoredefaultpath;
14
15 % addpath( genpath( '' ), '-begin' );
16 addpath( genpath( './00 Support' ), '-begin' );
17
18 % set( 0, 'DefaultFigurePosition', [ 400 400 900 400 ] ); % [ left bottom width height ]
19 set( 0, 'DefaultFigurePaperPositionMode', 'manual' );
20 set( 0, 'DefaultFigureWindowStyle', 'normal' );
21 set( 0, 'DefaultLineWidth', 1.5 );
22 set( 0, 'DefaultTextInterpreter', 'Latex' );
23
24 format ShortG;
25
26 pause( 1 );
27
28
29
30 %% Define Room
31
32 room.radius = 3; % m
33 room.length = 10; % m
34
35
36
37 %% Test Circular Mode Function
38
39 % psi = circular_mode_shape( 3, 1, 2, false ); % 3.7261 – CHECKED FROM CLASS (PLOT NOT CREATED)
40 % psi = circular_mode_shape( 3, 1, 2, true ); % 3.7261 – CHECKED FROM CLASS (PLOT CREATED)
41
42
43
44 %% Define Anonymous Function for the Natural Frequencies
45
46 h_natural_frequencies = @( c, nx, ntheta, nr, Lx, cylinder_radius, plot_flag ) (c/2) .* sqrt( (
    nx/Lx).^2 + (circular_mode_shape(nr, ntheta, cylinder_radius, plot_flag)/cylinder_radius)
    .^2 );
47
48
49
50 %% Calculate the Natural Frequencies
51
52 % The maximum number of radial modes is 5 (indexed from 0 to 4).
53 % The maximum number of angular modes is 8 (indexed from 0 to 7).
54
55 NX_SIZE = 20;
56 NTHETA_SIZE = 7;
57 NR_SIZE = 4;
58 natural_frequencies = nan( NX_SIZE, NTHETA_SIZE, NR_SIZE );
59
60 for nx = 0:1:NX_SIZE
61     for ntheta = 0:1:NTHETA_SIZE
62         for nr = 0:1:NR_SIZE
63             natural_frequencies( nx+1, ntheta+1, nr+1 ) = h_natural_frequencies( 343, nx, ntheta,
                nr, 10, 3, false );
64         end
65     end
66 end
67
68
69
70 %% Part a – Find 10 Lowest Resonance Frequencies
71
72 NUMBER_OF_LOWEST_FREQUENCIES = 11;
```

```

73     mode_indices = ( 1:1:NUMBER_OF_LOWEST_FREQUENCIES ).';
74
75 [ sortedValues, sortedIndices ] = sort( natural_frequencies(:) ); % 21-by-8-by-5 -> 840 elements
76
77 smallestValues = sortedValues( 1:NUMBER_OF_LOWEST_FREQUENCIES );
78 % [ mode_indices    round( smallestValues, 1 ) ]
79 %
80 % 1            0
81 % 2           17.2
82 % 3           33.5
83 % 4           34.3
84 % 5           37.6
85 % 6           47.9
86 % 7           51.5
87 % 8           55.6
88 % 9           58.2
89 % 10          61.4
90 % 11          65.3
91
92 smallestIndices = sortedIndices( 1:NUMBER_OF_LOWEST_FREQUENCIES );
93
94 [ x, y, z ] = ind2sub( size(natural_frequencies), smallestIndices );
95 % ( [ x y z ] - 1 )
96
97 % Verify the calculated mode indices.
98 h_natural_frequencies( 343, 0, 0, 0, 10, 3, false ); % 0 Hz
99 h_natural_frequencies( 343, 1, 0, 0, 10, 3, false ); % 17.2 Hz
100 h_natural_frequencies( 343, 0, 1, 0, 10, 3, false ); % 33.5 Hz
101 h_natural_frequencies( 343, 2, 0, 0, 10, 3, false ); % 34.3 Hz
102 h_natural_frequencies( 343, 1, 1, 0, 10, 3, false ); % 37.6 Hz
103 h_natural_frequencies( 343, 2, 1, 0, 10, 3, false ); % 48.0 Hz
104 h_natural_frequencies( 343, 3, 0, 0, 10, 3, false ); % 51.5 Hz
105 h_natural_frequencies( 343, 0, 2, 0, 10, 3, false ); % 55.6 Hz
106 h_natural_frequencies( 343, 1, 2, 0, 10, 3, false ); % 58.2 Hz
107 h_natural_frequencies( 343, 3, 1, 0, 10, 3, false ); % 61.4 Hz
108 h_natural_frequencies( 343, 2, 2, 0, 10, 3, false ); % 65.3 Hz
109
110
111
112 %% Part b – Two
113
114 % [ (1:11).' abs( smallestValues - 53 ) ]
115
116 temp = [ x y z ] - 1; temp( 7:8, :, : )
117
118 h_natural_frequencies( 343, 3, 0, 0, 10, 3, false ); % 51.5 Hz, (3, 0, 0)
119 h_natural_frequencies( 343, 0, 2, 0, 10, 3, false ); % 55.6 Hz, (0, 2, 0)
120
121
122
123 %% Part c
124
125 % See the report.
126
127
128
129 %% Clean-up
130
131 if ( ~isempty( findobj( 'Type', 'figure' ) ) )
132     monitors = get( 0, 'MonitorPositions' );
133     if ( size( monitors, 1 ) == 1 )
134         autoArrangeFigures( 2, 2, 1 );
135     elseif ( 1 < size( monitors, 1 ) )
136         autoArrangeFigures( 2, 2, 1 );
137     end
138 end
139
140
141 fprintf( 1, '\n\n*** Processing Complete ***\n\n' );
142
143
144
145 %% Reference(s)
146
147 % https://www.mathworks.com/matlabcentral/answers/1883747-how-to-find-the-5-minimum-values-in-a-multidimensional-matrix-and-the-indices-to-which-these-entries

```

2 Appendix - Matlab Code for Problem 2

```
1
2
3
4 %% Synopsis
5
6 % Problem 2 — Sabine Room
7
8
9
10 %% Environment
11
12 close all; clear; clc;
13 % restoredefaultpath;
14
15 % addpath( genpath( '' ), '-begin' );
16 addpath( genpath( '../00 Support' ), '-begin' );
17
18 % set( 0, 'DefaultFigurePosition', [ 400 400 900 400 ] ); % [ left bottom width height ]
19 set( 0, 'DefaultFigurePaperPositionMode', 'manual' );
20 set( 0, 'DefaultFigureWindowStyle', 'normal' );
21 set( 0, 'DefaultLineLineWidth', 1.5 );
22 set( 0, 'DefaultTextInterpreter', 'Latex' );
23
24 format ShortG;
25
26 pause( 1 );
27
28
29
30 %% Define Room
31
32 room.width = 8; % m
33 room.length = 6; % m
34 room.height = 3; % m
35 room.volume = room.width * room.length * room.height; % 144 m^3
36 room.area = 2*(room.width*room.height) + 2*(room.length*room.height) + 2*(room.width*room.
    length); % 180 m^2
37
38 alpha_average_walls_and_floor = 0.05; % For the walls and the floor.
39 alpha_average_ceiling = 0.15; % For the ceiling.
40
41 % For the 125 Hz octave band.
42
43
44
45 %% Part a — Estimate the Reverberant Sound Pressure Level
46
47 Lw = 10*log10( 25e-3 / 1e-12 ); % 103.98 dB
48
49 average_absorption_coefficient = ( (room.width*room.length)*alpha_average_ceiling + (room.width
    *room.length + 2*(room.width*room.height) + 2*(room.length*room.height) ) *
    alpha_average_walls_and_floor ) / room.area; % 0.076667 unitless
50
51 room_constant = room.area * average_absorption_coefficient / ( 1 - average_absorption_coefficient
    ); % 14.9 m^2 or Sabin
52
53
54 sound_pressure_level = Lw + 10*log10( 4 / room_constant ); % 98.3 dB
55
56
57
58 %% Part b — Calculate the Critical Distance
59
60 D0 = 1;
61
62 r = 0:0.05:12; % m
63
64 h_Lp_direct = @( Lw, D0, r ) Lw + 10*log10( D0./(4.*pi.*r.^2) );
65 h_Lp_reverberant = @( Lw, room_constant ) Lw + 10*log10( 4 ./ room_constant );
66 %
67 h_Lp_net = @( Lw, D0, r, room_constant ) Lw + 10*log10( D0./(4.*pi.*r.^2) + 4/room_constant ) +
    10*log10( 343*1.2/400 );
68
69
70 figure( ); ...
```

```

71     h1 = plot( r, h_Lp_direct( Lw, D0, r ) ); hold on;
72     h2 = plot( r, ones( size(r) ).*h_Lp_reverberant( Lw, room_constant ) );
73     h3 = plot( r, h_Lp_net( Lw, D0, r, room.volume ) ); grid on;
74     legend( [ h1, h2 h3 ], { 'Direct $L_p$', 'Reverberant $L_p$', 'Total $L_p$' }, '
        Interpreter', 'Latex' );
75
76     %
77     text( 0.56, 105, 'Critical Distance $\approx$ 0.55 meters.', 'Interpreter', 'Latex' );
78     line( [ 0.545 0.545 ], [ 90 110 ], 'Color', 'k', 'LineWidth', 0.6 );
79
80     xlabel( 'Distance from Source [meters]' ); ylabel( 'Sound Pressure Level [dB re:20e-6 Pa]' )
81     ;
82     title( 'Direct, Reverberant, and Total Sound Pressure Levels of 125 Hz Point Source' );
83     %
84     set( gca, 'XScale', 'log' );
85
86 % Estimate the critical distance (see page 84 of "06-Indoors.pdf" notes for ACS 537).
87 rc = 0.141 * sqrt( D0 * room_constant ); % 0.5451 meters
88
89 return
90 %% Clean-up
91
92 if ( ~isempty( findobj( 'Type', 'figure' ) ) )
93     monitors = get( 0, 'MonitorPositions' );
94     if ( size( monitors, 1 ) == 1 )
95         autoArrangeFigures( 2, 2, 1 );
96     elseif ( 1 < size( monitors, 1 ) )
97         autoArrangeFigures( 2, 2, 1 );
98     end
99 end
100
101 fprintf( 1, '\n\n*** Processing Complete ***\n\n' );
102
103
104
105
106 %% Reference(s)

```

3 Appendix - Matlab Code for Problem 3

```
1
2
3
4 %% Synopsis
5
6 % Question 3 – Transmission Loss Measurement
7
8
9 % Note(s):
10 %
11 % 1.) Lp1 depends on the transmission loss.
12 %
13 % If the transmission loss is low, then more energy goes to room 2 (i.e., the receiver room
14 % ).
15 % The noise reduction from the source room to the receiver room.
16 %
17 % Adding the barrier will change the level in the source room. Typically making the sound
18 % level higher in the source room.
19
20
21 %% Environment
22
23 close all; clear; clc;
24 % restoredefaultpath;
25
26 % addpath( genpath( '' ), '-begin' );
27 addpath( genpath( '../00 Support' ), '-begin' );
28
29 % set( 0, 'DefaultFigurePosition', [ 400 400 900 400 ] ); % [ left bottom width height ]
30 set( 0, 'DefaultFigurePaperPositionMode', 'manual' );
31 set( 0, 'DefaultFigureWindowStyle', 'normal' );
32 set( 0, 'DefaultLineLineWidth', 1.2 );
33 set( 0, 'DefaultLineMarker', 'x' );
34 set( 0, 'DefaultLineMarkerSize', 15 );
35 % set( 0, 'DefaultAxesLineStyleOrder', { '-' '--o' '+' } );
36 set( 0, 'DefaultTextInterpreter', 'Latex' );
37
38 format ShortG;
39
40 pause( 1 );
41
42
43
44 %% Dimensions of Rooms and Panel
45
46 room.length = 4; % m
47 room.width = 4; % m
48 room.height = 4; % m
49 room.volume = room.length * room.width * room.height; % 64 m^3
50 room.area = 2*(room.length * room.width) + 2*(room.length * room.height) + 2*(room.width *
51 room.height); % 96 m^2
52
53 panel.width = 0.8; % m
54 panel.height = 0.8; % m
55 panel.area = panel.width * panel.height; % 0.64 m^2
56
57 c = 343; % m/s
58
59
60 %% Measurement Data
61
62 octave_band_frequencies = [ 125 250 500 1000 2000 4000 ].'; % Hz
63 T60 = [ 2.0 2.1 1.8 1.5 1.2 0.9 ].'; % seconds
64 spl.source_room = [ 90 95 103 105 100 93 ].'; % dB re: 20e-6 Pa
65 spl.receiver_room = [ 50 50 46 50 50 38 ].'; % dB re: 20e-6 Pa
66 % [ octave_band_frequencies T60 spl.source_room spl.receiver_room (spl.source_room - spl.
67 receiver_room) ]
68
69
70 %% Calculate Average Absorption in the Receiver Room using Reverberation Time Measurements
71
```

```

72 average_absorption = @( volume, area, c, T60 ) ( 55.25 .* volume ) ./ ( area .* c .* T60 );
73
74 receiver_room.average_absorption = average_absorption( room.volume, room.area, c, T60 );
75
76 % Assumption: Calibration panel has very high transmission loss.
77
78 figure( ); ...
79 stem( octave_band_frequencies, receiver_room.average_absorption, 'Marker', '.', 'MarkerSize',
12, 'Color', 'b' ); grid on;
80 xlabel( 'Frequency [Hz]' ); ylabel( 'Average Absorption [m^2]' );
81 title( 'Average Absorption' );
82 %
83 xticks( octave_band_frequencies ); xticklabels( num2cell( octave_band_frequencies ) );
84 set( gca, 'XScale', 'log' );
85 xlim( [ 80 6e3 ] ); ylim( [ 0 0.14 ] );
86
87
88


---


89 %% Calculate the Receiver Room Constant
90
91 % The calibration plate isolates the receiver room.
92
93 % The receiver room does not consider the calibration plate.
94
95 room_constant = @( average_absorption, area ) ( average_absorption * area ) ./ ( 1 -
average_absorption ); % Unitless
96
97 receiver_room.room_constant = room_constant( receiver_room.average_absorption, room.area );
98
99
100


---


101 %% Calculate the Transmission Loss in Each Octave Band
102
103 transmission_coefficient = @( receiver_room_pressure, source_room_pressure, panel_area,
receiver_room_constant ) ( ( receiver_room_pressure ./ source_room_pressure ) .*
receiver_room_constant ) ./ panel_area;
104
105 tau = transmission_coefficient( 10.^(spl.receiver_room./10)*20e-6, 10.^(spl.source_room./10)*20e
-6, panel.area, receiver_room.room_constant );
106
107 TL = -10*log10( tau );
108
109 figure( ); ...
110 stem( octave_band_frequencies, TL, '.', 'MarkerSize', 15, 'Color', 'b' ); grid on;
111 xlabel( 'Frequency [Hz]' ); ylabel( 'Transmission Loss [dB]' );
112 title( 'Transmission Loss' );
113 %
114 xticks( octave_band_frequencies ); xticklabels( num2cell( octave_band_frequencies ) );
115 set( gca, 'XScale', 'log' );
116 xlim( [ 80 6e3 ] ); ylim( [ 0 55 ] );
117
118
119


---


120 %% Clean-up
121
122 if ( ~isempty( findobj( 'Type', 'figure' ) ) )
123     monitors = get( 0, 'MonitorPositions' );
124     if ( size( monitors, 1 ) == 1 )
125         autoArrangeFigures( 2, 2, 1 );
126     elseif ( 1 < size( monitors, 1 ) )
127         autoArrangeFigures( 2, 2, 1 );
128     end
129 end
130
131
132 fprintf( 1, '\n\n\n*** Processing Complete ***\n\n\n' );
133
134
135


---


136 %% Reference(s)

```

4 Appendix - Matlab Code for Problem 4

```
1
2
3
4 %% Synopsis
5
6 % Problem 4 – Panel Transmission Loss
7
8
9
10 %% Environment
11
12 close all; clear; clc;
13 % restoredefaultpath;
14
15 % addpath( genpath( '' ), '-begin' );
16 addpath( genpath( '../40 Assignments/00 Support' ), '-begin' );
17
18 % set( 0, 'DefaultFigurePosition', [ 400 400 900 400 ] ); % [ left bottom width height ]
19 set( 0, 'DefaultFigurePaperPositionMode', 'manual' );
20 set( 0, 'DefaultFigureWindowStyle', 'normal' );
21 set( 0, 'DefaultLineLineWidth', 0.8 );
22 set( 0, 'DefaultTextInterpreter', 'Latex' );
23
24 format ShortG;
25
26 pause( 1 );
27
28
29
30 %% Define Panel
31
32 panel.length = 80e-2; % m
33 panel.E = 200e9; % Pa
34 panel.density = 7800; % kg/m^3
35 panel.v = 0.29; % Poisson's Ratio (unitless)
36 panel.thickness = 1.2e-3; % m
37 panel.eta = 0.001; % Loss factor (unitless)
38
39 c = 343; % m/s
40 rho0 = 1.21; % kg/m^3
41
42
43
44 %% Measured Panel Data
45
46 octave_band_frequencies = [ 63 125 250 500 1000 2000 4000 8000 ].'; % Hz
47 TL = [ 9 14 21 27 32 37 43 42 ].'; % dB
48
49
50
51 %% Problem 4a – Infinite, Rigid Panel Model with Normal Incidence
52
53 D = ( panel.E * panel.thickness.^3 ) / ( 12 * ( 1 - panel.v^2 ) ); % 31.4
54
55 ms = panel.density * panel.thickness; % 9.4 kg/m^2
56
57 wo = pi^2 / panel.length * sqrt( D / ms ); % 22.6 radians/s
58 s = wo^2 * ms; % 4,785.9 kg radians / m^2s^2
59
60 fo = wo / (2*pi); % 4 Hz
61
62
63 % Define an Anonymous function for the rigid panel with normal incidence.
64 h_tau_infinite_rigid_panel = @( f, wo, ms, s, rho0, c, eta) 4 ./ ( ( (2*pi.*f*ms - s./(2*pi.*f))
65     ./ (rho0 * c) ).^2 + ( (wo*ms*eta) ./ (rho0*c) + 2 ).^2 );
66
67
68 %% Problem 4b – Infinite, Flexible Panel Model with Random Incidence
69
70 % The panel has bending waves.
71
72
73 % Part (i.)
74
```



```

75 % The critical frequency.
76 critical_frequency = c^2 / (2*pi) * sqrt( ms / D ); % 10.22 kHz
77
78 % Verify the critical frequency using a 90 degree angle of incidence.
79 critical_frequency_verify_1 = 1./(2*pi) .* sqrt( ms / D ) .* ( c / sind( 90 ) ).^2; % 10.22 kHz
80
81 % Verify the critical frequency using the properties of the panel.
82 critical_frequency_verify_2 = c^2 / ( 1.8 * panel.thickness * sqrt( panel.E / ( panel.density * (
    1 - panel.v^2) ) ) ); % 10.3 kHz
83
84
85 % Coincidence frequency for a 75 degree angle of incidence.
86 phi = 75;
87 h_coincidence_frequency = @( ms, D, c, phi ) 1./(2*pi) * sqrt( ms / D ) .* ( c ./ sind( phi
    ) ).^2;
88 h_coincidence_frequency( ms, D, c, phi ); % 10,949 Hz
89
90
91 % Define an Anonymous function for the flexible panel with random incidence.
92 h_tau_infinite_flexible_panel = @( f, rho0, c, phi, D, eta ) ( 2*rho0.*c*secd(phi)).^2 ./ ( (2*
    rho0.*c*secd(phi) + D*eta*(2*pi.*f./c).^4./(2*pi.*f)*sind(phi)^4).^2 + ...
93 (2*pi.*f*ms - D*(2*pi.*f./c).^4./(2*pi.*f)*sind(phi)^4).^2 );
94
95
96
97 % Part (ii.) — Transmission loss for a 75 degree angle of incidence.
98 f = 0.1:1:100 e3;
99
100 figure( ); ...
101 plot( f, -10*log10( h_tau_infinite_flexible_panel( f, rho0, c, phi, D, panel.eta ) ), '
    LineStyle', '-', 'Marker', 'none', 'Color', [0.00, 0.45, 0.74] ); grid on;
102 text( 12e3, 5, sprintf( 'Coincidence\nFrequency\nof 10,494 Hz' ) );
103 xlabel( 'Frequency [Hz]' ); ylabel( 'Transmission Loss [dB]' );
104 set( gca, 'XScale', 'log' );
105 axis( [ 1 200e3 -5 80 ] );
106 %
107 % Textheight: 744 pt. and Textwidth: 493 pt. from LaTeX document
108 %
109 % set( gcf, 'units', 'point', 'pos', [ 200 200 493*0.8 744*0.3 ] );
110 % pos = get( gcf, 'Position' );
111 % set( gcf, 'PaperPositionMode', 'Auto', 'PaperUnits', 'points', 'PaperSize', [pos(3)
    , pos(4)] );
112 % print(gcf, 'Q4 TL for 75 AOI', '-dpdf', '-r0' );
113 %
114 % https://tex.stackexchange.com/questions/179382/best-practices-for-using-matlab-images-in-latex
115
116
117
118 % Part (iii.)
119 f = 0.1:1:100 e3;
120
121 eta = panel.eta; phi_set = 0:10:90; t_set = [ ];
122
123 figure( ); ...
124 hold on;
125 for phi = phi_set
126     plot( f, -10*log10( h_tau_infinite_flexible_panel( f, rho0, c, phi, D, panel.eta ) ), '
        LineStyle', '-', 'Marker', 'none', 'Color', [0.00, 0.45, 0.74] );
127     t_set = [ t_set; h_tau_infinite_flexible_panel( f, rho0, c, phi, D, panel.eta ) ];
128 end
129 %
130 grid on; box on;
131 xlabel( 'Frequency [Hz]' ); ylabel( 'Transmission Loss [dB]' );
132 set( gca, 'XScale', 'log' );
133 axis( [ 1 200e3 -5 80 ] );
134 %
135 % Textheight: 744 pt. and Textwidth: 493 pt. from LaTeX document
136 %
137 % set( gcf, 'units', 'point', 'pos', [ 200 200 493*0.8 744*0.3 ] );
138 % pos = get( gcf, 'Position' );
139 % set( gcf, 'PaperPositionMode', 'Auto', 'PaperUnits', 'points', 'PaperSize', [pos(3)
    , pos(4)] );
140 % print(gcf, 'Q4iii TL for 75 AOI', '-dpdf', '-r0' );
141 %
142 % https://tex.stackexchange.com/questions/179382/best-practices-for-using-matlab-images-in-latex
143
144
145 tau_d = nanmean( t_set .* sind( 2*phi_set ).', 1 );

```

```

146
147
148
149 %% Combined Transmission Loss Plot
150
151 figure( ); ...
152 h1 = stem( octave_band_frequencies, TL, 'LineStyle', 'none', 'Marker', 'o', 'MarkerSize', 8,
153           'MarkerFaceColor', 'r', 'MarkerEdgeColor', 'k' ); hold on;
154 h2 = plot( f, -10*log10( h_tau_infinite_rigid_panel( f, wo, ms, s, rho0, c, panel.eta ) ), '
155           'LineStyle', '-', 'Color', 'k' );
156 h3 = plot( f, -10*log10( h_tau_infinite_rigid_panel( f, wo, ms, s, rho0, c, panel.eta )
157           ./ (200*panel.eta) * ( 4*panel.length / ( panel.length^2 * critical_frequency ) ) ), '
158           'LineStyle', '-', 'Marker', 'none', 'Color', 'k' );
159 h4 = plot( f, -10*log10( tau_d ), 'LineStyle', '-', 'Marker', 'none', 'Color', [0.00, 0.45,
160           0.74] );
161 h5 = line( [ 16e3 16e3 ], [ 0 65 ], 'Color', 'r' ); grid on; % 16 kHz Demarcation
162 legend( ...
163         [ h1, h2, h3, h4, h5 ], ...
164         'Target Transmission Loss', ...
165         'Infinite Rigid Panel', ...
166         'Infinite Flexible Panel with Diffuse Incidence', ...
167         'Finite Flexible Panel Model', ...
168         '16 kHz Demarcation', ...
169         'Location', 'SouthOutside' );
170
171 xlabel( 'Frequency [Hz]' ); ylabel( 'Transmission Loss [dB]' );
172 title( 'Measured Panel Transmission Losses' );
173 set( gca, 'XScale', 'log' );
174 axis( [ 1 200e3 -5 80 ] );
175 %
176 % Textheight: 744 pt. and Textwidth: 493 pt. from LaTeX document
177 %
178 % set( gcf, 'units', 'point', 'pos', [ 200 200 493*0.8 744*0.45 ] );
179 % pos = get( gcf, 'Position' );
180 % set( gcf, 'PaperPositionMode', 'Auto', 'PaperUnits', 'points', 'PaperSize', [ pos(3)
181 % , pos(4) ] );
182 % print(gcf, 'Q4d TL for 75 AOI', '-dpdf', '-r0' );
183 %
184 % https://tex.stackexchange.com/questions/179382/best-practices-for-using-matlab-images-in-latex
185
186
187 %% Plot Data and Model — Different Side Materials
188
189 % h_tau_infinite_rigid_panel_side_materials = @( f, wo, ms, s, rho0, c, eta, n ) (4*n) ./ ( (
190 % (2*pi.*f*ms - s./(2*pi.*f)) ./ (rho0 * c) ).^2 + ( (wo*ms*eta) ./ (rho0*c) + n + 1 ).^2 );
191
192 % f = 1e-2:1e-2:20e3;
193 %
194 % phi = 15;
195 % eta = panel.eta;
196 %
197 % figure( ); ...
198 % plot( f ./ (wo / (2*pi) ), -10*log10( h_tau_infinite_rigid_panel_side_materials( f, wo, ms,
199 % s, rho0, c, panel.eta, 1 ) ), 'LineStyle', '-' ); hold on;
200 % plot( f ./ (wo / (2*pi) ), -10*log10( h_tau_infinite_rigid_panel_side_materials( f, wo, ms,
201 % s, rho0, c, panel.eta, 1/3600 ) ), 'LineStyle', '-' );
202 % plot( f ./ (wo / (2*pi) ), -10*log10( h_tau_infinite_rigid_panel_side_materials( f, wo, ms,
203 % s, rho0, c, panel.eta, 3600 ) ), 'LineStyle', '-' ); grid on;
204 %
205 % legend( ...
206 %         'Same Fluid', ...
207 %         'Water to Air', ...
208 %         'Air to Water', ...
209 %         'Location', 'North' );
210 %
211 % xlabel( 'Frequency [ $\frac{\omega}{\omega_o}$ ]' ); ylabel( 'Transmission Loss [dB]' );
212 % title( 'Measured Panel Transmission Losses' );
213 % set( gca, 'XScale', 'log' );
214 % axis( [ 40 12e3 -5 45 ] );
215
216
217 %% Change in Stiffness
218
219 % figure( ); ...
220 % stem( octave_band_frequencies ./ (wo / (2*pi) ), TL, 'LineWidth', 0.5, 'Marker', 'o', '

```

```

MarkerSize', 8, 'MarkerEdgeColor', 'b', 'MarkerFaceColor', 'r' ); hold on;
214 %
215 %     plot( f ./ (wo / (2*pi) ), -10*log10( h_tau_infinite_rigid_panel( f, wo, ms, s, rho0, c,
panel.eta ) ), 'LineStyle', '-' );
216 %     plot( f ./ (wo / (2*pi) ), -10*log10( h_tau_infinite_rigid_panel( f, wo, ms, s*100, rho0, c
, panel.eta ) ), 'LineStyle', '--' );
217 %     plot( f ./ (wo / (2*pi) ), -10*log10( h_tau_infinite_rigid_panel( f, wo, ms, s*1e-2, rho0,
c, panel.eta ) ), 'LineStyle', '--' );
218 %
219 %     legend( ...
220 %         'Target TL Values', ...
221 %         'Infinite Rigid Panel with Normal Incidence Sound', ...
222 %         'Infinite Rigid Panel with Normal Incidence Sound (s * 100)', ...
223 %         'Infinite Rigid Panel with Normal Incidence Sound (s / 100)', ...
224 %         'Location', 'North' );
225 %
226 %     xlabel( 'Frequency [ $\frac{\omega}{\omega_o}$ ] ' ); ylabel( 'Transmission Loss [dB]' );
227 %     title( 'Measured Panel Transmission Losses - Change in Stiffness' );
228 %     set( gca, 'XScale', 'log' );
229 %     % axis( [ 40 12e3 -5 45] );
230
231
232
233 %% Change in Mass
234
235 % figure( ); ...
236 %     stem( octave_band_frequencies ./ (wo / (2*pi) ), TL, 'LineWidth', 0.5, 'Marker', 'o', '
MarkerSize', 8, 'MarkerEdgeColor', 'b', 'MarkerFaceColor', 'r' ); hold on;
237 %
238 %     plot( f ./ (wo / (2*pi) ), -10*log10( h_tau_infinite_rigid_panel( f, wo, ms*100, s, rho0, c
, panel.eta ) ), 'LineStyle', '-' );
239 %     plot( f ./ (wo / (2*pi) ), -10*log10( h_tau_infinite_rigid_panel( f, wo, ms, s, rho0, c,
panel.eta ) ), 'LineStyle', '-' );
240 %     plot( f ./ (wo / (2*pi) ), -10*log10( h_tau_infinite_rigid_panel( f, wo, ms*1e-2, s, rho0,
c, panel.eta ) ), 'LineStyle', '--' );
241 %
242 %     legend( ...
243 %         'Target TL Values', ...
244 %         'Infinite Rigid Panel with Normal Incidence Sound', ...
245 %         'Infinite Rigid Panel with Normal Incidence Sound (s * 100)', ...
246 %         'Infinite Rigid Panel with Normal Incidence Sound (s / 100)', ...
247 %         'Location', 'North' );
248 %
249 %     xlabel( 'Frequency [ $\frac{\omega}{\omega_o}$ ] ' ); ylabel( 'Transmission Loss [dB]' );
250 %     title( 'Measured Panel Transmission Losses - Change in Mass' );
251 %     set( gca, 'XScale', 'log' );
252 %     % axis( [ 40 12e3 -5 45] );
253
254
255
256 %% Change in Loss Factor
257
258 % figure( ); ...
259 %     stem( octave_band_frequencies ./ (wo / (2*pi) ), TL, 'LineWidth', 0.5, 'Marker', 'o', '
MarkerSize', 8, 'MarkerEdgeColor', 'b', 'MarkerFaceColor', 'r' ); hold on;
260 %
261 %     plot( f ./ (wo / (2*pi) ), -10*log10( h_tau_infinite_rigid_panel( f, wo, ms, s, rho0, c,
panel.eta ) ), 'LineStyle', '-' );
262 %     plot( f ./ (wo / (2*pi) ), -10*log10( h_tau_infinite_rigid_panel( f, wo, ms, s, rho0, c,
panel.eta*1e2 ) ), 'LineStyle', ':' );
263 %     plot( f ./ (wo / (2*pi) ), -10*log10( h_tau_infinite_rigid_panel( f, wo, ms, s, rho0, c,
panel.eta*1e-2 ) ), 'LineStyle', ':' );
264 %
265 %     legend( ...
266 %         'Target TL Values', ...
267 %         'Infinite Rigid Panel with Normal Incidence Sound', ...
268 %         'Infinite Rigid Panel with Normal Incidence Sound (eta * 100)', ...
269 %         'Infinite Rigid Panel with Normal Incidence Sound (eta / 100)', ...
270 %         'Location', 'North' );
271 %
272 %     xlabel( 'Frequency [ $\frac{\omega}{\omega_o}$ ] ' ); ylabel( 'Transmission Loss [dB]' );
273 %     title( 'Measured Panel Transmission Losses - Change in Loss Factor' );
274 %     set( gca, 'XScale', 'log', 'YScale', 'log' );
275 %     % axis( [ 40 12e3 -5 45] );
276
277
278
279 %% Clean-up

```

```

280
281 % if ( ~isempty( findobj( 'Type', 'figure' ) ) )
282 %     monitors = get( 0, 'MonitorPositions' );
283 %     if ( size( monitors, 1 ) == 1 )
284 %         autoArrangeFigures( 2, 2, 1 );
285 %     elseif ( 1 < size( monitors, 1 ) )
286 %         autoArrangeFigures( 2, 2, 1 );
287 %     end
288 % end
289
290
291 fprintf( 1, '\n\n\n*** Processing Complete ***\n\n\n' );
292
293
294
295 %% Reference(s)

```

5 Appendix - Matlab Code for Problem 5

```
1
2
3
4 %% Synopsis
5
6 % Problem 5 — Large Enclosure Design
7
8
9
10 %% Environment
11
12 close all; clear; clc;
13 % restoredefaultpath;
14
15 % addpath( genpath( '' ), '-begin' );
16 addpath( genpath( '../40 Assignments/00 Support' ), '-begin' );
17
18 % set( 0, 'DefaultFigurePosition', [ 400 400 900 400 ] ); % [ left bottom width height ]
19 set( 0, 'DefaultFigurePaperPositionMode', 'manual' );
20 set( 0, 'DefaultFigureWindowSize', 'normal' );
21 set( 0, 'DefaultLineLineWidth', 1.2 );
22 set( 0, 'DefaultTextInterpreter', 'Latex' );
23
24 format ShortG;
25
26 pause( 1 );
27
28
29
30 %% Define Machine
31
32 machine.area = 3; % m^2
33 machine.absorption = 0.07; % m^2 or Sabine
34 machine.D = 1; % Unitless — In air.
35
36 machine.distance = 10; % m
37
38
39
40 %% Measurement Data
41
42 octave_band_frequencies = [ 250 500 1000 2000 4000 ].'; % Hz
43 Lw = [ 105 115 106 108 119 ].'; % dB re: 1 pW
44
45
46
47 %% Per Octave Band Insertion Loss
48
49 Lp_10_meters = Lw + 10*log10( machine.D / ( 4 * pi * machine.distance^2 ) ); % dB re: 20e-6 Pa
50 %
51 % The value of R is infinite. The machine is outside in open air.
52
53 octave_band_IL = Lp_10_meters - 30;
54
55
56
57 %% Define Anonymous Function for Insertion Loss
58
59 h_IL_large = @( Sw, alpha_w, Si, alpha_i, TL ) 10*log10( 1 + (Sw*alpha_w + Si*alpha_i)./(Sw
+ Si)*10^(TL/10) );
60
61
62
63 %% Find Values of TL and Aborption that will Meet the Target Insertion Loss — Ground Reflecting
64
65 % Assumption(s):
66 %
67 % 1.) The enclosure is a cube.
68 % 2.) The machine sits on the ground.
69 % 2.) There is no noise transmission through the ground.
70
71 enclosure.dimension = 2.0; % m
72 enclosure.area = 5 * enclosure.dimension^2; % 20 m^2
73
74 % Volume of the enclosure is much bigger than the machine Diffuse sound field in the enclosure.
```

```

75
76
77 switch ( 4 )
78
79     case 1
80
81         % https://www.controlnoise.com/wp-content/uploads/2022/02/Acoustic-Enclosures-Datasheet.pdf
82
83         % 250 Hz – QBV-2
84         alpha_w = 0.27; % From specification sheet.
85         TL = 22; % From specification sheet.
86         IL_estimates(1) = h_IL_large( enclosure.area, alpha_w, machine.area, machine.
            absorption, TL );
87
88         % 500 Hz – QBV-2
89         alpha_w = 0.96; % From specification sheet.
90         TL = 28; % From specification sheet.
91         IL_estimates(2) = h_IL_large( enclosure.area, alpha_w, machine.area, machine.
            absorption, TL );
92
93         % 1 kHz – QBV-2
94         % alpha_w = 1.13; % From specification sheet.
95         alpha_w = 0.99; % From specification sheet. See comment on slide 28 of Lecture 10.
96         TL = 40; % From specification sheet.
97         IL_estimates(3) = h_IL_large( enclosure.area, alpha_w, machine.area, machine.
            absorption, TL );
98
99         % 2 kHz – QBV-2
100        % alpha_w = 1.08; % From specification sheet.
101        alpha_w = 0.99; % From specification sheet. See comment on slide 28 of Lecture 10.
102        TL = 56; % From specification sheet.
103        IL_estimates(4) = h_IL_large( enclosure.area, alpha_w, machine.area, machine.
            absorption, TL );
104
105        % 4 kHz – QBV-2
106        alpha_w = 0.99; % From specification sheet.
107        TL = 61; % From specification sheet.
108        IL_estimates(5) = h_IL_large( enclosure.area, alpha_w, machine.area, machine.
            absorption, TL );
109
110
111    case 2
112
113        % https://www.controlnoise.com/wp-content/uploads/2022/02/Acoustic-Enclosures-Datasheet.pdf
114
115        % Note: Absorption values are carried over from QBV-2.
116
117        % 250 Hz – QBV-3
118        alpha_w = 0.96; % From specification sheet.
119        TL = 25; % From specification sheet.
120        IL_estimates(1) = h_IL_large( enclosure.area, alpha_w, machine.area, machine.
            absorption, TL );
121
122        % 500 Hz – QBV-3
123        alpha_w = 0.87; % From specification sheet.
124        TL = 33; % From specification sheet.
125        IL_estimates(2) = h_IL_large( enclosure.area, alpha_w, machine.area, machine.
            absorption, TL );
126
127        % 1 kHz – QBV-3
128        % alpha_w = 1.13; % From specification sheet.
129        alpha_w = 0.66; % From specification sheet. See comment on slide 28 of Lecture 10.
130        TL = 46; % From specification sheet.
131        IL_estimates(3) = h_IL_large( enclosure.area, alpha_w, machine.area, machine.
            absorption, TL );
132
133        % 2 kHz – QBV-3
134        % alpha_w = 1.08; % From specification sheet.
135        alpha_w = 0.47; % From specification sheet. See comment on slide 28 of Lecture 10.
136        TL = 53; % From specification sheet.
137        IL_estimates(4) = h_IL_large( enclosure.area, alpha_w, machine.area, machine.
            absorption, TL );
138
139        % 4 kHz – QBV-3
140        alpha_w = 0.30; % From specification sheet.
141        TL = 58; % From specification sheet.

```

```

142         IL_estimates(5) = h_IL_large( enclosure.area , alpha_w , machine.area , machine.
143             absorption , TL );
144
145 case 3
146
147     % https://www.acousticworld.com/machine-acoustic-enclosures/
148
149     % 250 Hz
150     % alpha_w = 1.13; % From specification sheet.
151     alpha_w = 0.99;
152     TL = 34; % From specification sheet.
153     IL_estimates(1) = h_IL_large( enclosure.area , alpha_w , machine.area , machine.
154         absorption , TL );
155
156     % 500 Hz
157     % alpha_w = 1.12; % From specification sheet.
158     alpha_w = 0.99;
159     TL = 48; % From specification sheet.
160     IL_estimates(2) = h_IL_large( enclosure.area , alpha_w , machine.area , machine.
161         absorption , TL );
162
163     % 1 kHz
164     % alpha_w = 1.09; % From specification sheet.
165     alpha_w = 0.99;
166     TL = 61; % From specification sheet.
167     IL_estimates(3) = h_IL_large( enclosure.area , alpha_w , machine.area , machine.
168         absorption , TL );
169
170     % 2 kHz
171     % alpha_w = 1.03; % From specification sheet.
172     alpha_w = 0.99;
173     TL = 66; % From specification sheet.
174     IL_estimates(4) = h_IL_large( enclosure.area , alpha_w , machine.area , machine.
175         absorption , TL );
176
177     % 4 kHz
178     % alpha_w = 0.91; % From specification sheet.
179     TL = 70; % From specification sheet.
180     IL_estimates(5) = h_IL_large( enclosure.area , alpha_w , machine.area , machine.
181         absorption , TL );
182
183 case 4
184
185     % HTL-4 from specification sheet shown in class.
186
187     % 250 Hz
188     % alpha_w = 1.13; % From specification sheet.
189     alpha_w = 0.99;
190     TL = 39; % From specification sheet.
191     IL_estimates(1) = h_IL_large( enclosure.area , alpha_w , machine.area , machine.
192         absorption , TL );
193
194     % 500 Hz
195     % alpha_w = 1.12; % From specification sheet.
196     alpha_w = 0.99;
197     TL = 59; % From specification sheet.
198     IL_estimates(2) = h_IL_large( enclosure.area , alpha_w , machine.area , machine.
199         absorption , TL );
200
201     % 1 kHz
202     % alpha_w = 1.09; % From specification sheet.
203     alpha_w = 0.99;
204     TL = 68; % From specification sheet.
205     IL_estimates(3) = h_IL_large( enclosure.area , alpha_w , machine.area , machine.
206         absorption , TL );
207
208     % 2 kHz
209     % alpha_w = 1.03; % From specification sheet.
210     alpha_w = 0.99;
211     TL = 67; % From specification sheet.
212     IL_estimates(4) = h_IL_large( enclosure.area , alpha_w , machine.area , machine.
213         absorption , TL );
214
215     % 4 kHz
216     % alpha_w = 0.91; % From specification sheet.
217     TL = 72; % From specification sheet.

```

```

210         IL_estimates(5) = h_IL_large( enclosure.area , alpha_w , machine.area , machine.
211             absorption , TL );
212     end
213
214
215
216 %% Calculate the Differences
217
218 [ octave_band_IL      IL_estimates.'      (octave_band_IL - IL_estimates.') ]
219
220 data = [ ...
221     250      44      28.0      19.7      10.6      5.6; ...
222     500      54      26.7      22.2      6.6      -4.4; ...
223     1000     45      5.6      1.4     -15.4     -22.4; ...
224     2000     47     -8.4     -2.2     -18.4     -19.4; ...
225     4000     58     -2.4      5.7     -11.0     -13.0 ];
226
227 figure( ); ...
228 h1 = plot( data(:, 1) , data(:, 3) , 'LineStyle', '-', 'Color', 'k', 'Marker', '+', '
229     MarkerSize', 8 ); hold on;
230 h2 = plot( data(:, 1) , data(:, 4) , 'LineStyle', '-', 'Color', 'k', 'Marker', '+', '
231     MarkerSize', 8 );
232 h3 = plot( data(:, 1) , data(:, 5) , 'LineStyle', ':', 'Color', 'k', 'Marker', '+', '
233     MarkerSize', 8 );
234 h4 = plot( data(:, 1) , data(:, 6) , 'LineStyle', '-', 'Color', 'k', 'Marker', '+', '
235     MarkerSize', 8 ); grid on;
236 line( [200 5500], [0 0] , 'Color', 'r' );
237 legend( [ h1 h2 h3 h4 ] , { 'Case 1 - Control Noise QBV 2', 'Case 2 - Control Noise QBV 3', '
238     Case 3 - Acoustics World HTL (100MM)', 'Case 4 - HTL 4 (class table)' }, 'Location', '
239     SouthOutside' );
240 xlabel( 'Frequency [Hz]' ); ylabel( 'Insertion Loss Difference [dB]' );
241 %
242 axis( [ 150 6e3 -30 30 ] );
243 set( gca, 'XScale', 'log' );
244 %
245 % Textheight: 744 pt. and Textwidth: 493 pt. from LaTeX document
246 %
247 set((gcf, 'units', 'point', 'pos', [ 200 200 493*0.8 744*0.5 ] );
248 pos = get( gcf, 'Position' );
249 set( gcf, 'PaperPositionMode', 'Auto', 'PaperUnits', 'points', 'PaperSize', [pos(3),
250     pos(4)] );
251 %
252 print(gcf, 'Q5_IL_Plot', '-dpdf', '-r0' );
253 %
254 % https://tex.stackexchange.com/questions/179382/best-practices-for-using-matlab-images-in-latex
255
256
257 %% Clean-up
258
259 % if ( ~isempty( findobj( 'Type', 'figure' ) ) )
260 %     monitors = get( 0, 'MonitorPositions' );
261 %     if ( size( monitors, 1 ) == 1 )
262 %         autoArrangeFigures( 2, 2, 1 );
263 %     elseif ( 1 < size( monitors, 1 ) )
264 %         autoArrangeFigures( 2, 2, 1 );
265 %     end
266 % end
267
268 fprintf( 1, '\n\n\n*** Processing Complete ***\n\n\n' );
269
270
271
272 %% Reference(s)
273
274 %
275 % Textheight: 744 pt. and Textwidth: 493 pt. from LaTeX document
276 %
277 set( gcf, 'units', 'point', 'pos', [ 200 200 493*0.8 744*0.45 ] );
278 pos = get( gcf, 'Position' );
279 set( gcf, 'PaperPositionMode', 'Auto', 'PaperUnits', 'points', 'PaperSize', [pos(3),
280     pos(4)] );
281 %
282 print(gcf, 'Q4d_TL_for_75_AOI', '-dpdf', '-r0' );
283 %
284 % https://tex.stackexchange.com/questions/179382/best-practices-for-using-matlab-images-in-latex

```


6 Appendix - Matlab Code for Problem 6

```
1
2
3
4 %% Synopsis
5
6 % Lecture 11, Wednesday, February 19, 2025
7
8 % The compressor elevated above the ground.
9
10
11
12 %% Environment
13
14 close all; clear; clc;
15 % restoredefaultpath;
16
17 % addpath( genpath( '' ), '-begin' );
18 addpath( genpath( '../40 Assignments/00 Support' ), '-begin' );
19
20 % set( 0, 'DefaultFigurePosition', [ 400 400 900 400 ] ); % [ left bottom width height ]
21 set( 0, 'DefaultFigurePaperPositionMode', 'manual' );
22 set( 0, 'DefaultFigureWindowStyle', 'normal' );
23 set( 0, 'DefaultLineLineWidth', 0.8 );
24 set( 0, 'DefaultTextInterpreter', 'Latex' );
25
26 format ShortG;
27
28 pause( 1 );
29
30 PRINT_FIGURES = 0;
31
32
33
34 %% Define Anonymous Functions
35
36 h_RA_term_1 = @( rho0, c, S, k, delta_mu, D, w ) ( rho0*c/S ) * ( ( k * sqrt( (2*3.178e-5) / (
    rho0*w) ) * D * 0.004 ) / (2*S) * 1.4364 );
37 h_RA_term_2 = @( rho0, c, S, k, delta_mu, D, w, h ) ( rho0*c/S ) * 0.288*k*3.178e-5*log10((4*
    S)/(pi*h^2));
38 h_RA_term_3 = @( rho0, c, S, k, delta_mu, D, w, h ) ( rho0*c/S ) * (0.5*S*k^2)/(2*pi);
39
40
41
42 %% Define Compressor
43
44 compressor.width = 1; % m
45 compressor.depth = 1; % m
46 compressor.height = 2; % m
47     compressor.area = 2*(compressor.width * compressor.depth) + 2*(compressor.width * compressor.
        height) + 2*(compressor.depth * compressor.height); % 3 m^2
48     compressor.volume = compressor.width * compressor.depth * compressor.height; % m^3
49
50 compressor.power_level = 105; % dB re: 1e-12 Watts
51 compressor.frequency = 50; % Hz
52
53 c = 343; % m/s
54
55 rho0 = 1.2; % kg/m^3 CHECK
56
57
58
59 %% Sound Level Target
60
61 sound_level_target = 82; % dB re: 20e-6 Pascals
62
63
64
65 %% Define Workshop
66
67 R = 40; % m^2 or Sabins
68
69
70
71 %% Define Close-fitting Enclosure
72
```

```

73 helmholtz_factor = (2 * pi * compressor.frequency) / c; % 0.92 m
74 %
75 % For a small enclosure, k*d << 1. Therefore d << 1.1.
76 d = 0.75;
77 d = 0.25;
78 % d = 1;
79 % helmholtz_factor * d; % 0.69
80
81 enclosure.width = compressor.width + d; % m
82 enclosure.depth = compressor.depth + d; % m
83 enclosure.height = 3; % m; compression height is 2 m
84 % enclosure.height = compressor.height + d;
85 enclosure.area = 2*(enclosure.width * enclosure.depth) + 2*(enclosure.width * enclosure.
    height) + 2*(enclosure.depth * enclosure.height);
86 enclosure.volume = enclosure.width * enclosure.depth * enclosure.height;
87
88 enclosure.E = 3.6e9; % Pascals
89 enclosure.thickness = 3.81e-2; % m
90 enclosure.density = 800; % kg/m^3
91 enclosure.poisson_ratio = 0.25; % Unitless
92
93 % Clamped boundary conditions.
94
95
96
97 %% Calculate Diffuse Sound Pressure Level
98
99 % Assume distance is beyond the critical distance, so the distance value is
100 % large and its associated term is not relevant.
101
102 sound_pressure_level = 105 + 10*log10( 4/R ); % 95 dB SPL
103
104
105
106 %% Calculate the Required Insertion Loss
107
108 target_insertion_loss = sound_pressure_level - 82 % 13 dB
109
110
111
112 %% Insertion Loss
113
114 % For the insertion loss to be high, we need:
115 %
116 % 1.) Compliance of the air to be high; volume of enclosure must be large.
117 % 2.) Compliance of each enclosure wall to be low; low area, high stiffness, edges clamped).
118 % AREA IS THE DOMINATE FACTOR OVER VOLUME.
119
120
121 % The correction factor for clamped walls. See Figure 12.4 on slide 9 of the Lecture 11 notes.
122 aspect_ratio = enclosure.height / enclosure.width; % 1.7
123 correction_factor = 2; % Approximate value read from the Figure 12.4.
124
125 bending_stiffness = ( enclosure.E * enclosure.thickness^3 ) / ( 12*( 1 - enclosure.poisson_ratio
    ^2 ) ); % 1.78e7
126 h_wall_compliance = @( wall_area, correction_factor ) ( 0.001 * wall_area^3 *
    correction_factor ) / bending_stiffness;
127
128 Ca = enclosure.volume / ( rho0 * c^2 );
129
130
131 % Top
132 top.area = enclosure.width * enclosure.depth;
133 top.aspect_ratio = max( enclosure.width, enclosure.depth ) / min( enclosure.width, enclosure.
    depth );
134 top.correction_factor = 3.8;
135 top.compliance = h_wall_compliance( top.area, top.correction_factor );
136
137
138 % Side 1
139 side_1.area = enclosure.depth * enclosure.height;
140 side_1.aspect_ratio = max( enclosure.width, enclosure.height ) / min( enclosure.width, enclosure.
    height );
141 side_1.correction_factor = 2;
142 side_1.compliance = h_wall_compliance( side_1.area, side_1.correction_factor );
143
144 % Side 2
145 side_2.compliance = side_1.compliance;

```

```

146
147
148 % Side 3
149 side_3.area = enclosure.width * enclosure.height;
150 side_3.aspect_ratio = max( enclosure.width, enclosure.height ) / min( enclosure.width, enclosure.
    height );
151 side_3.correction_factor = 2;
152 side_3.compliance = h_wall_compliance( side_3.area, side_3.correction_factor );
153
154 % Side 4
155 side_4.compliance = side_3.compliance;
156
157
158 estimated_insertion_loss = 20*log10( 1 + Ca / ( top.compliance + 2*side_1.compliance + 2* side_3.
    compliance ) ); % 59.2 dB
159
160
161
162 %% Compliance of the Air Intake
163
164 air_intake_radius = 10e-2; % m
165 air_intake_thickness = enclosure.thickness; % m
166 air_intake_frequency = 50; % Hz
167 air_intake_angular_frequency = 2*pi*air_intake_frequency; % radians/s
168
169 viscosity = 1.5e-5; % m^2/s
170
171 h = 0.3; % CHECK
172
173 f = 50;
174 term_1 = h_RA_term_1( rho0, c, pi*(air_intake_radius^2)^2/4, 2*pi*f/c, sqrt( (2 * 3.178e-5 )
    / ( 2*pi*f * rho0 ) ), pi * 0.1, 2*pi*f );
175 term_2 = h_RA_term_2( rho0, c, pi*(air_intake_radius^2)^2/4, 2*pi*f/c, sqrt( (2 * 3.178e-5 )
    / ( 2*pi*f * rho0 ) ), pi * 0.1, 2*pi*f, 0.3 );
176 term_3 = h_RA_term_3( rho0, c, pi*(0.1)^2/4, 2*pi*f/c, sqrt( (2 * 3.178e-5 ) / ( 2*pi*f *
    rho0 ) ), pi * 0.1, 2*pi*f, 0.3 );
177 impedance.real = term_1 + term_2 + term_3;
178
179
180 % Deng (1998)
181 epsilon = 1;
182 L_o = air_intake_radius * ( 1.27 / (1 + 1.92*epsilon) - 0.086 );
183
184 L_e = enclosure.thickness + 2*L_o;
185 impedance.imaginary = 1j * rho0 * (2 * pi * f) * L_e / ( pi*0.1^2/4 );
186
187
188 impedance.net = impedance.real + impedance.imaginary;
189 compliance_of_hole = 1 / impedance.net;
190 Cl = abs( compliance_of_hole );
191
192 estimated_insertion_loss
193 estimated_insertion_loss_with_hole = 20*log10( (Cl + Ca) / ( Cl + ( top.compliance + 2*side_1.
    compliance + 2* side_3.compliance ) ) )
194
195
196 13 - estimated_insertion_loss_with_hole;
197
198
199
200 critical_frequency = c^2/(2*pi)*sqrt( enclosure.density * enclosure.thickness / bending_stiffness
    );
201 %
202 % The critical frequency is 25 Hz.
203 %
204 % The frequency of the compressor is 50 Hz.
205
206
207
208
209
210 %% Clean-up
211
212 if ( ~isempty( findobj( 'Type', 'figure' ) ) )
213     monitors = get( 0, 'MonitorPositions' );
214     if ( size( monitors, 1 ) == 1 )
215         autoArrangeFigures( 2, 2, 1 );
216     elseif ( 1 < size( monitors, 1 ) )

```

```
217         autoArrangeFigures( 2, 2, 1 );
218     end
219 end
220
221
222 fprintf( 1, '\n\n*** Processing Complete ***\n\n' );
223
224
225
226 %% Reference(s)
```
