Validation of Transmission Loss Simulation Approach with Goal to Estimate Launch Vehicle Internal Cavity Acoustics

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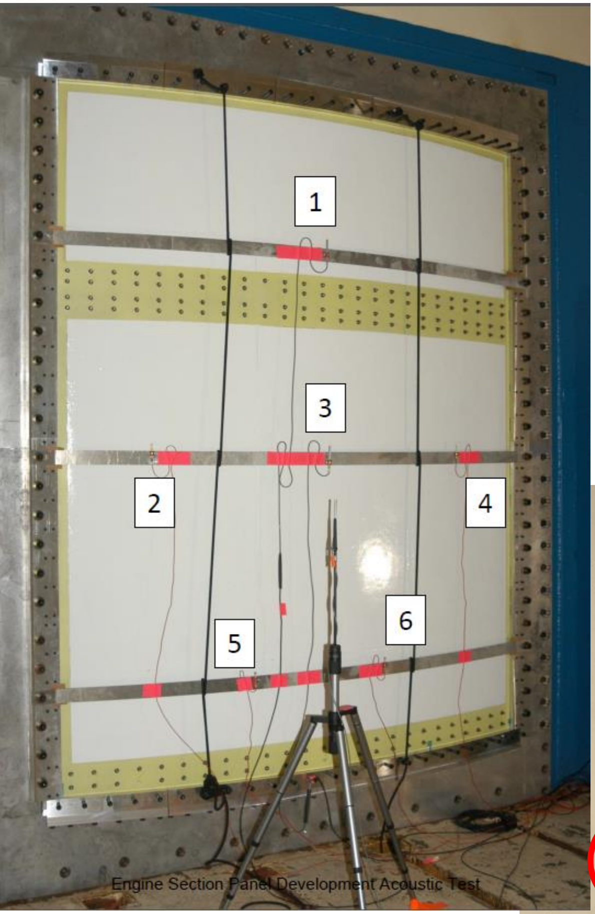
Agenda

- Introduction/Motivation - Use of the Lorch Results
  - *Comparison of measured average sound pressure levels (SPLs) in two reverberant rooms is the standard approach (Reference ASTM E90). Both Source room and receiver room are reverberant.*
  - *Lorch used an approach based on sound intensity that allowed the receiver room to be anechoic rather than reverberant.*
  - *Lorch's approach assumptions should affect the measurement setup for a transmission loss test.*
- Response Analysis Choices to Generate Hybrid Transmission Loss Estimate
- Panel Design Factors - Finite Element Model of Large Grid Test Article Panel
- Evaluating the applicability of a single panel transmission loss result for estimating the internal cavity acoustics of a launch vehicle compartment.
- Sound Power Estimates for Cavity Acoustic Response using VA one
- Conclusions and Forward Work

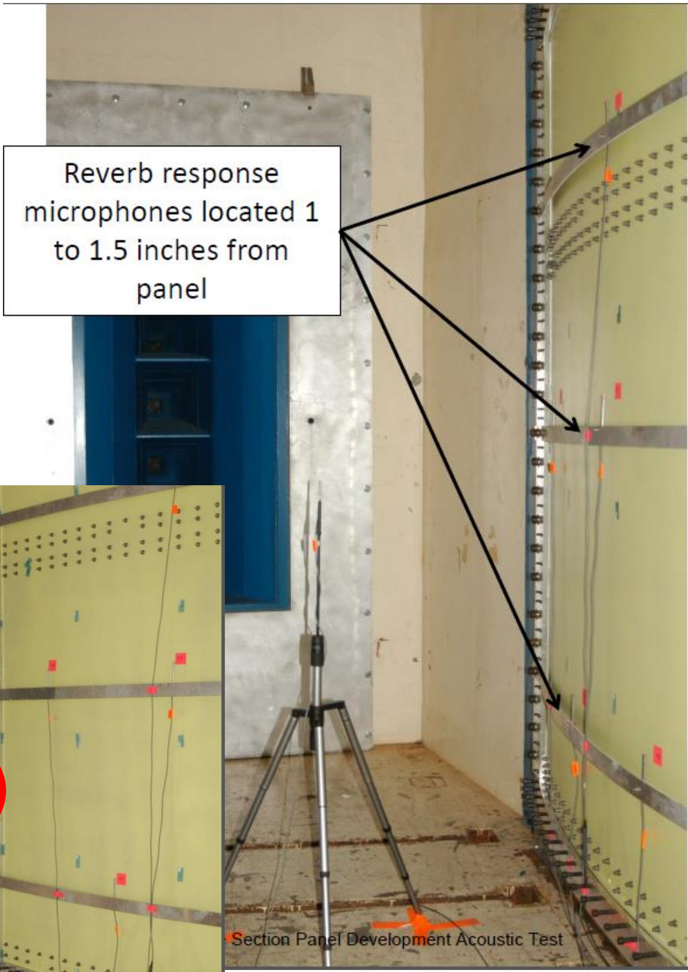
Introduction/Motivation
Use of the Lorch 1980 Published Results

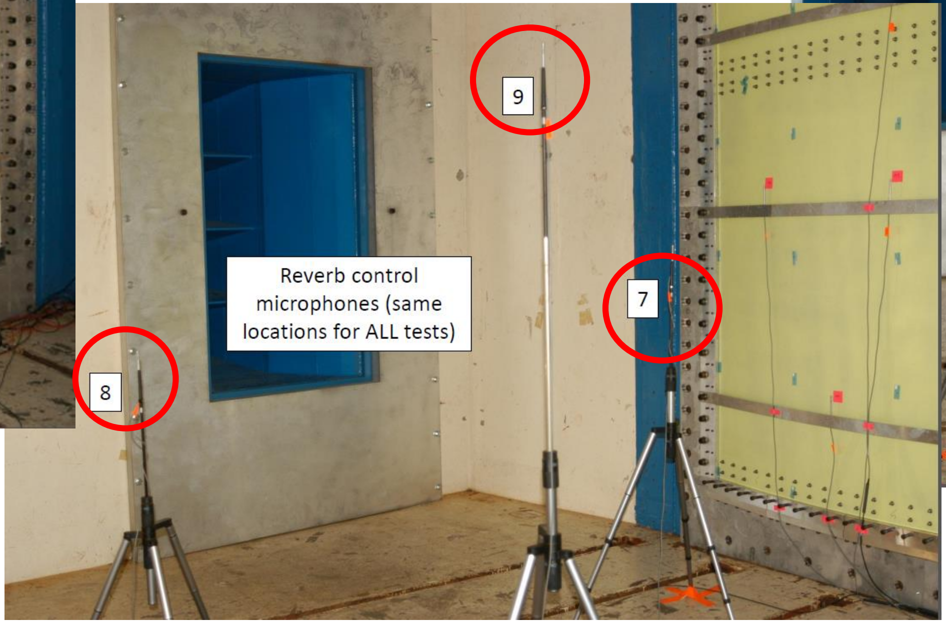
- Lorch, D. R., AIAA-80-1033, "Noise Reduction Measurements of integrally Stiffened Fuselage Panels," Douglas Aircraft Company, McDonnell Douglas Corporation, Long Beach California. AIAA 6th Acoustics Conference, June 1980.
- Lorch measured transmission loss across a panel separating a reverberant source room from an anechoic receiver room. This differed from the standard approach where both source and receiver rooms were set up to be reverberant.
- An attempt to verify the Hybrid Transmission Loss results using a NASTRAN FEM and VA One Diffuse Acoustic Field by comparison to the Lorch measured results.
- We have also examined his assumptions to provide a suitable test configuration in the MSFC facility. Similar to Lorch, MSFC has an anechoic chamber adjoining the Reverberant Chamber. The goal is to measure:
  - *The diffuse field in the source room*
  - *The plane waves radiated from the panel in the near field in the receiver room.*
- The published Lorch data provides an opportunity to evaluate/verify from measurements the estimate of "Hybrid Transmission Loss" produced using NASTRAN Modes as an input to VA One Response.
- We can also illustrate how useful the Transmission Loss (TL) results might be to guide a Cavity internal acoustics assessment.

Approach Assumptions Affect the Measurement Test Setup – Reverb Side



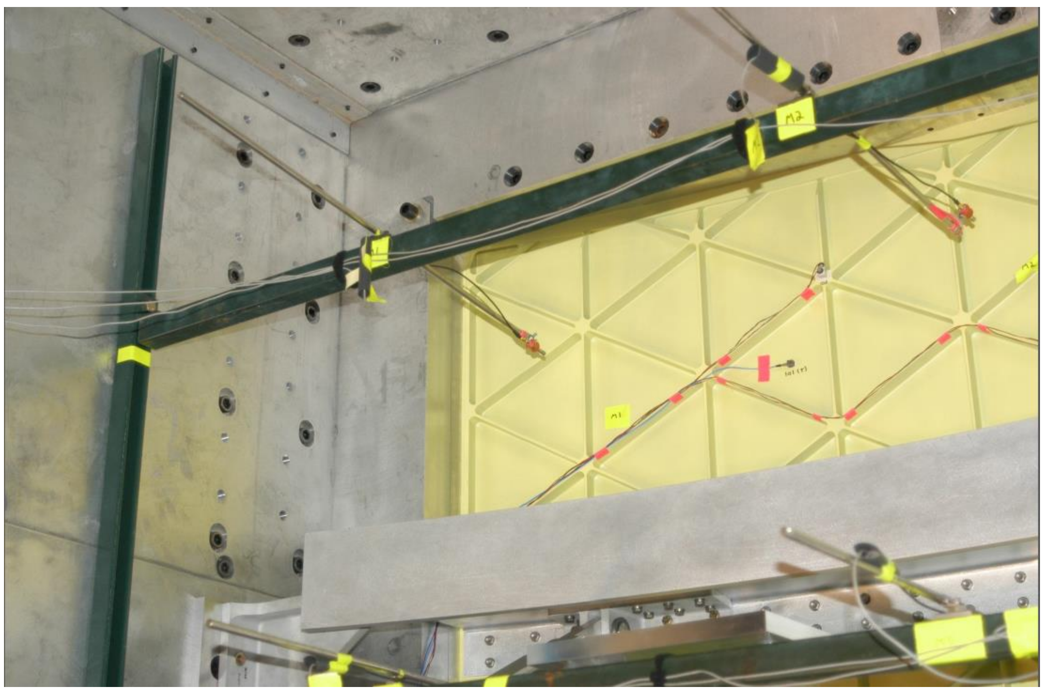
- 6 microphones 1 – 1.5 in from panel
- 3 microphones on tripod near center of room used to measure the Diffuse Field.

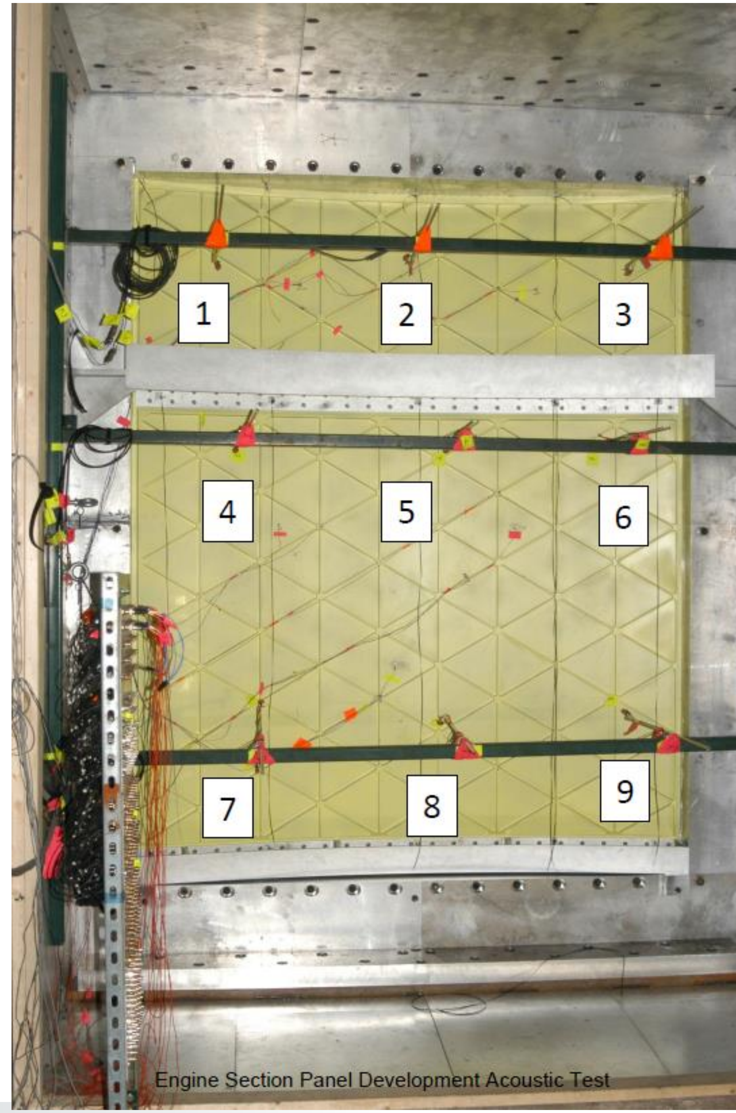




Approach Assumptions Affect the Measurement Test Setup – Anechoic Side

- 9 microphones located 1 inch away from interior panel wall. Used to measure the progressive plane waves radiated from panel.





Approach Assumptions - Lorch Equations

- Required equations for a reverb to anechoic chamber test setup

$TL = \bar{L}_S - \bar{L}_R'$

Not appropriate to measure Average SPL in Anechoic Receiver room.

In the source room, where a diffuse field exists, the acoustic intensity, I_S, is given by:

$$I_S = P_S^2/4\rho c \quad (2) \text{ Ref 6}$$

Assuming the sound traveling through the test panel propagates approximately as a plane progressive wave for a short distance away from the panel in the receiver room, then the acoustic intensity in this region is given by:

$$I_R = P_R^2/\rho c \quad (3) \text{ Ref 6}$$

The sound transmission coefficient is then determined by the ratio of space-averaged receiver and source room intensities, or

$$\tau = \frac{I_R}{I_S} \quad (4)$$

The sound transmission loss is calculated as follows:

$$TL = 10 \log \frac{1}{\tau} = 10 \log \frac{I_S}{I_R} \quad (5)$$

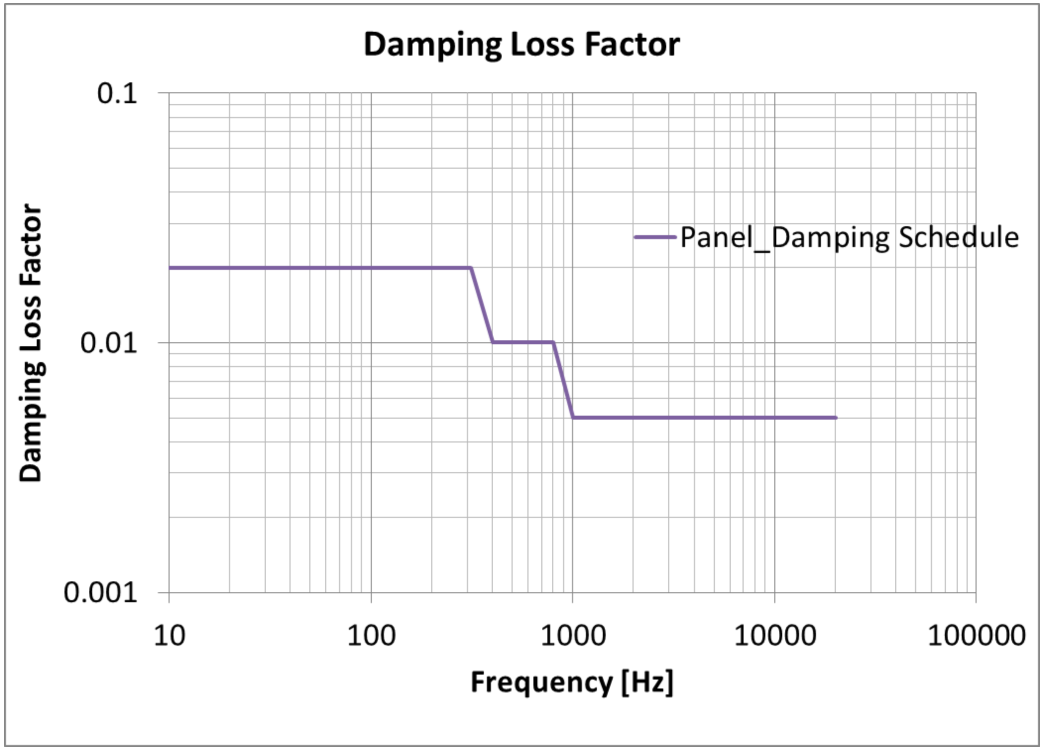
$TL = NR - 6$

NOMENCLATURE

τ	—	Sound transmission coefficient
TL	—	Sound transmission loss, dB
S	—	Area of sound-transmitting surface of test specimen, ft^2
A_R	—	Sound absorption of receiving room, sabins
$\bar{L}_S$	—	Average sound pressure level in the source room, dB
$\bar{L}_R$	—	Average sound pressure level in the receiver room, dB
$\bar{L}_R'$	—	Space-averaged sound pressure level near the test panel surface in the receiver room, dB
c	—	Speed of sound in air, ft/sec
I_S	—	Intensity in the source room, watts/ft^2
I_R	—	Intensity in the receiver room, watts/ft^2
P_S	—	RMS pressure level in the source room, μPa
P_R	—	RMS pressure level in the receiver room, μPa
NR	—	Noise reduction, dB
ρ	—	Density of air, lb_m/ft^3

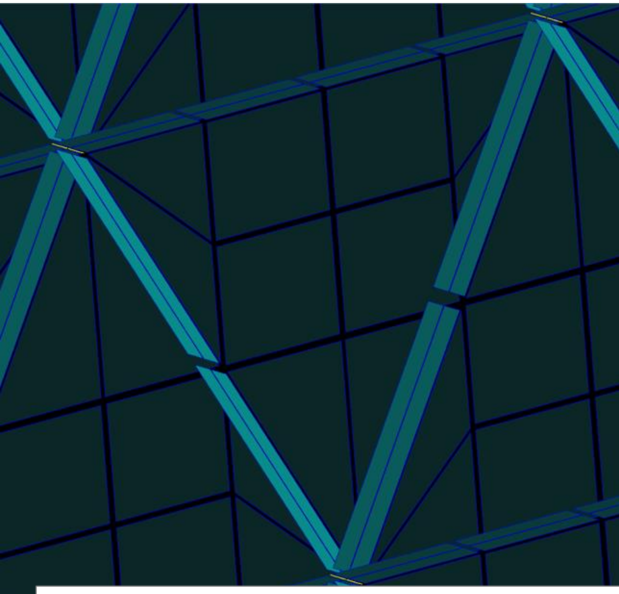
Hybrid SEA/FEM Response Simulation Choices
Lorch Transmission Loss Results

- The validation presented here addresses only the measured results published by Lorch for one of his Isogrid Panel test articles (Large Grid Test Article).
- FEM representing the Large Grid Test Article was prepared in NASTRAN, from the few details he tabulated in his paper.
- Important Factors for the Finite Element Analysis:
  - *Boundary Conditions*
  - *Damping*
  - *Frequency Resolution*
  - *Mesh Density*
  - *Forcing Function Patch Resolution.*



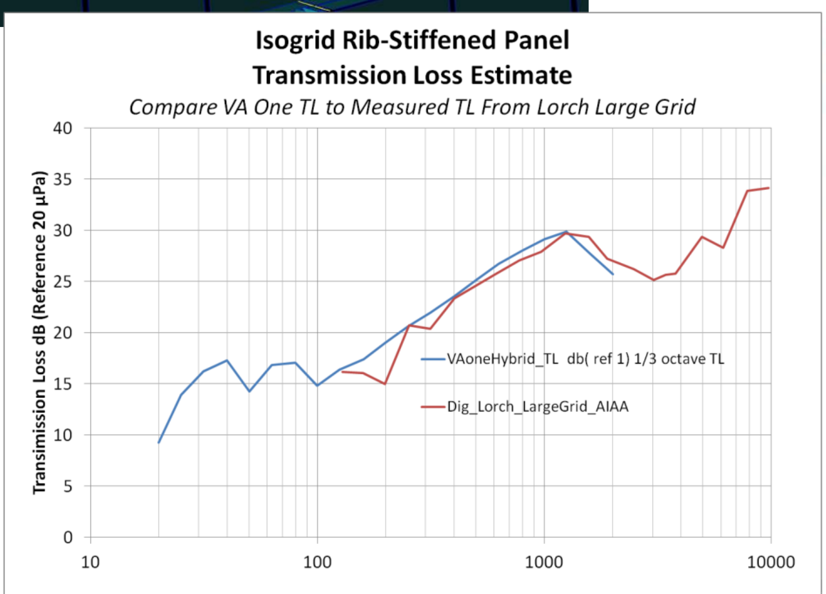
- Hybrid Transmission Loss was calculated in VA One using a 1/36th octave band resolution. Response was later filtered to convert it to 1/3rd octave for comparison to the Lorch published results.

Design Details and FEM Choices for Modeling the Large Grid Test Article



Approach validation Trials With the Similar Shell explicit FEM

- **Finite Element Mesh was made fine enough to include nodes in the interior of the isogrid cell in this case 4 nodes interior that are not congruent with the rib nodes**
- **The 4.16” triangle height was broken into four units in one direction and three units in the other direction.**
- **Structural modes may limit frequency range more than the forcing function resolution.**
- **Approximate 1 inch spacing between element centers corresponds to a patch density adequate for about 3000 Hz (Reference Smith 2013)**



Traingle Side, N	4.8	[in]
Traingle Height, h	4.16	[in]
Skin Thickness, t	0.069	[in]
Rib thicknes, b	0.075	[in]
Rib Depth, d	0.44	[in]

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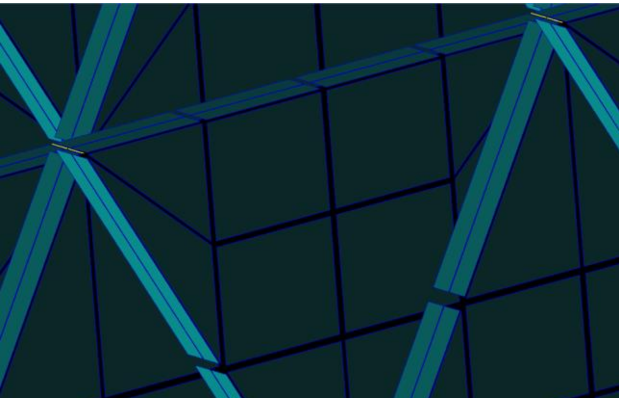
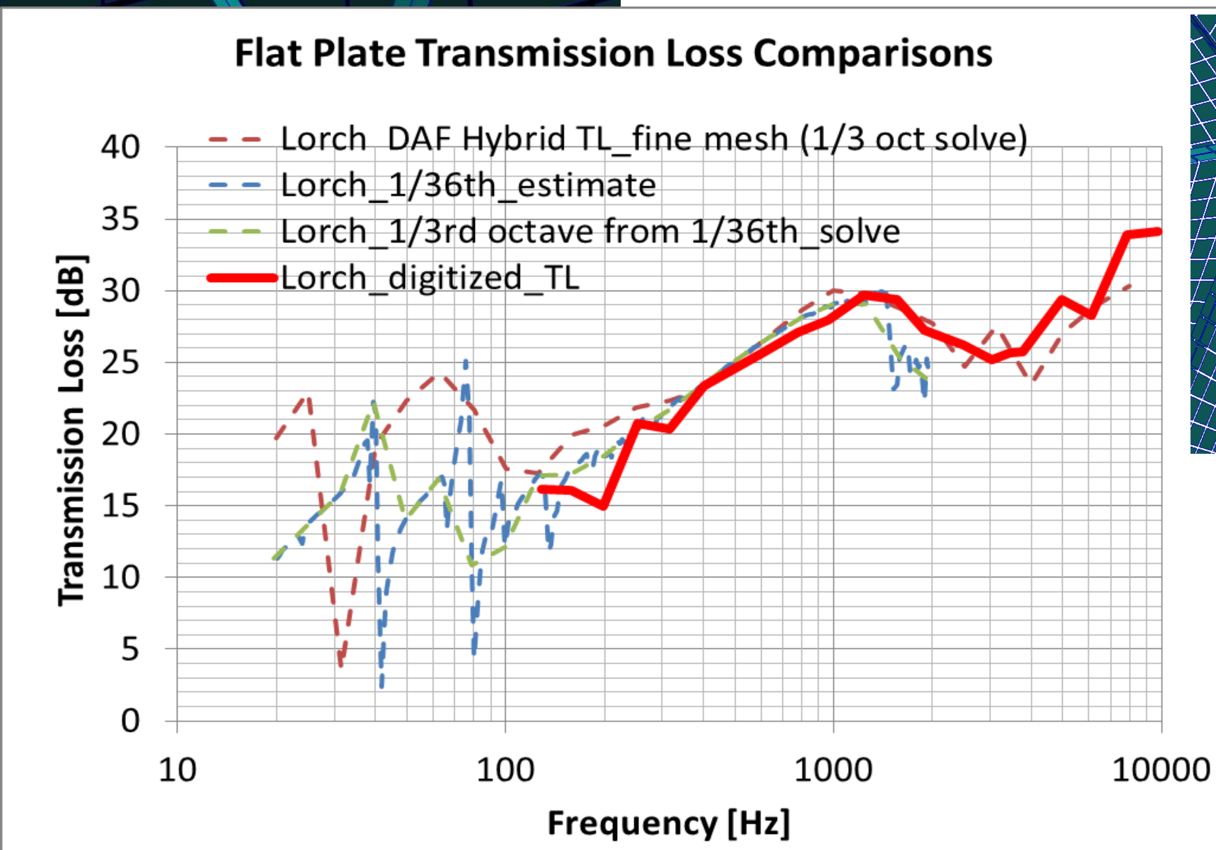
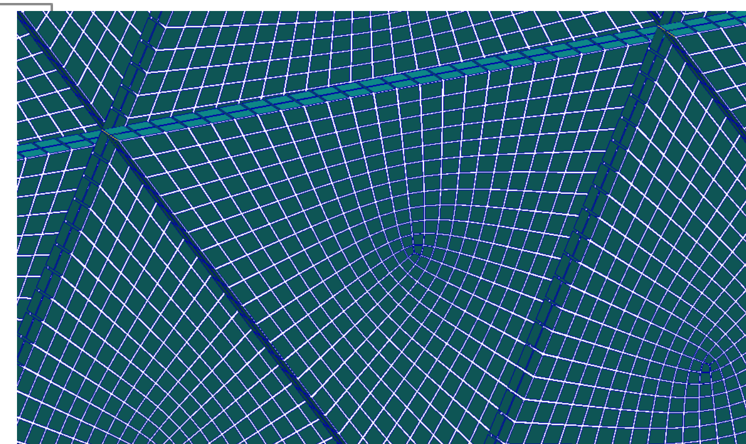
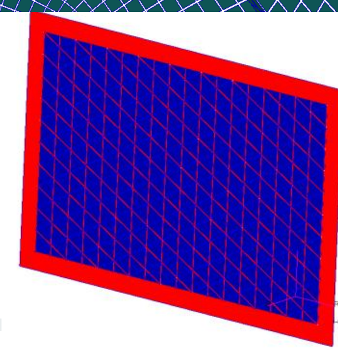
Comparison of Hybrid FE Results Estimating Transmission Loss to Measured



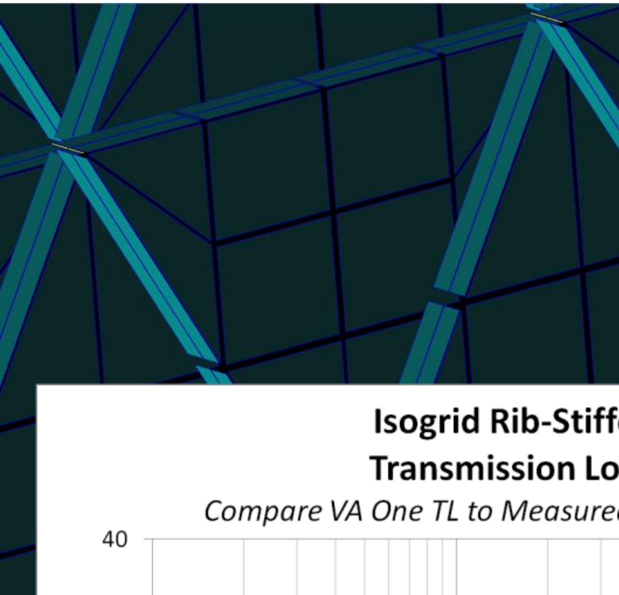
- **A colleague who became interested in our results, shared a variation where the mesh density of the FEM was refined in the hope of pushing the analytical assessment to Higher frequencies.**
- **Appreciation is expressed to Justin Harrison (CRM Solutions Incorporated) who shared the fine mesh results in time to include them here by permission.**





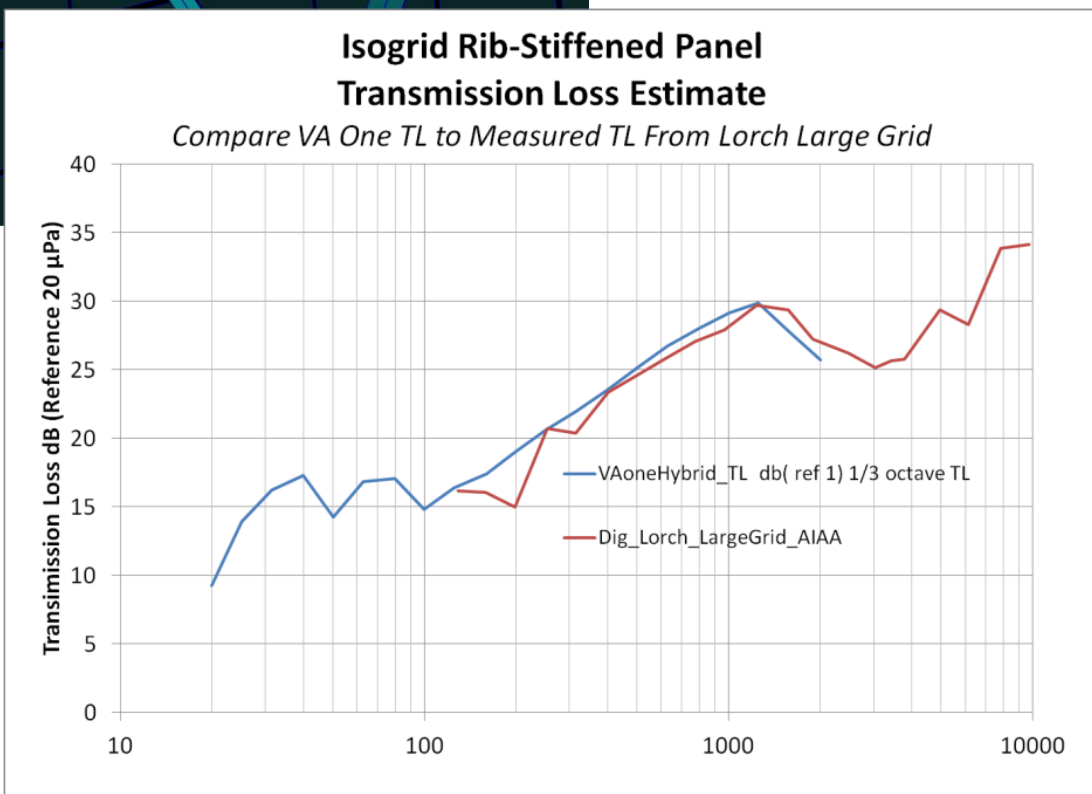


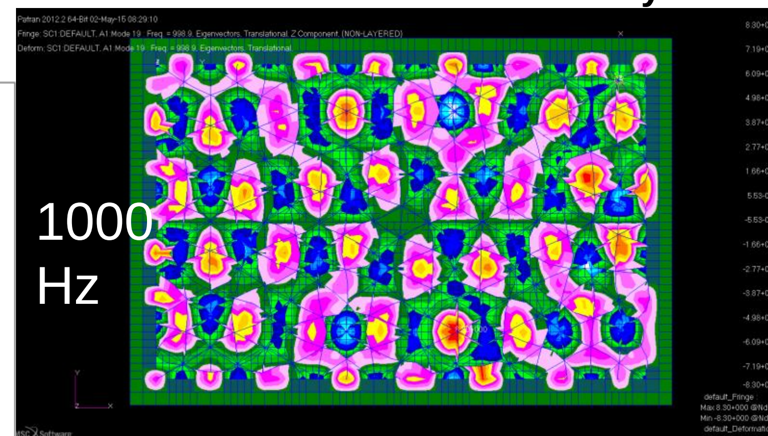
Panel Design Factors
Panel Bending Modes vs Pocket Modes

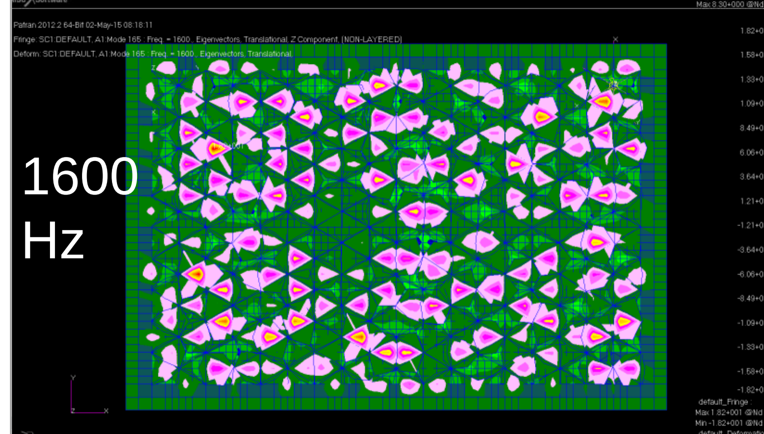


Approach validation Trials

- **The mass of the ribs is carried along in the Panel Bending Modes.**
- **The mass of the ribs does not participate once the wavelengths are short enough to set up Pocket Modes in the isogrid cells.**
- **Pocket Modes radiate sound to the interior more efficiently.**







Panel Design Factors

Determine Frequency Range Pocket Modes are Observed

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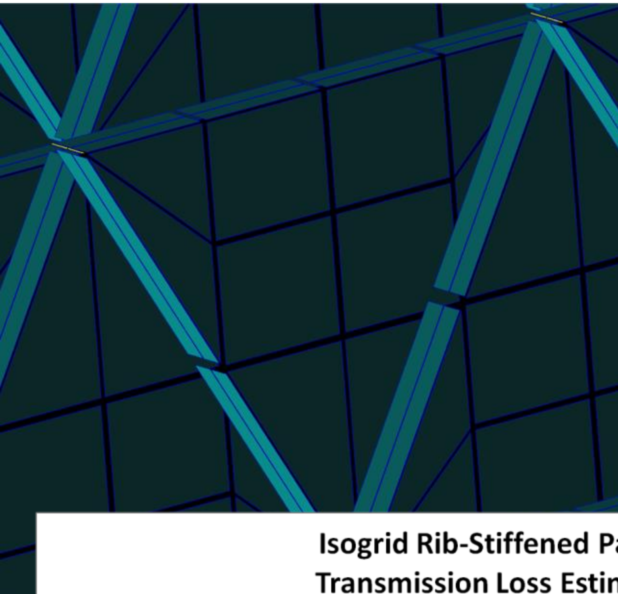
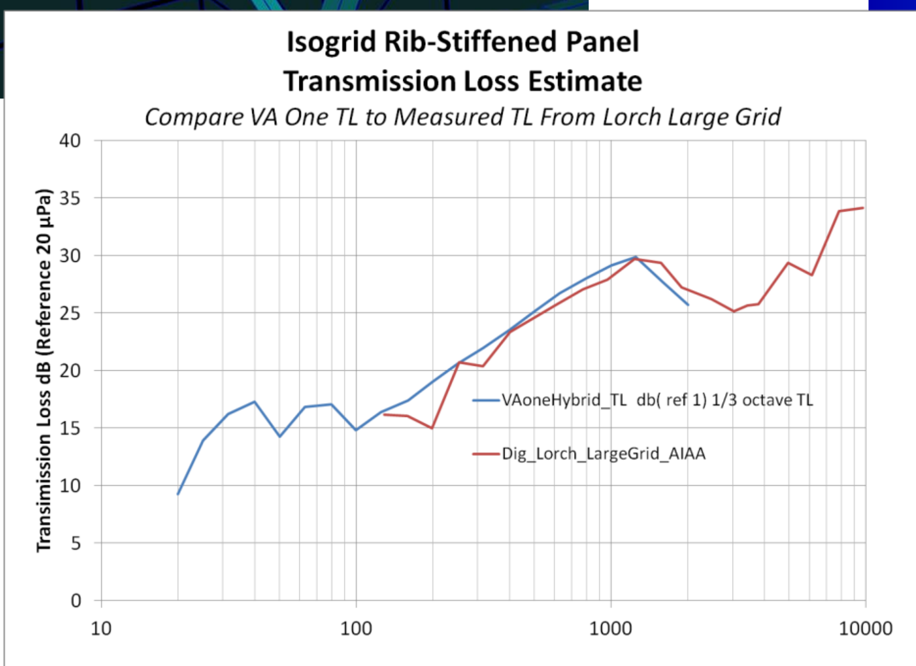
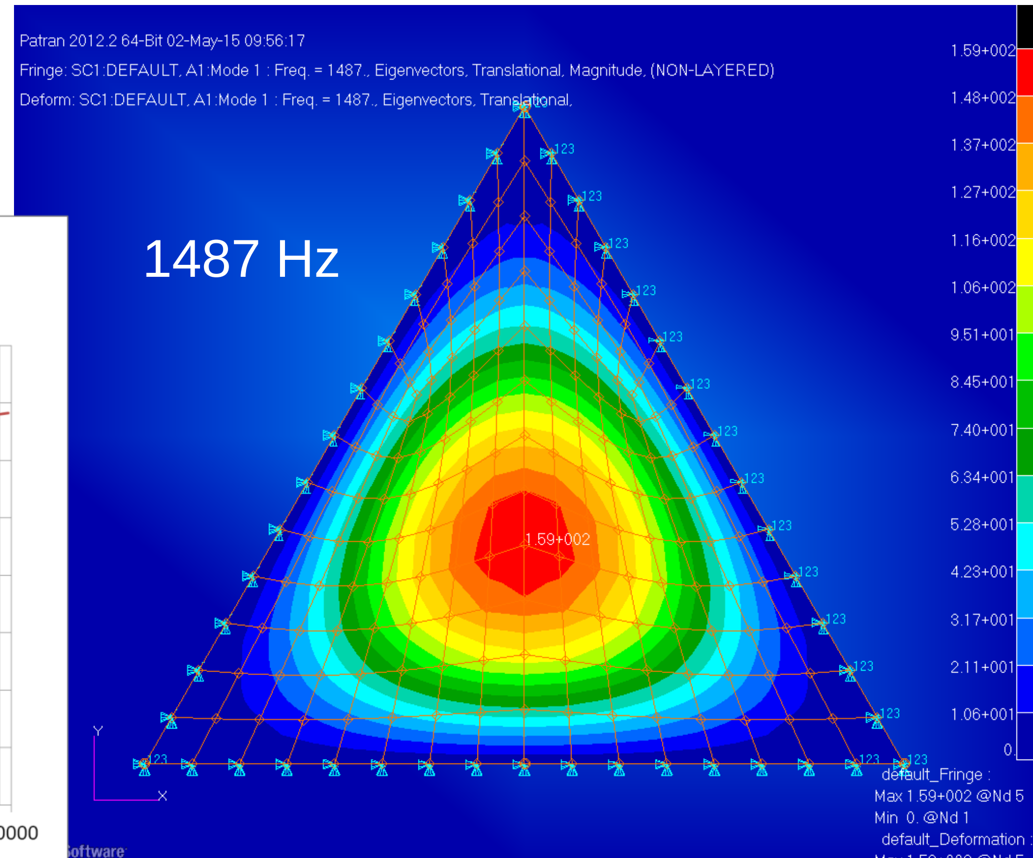


- Suggest simple estimate of the frequency range where pocket modes probably begin to diminish transmission loss.
- Calculate Fundamental Mode for **Simply Supported Equilateral Triangle** Using breakout model same material, pocket dimensions and skin thickness.





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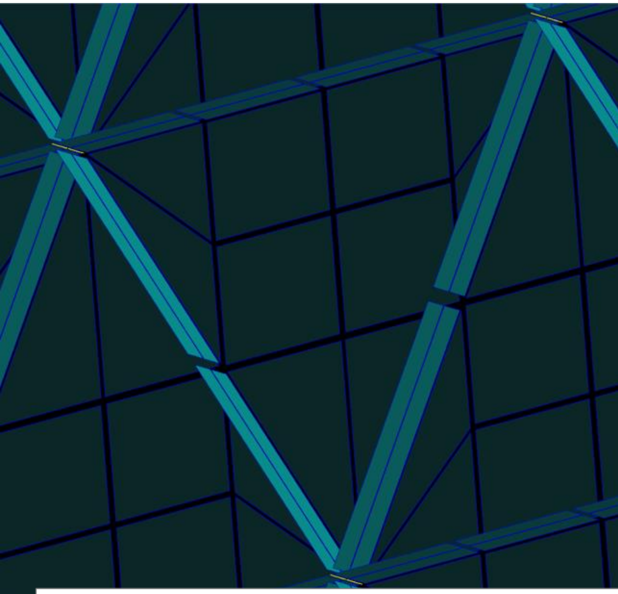
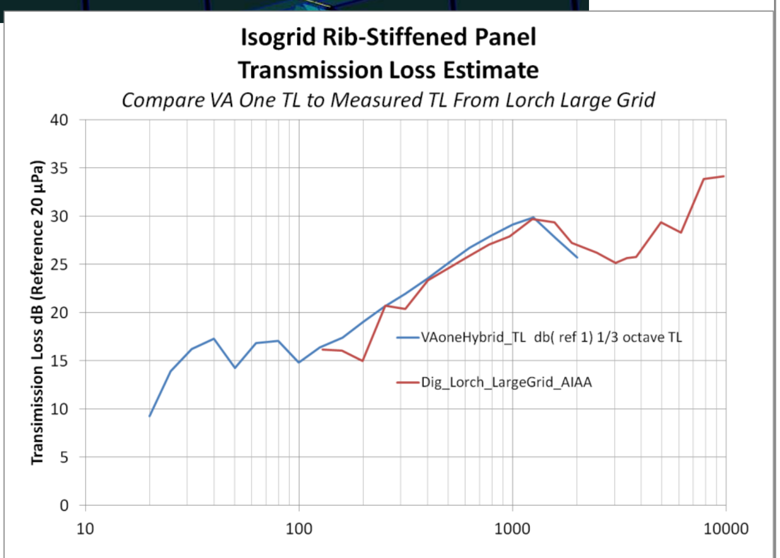
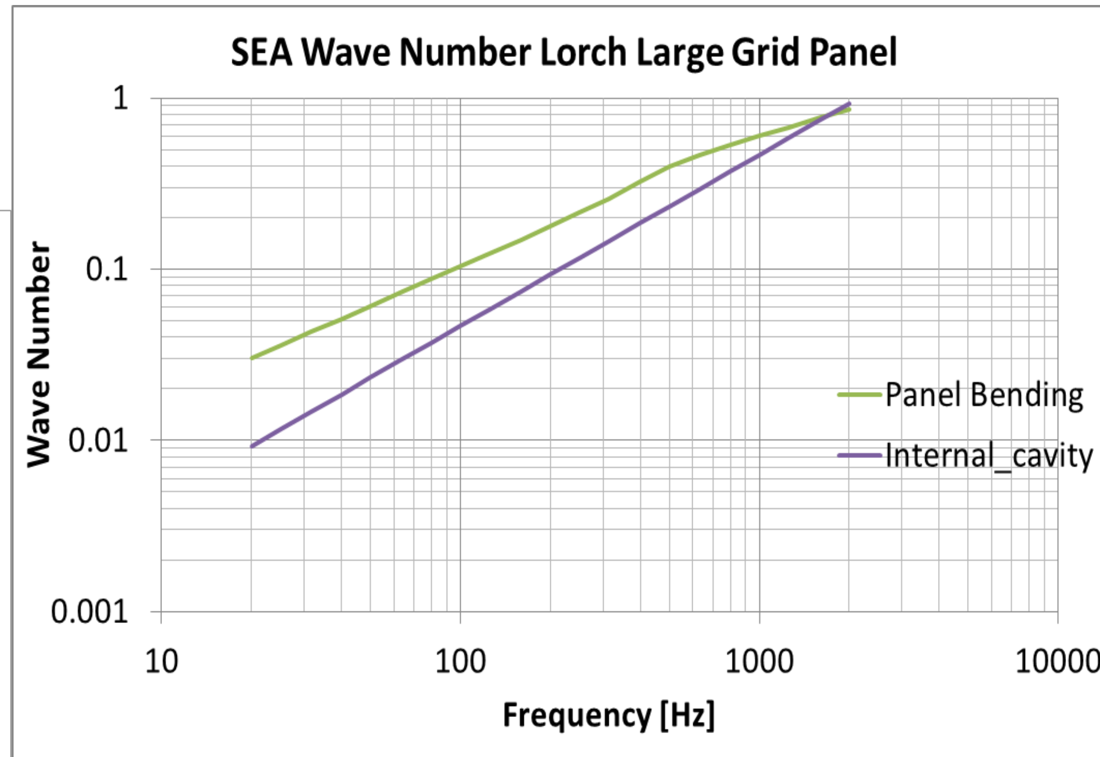
Panel Design Factors
Panel Bending Coincidence



SEA was used for a quick estimate of Wave numbers.

- **Fluid structural coincident frequency also may occur above 1000 Hz according to the smeared property estimate of the wave numbers**
- **Smeared properties follow the approach of the Isogrid Design Handbook (Reference Meyer 2004).**





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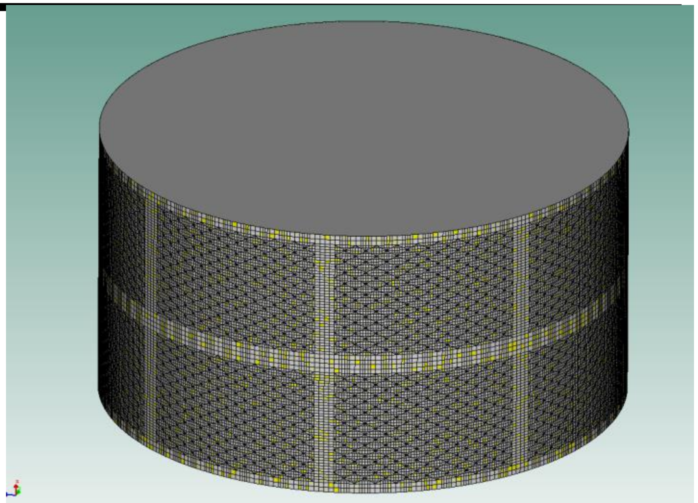
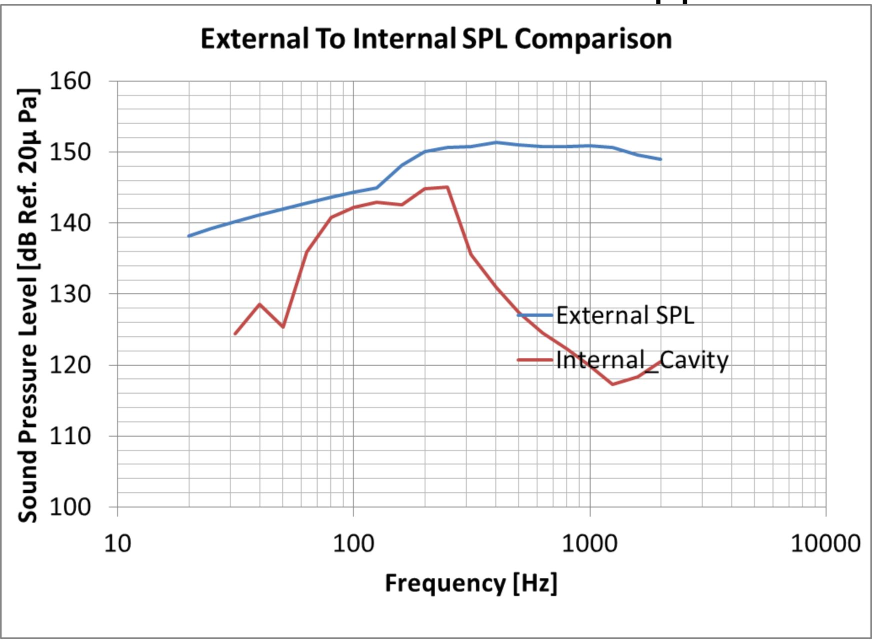
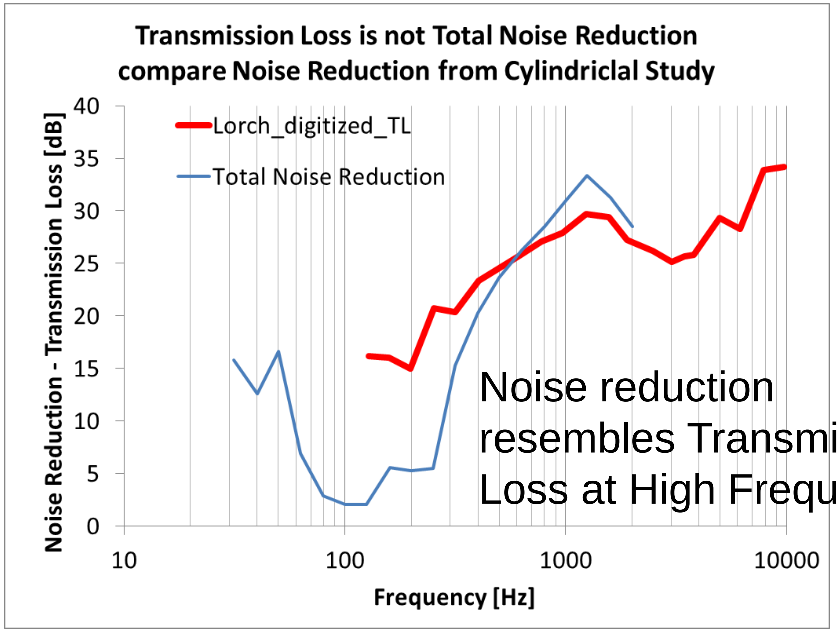
Hypothetical Launch Vehicle Compartment Assembly of 16 similar panels into Cylinder

- We can determine Total Noise Reduction from a Hybrid Analysis by subtracting the resulting estimate for Internal Cavity acoustics from the External Acoustic Excitation.
- Hypothetical Cylindrical Launch vehicle section fashioned from 16 panels with Lorch Large Grid design parameters. Radius 105.4 in. Height 112 in
- Identical DAF excitation applied to each panel.







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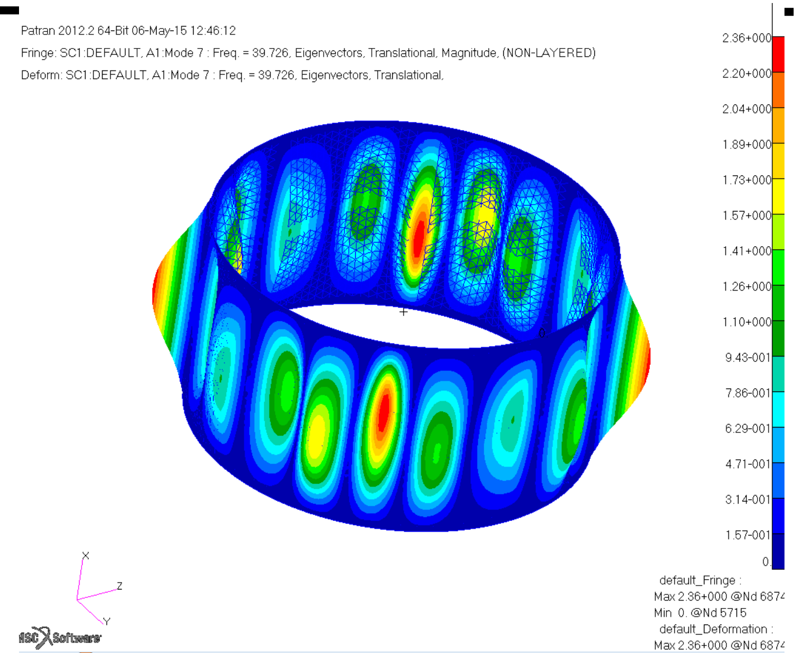
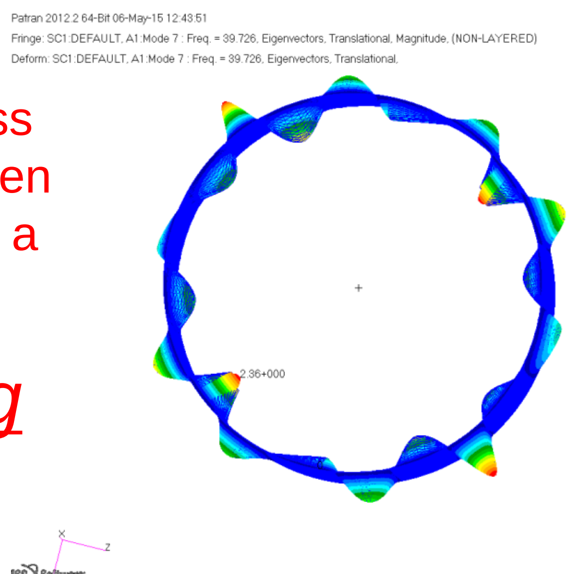
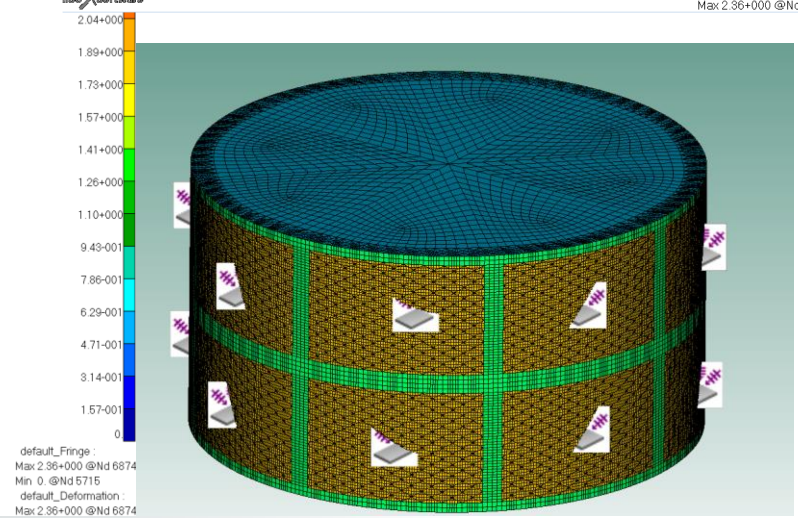
Is Single Panel Measured TL useful for Assessing Cavity Acoustic Environment?

- In this example, the boundary conditions for the panel have changed fairly drastically from the Flat Panel Test.
- The single panel had been clamped on four sides. In this integrated configuration it is welded to the next panel on 3 sides.
- The mode shapes that span two panels axially were not possible in the Lorch Flat Panel Test Configuration.







The transmission loss results may have been more transferable to a

Design that included *Ring Frames.*

Measured Panel Transmission Loss was not so helpful in the Low/Mid Frequency Range?

- In the first Cylindrical case assessed the Transmission Loss seems to be a helpful predictor only at frequencies from 700 to 1000 Hz.
- In the Cylindrical Hybrid FEM analysis, the estimated internal acoustics respond quite close to external acoustics in the range from 100-250 Hz. Seeming to contradict both the transmission loss test and the matching single panel Hybrid FEM analysis.
- A quick assessment using SEA to estimate Panel and cavity wave numbers (slide 12) seems to indicate that the diffuse field should be very inefficient eliciting resonant response from the structure in the 100-250 Hz range.
- We turn to Finite Element Analysis to provide more information.
  - *Boundary conditions and system architecture effects can be understood from the mode shapes of the cylinder we are assessing.*
  - *Mode shapes in this unsupported architecture tend to span across two panels in the axial direction.*
  - *This ability to develop large bending shapes across two panels was not possible in the smaller clamped panel configuration of the transmission loss test.*

Lorch Panel adjustment Flat to Curved
16 similar panels used to build up Cylinder

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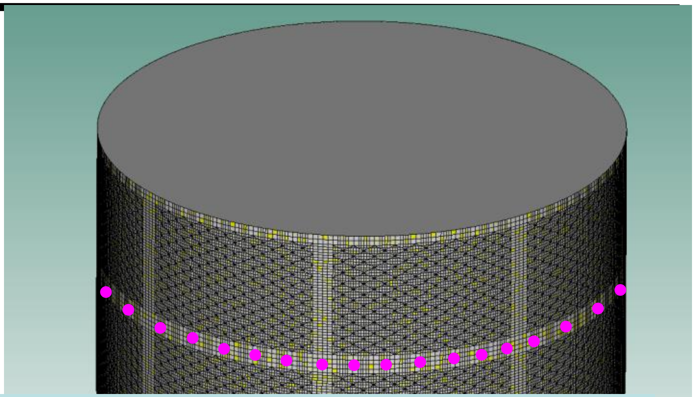
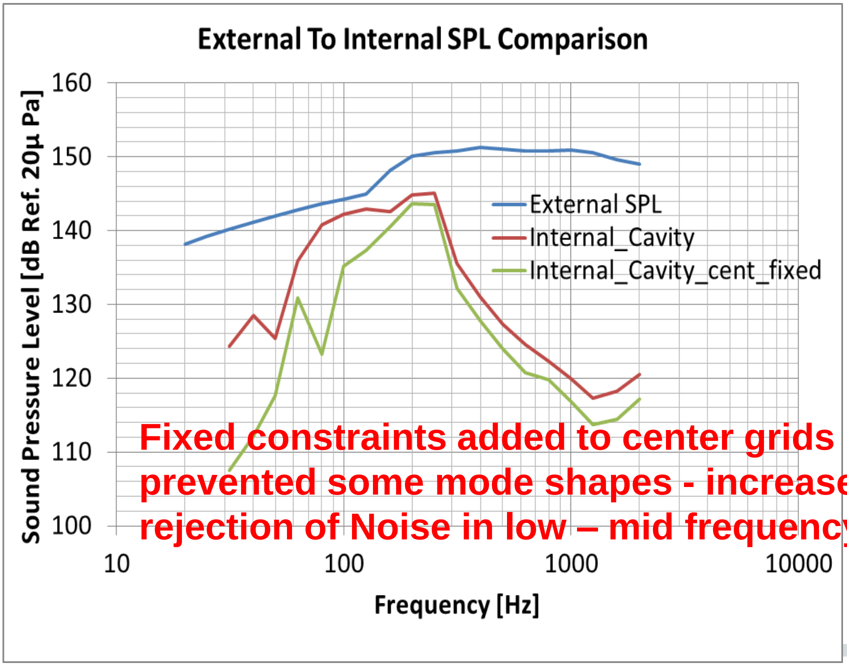
- At High frequency the TL could be used in the typical Sabine equation where other factors such as the cavity fluid and surface absorption are added to the TL as additional sources of noise reduction.
- Cavity absorption was assumed at 1% in the analysis there were no treatments applied to the surfaces of the panels.

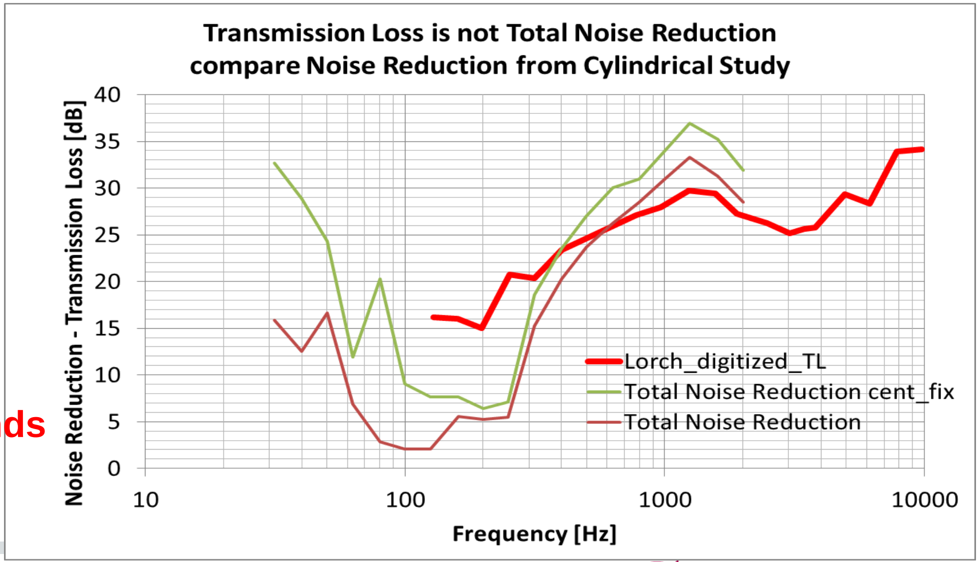


Constraint added along midline between fwd and aft welded panels approximating a ring frame effect on panel modes.



Fixed constraints added to center grids prevented some mode shapes - increased rejection of Noise in low – mid frequency bands

The measured TL acts like cylindrical vehicle Total Noise Reduction over the frequency range from 700-2000 Hz.



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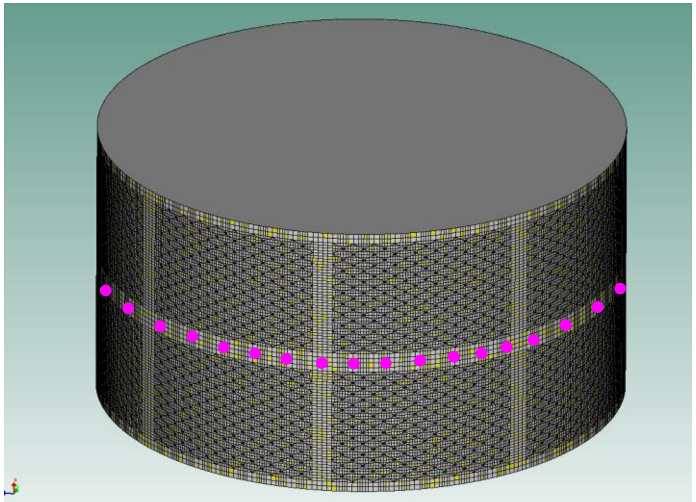
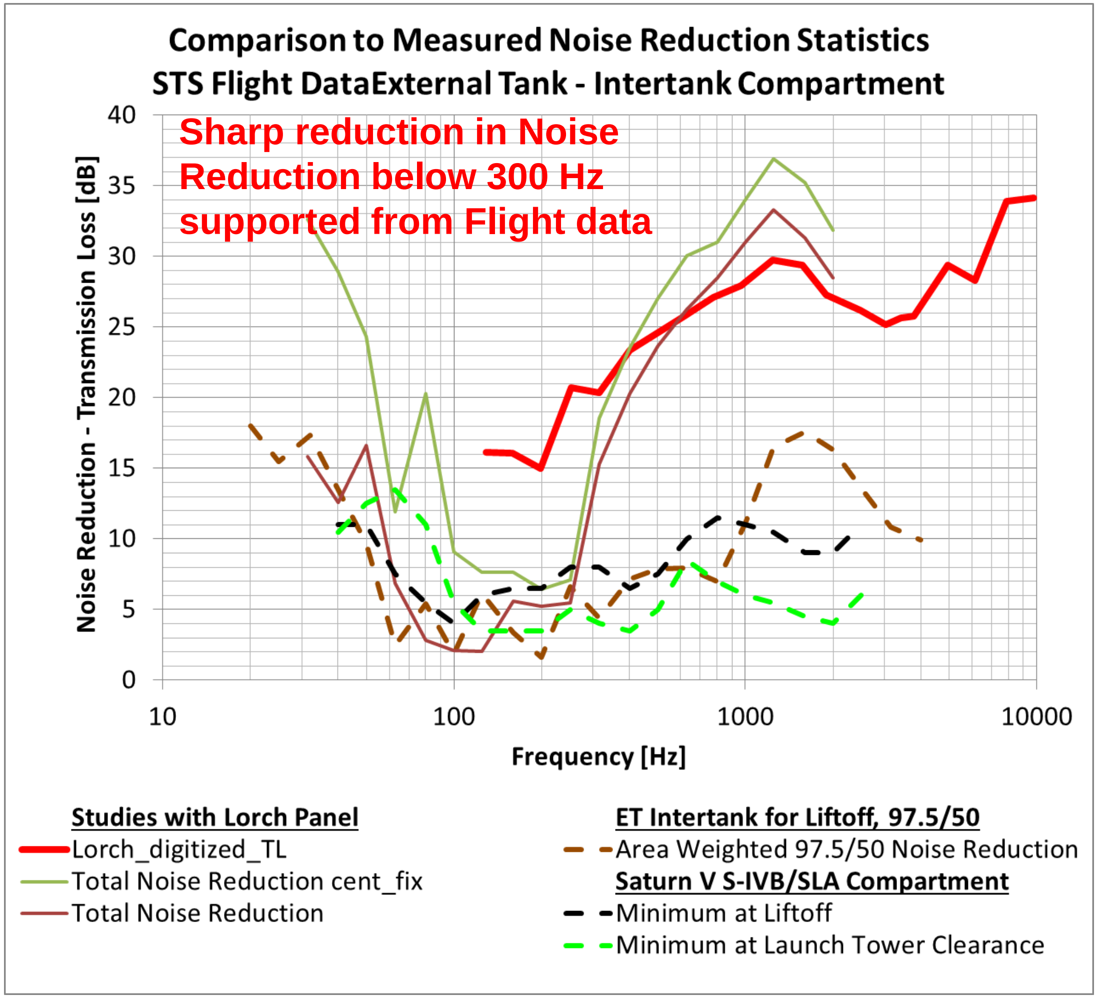
Compare Noise Reduction Estimate to Measured Statistics From Development Flights

- The STS & Saturn V data seems to confirm that a cylindrical vehicle compartment can be fairly transparent to sound in the Frequency range from 80-250 Hz.
- Also, a corresponding increase in noise reduction in the lowest frequency bands seems consistent with these STS observations from measured data.

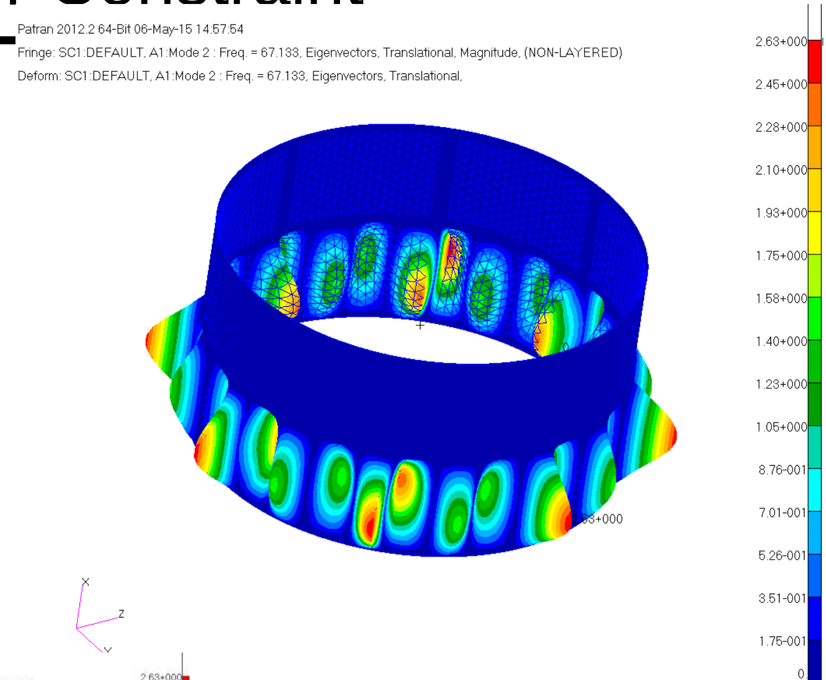




The Noise Reduction Estimates from Lorch Panel Studies remain consistent with Single Panel Transmission Loss spectrum shape in bands from 500-2000 Hz.

Cylindrical Assessment Modes With Additional Center Constraint

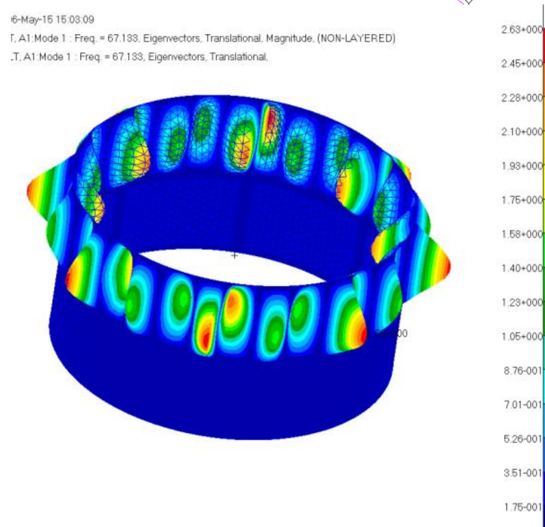
- A NASTRAN Trial was made where the central nodes dividing the cylinder forward and aft were fixed.
- This resulted in mode shapes that are more like the flat panel modes apparent during the flat panel test.
- If the vehicle incorporated ring frames that might be sufficient to make the test results more useful for Launch vehicle estimates.

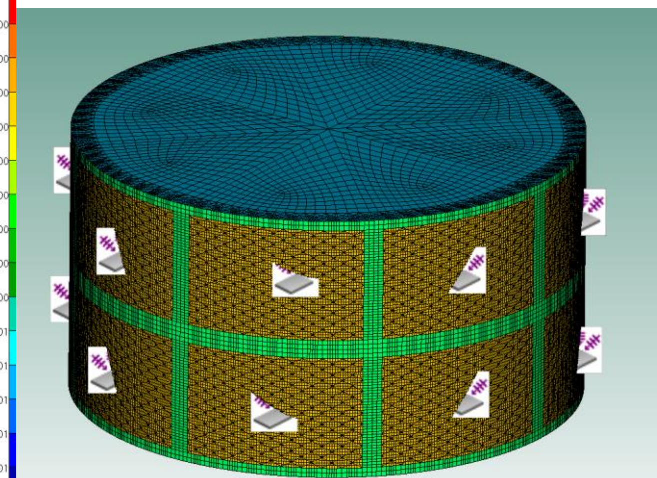


Suggested Lessons:

Choose the right test article to assess your vehicle architecture.

Avoiding Longer bending modes using frames can make a vehicle section better able to reject sound energy.





Was the Measured Panel Transmission Loss a useful guide in the Low to Mid Frequency Range?

- Perhaps we can say that The measured TL approximates the Noise Reduction for the hypothetical cylindrical vehicle within 2-3 dB over the freq. range from 300-2000 Hz.
- Also, it was observed that at High frequency the TL resembled the shape of the total noise reduction, but was lower in magnitude than the Total Noise Reduction only at High Frequency.
  - *The Transmission Loss provided by the panel is only a portion of the total noise reduction.*
  - *Other factors such as absorption by the cavity fluid, and absorption by the surfaces bounding the cavity also contribute to the total noise Reduction.*
  - *The simplicity of the Hybrid Response Analysis that developed the internal acoustic noise estimate may have contributed to the dip of Total Nosie Reduction below measured TL.*
    - Coupling loss reduced by the absence of forward or aft structures
    - No treatments were applied to surfaces. 1.0% absorption is a minimum typical of a reverberant chamber from T60 tests. We expect launch vehicle compartments to contribute more.
- Similar results have come to light where low Noise Reductions Measured in the mid frequency range from Saturn V and STS Flights.
- Since the modes shapes of the panels will be somewhat different in any vehicle assembly, we should, therefore, recognize that measured TL will most useful in mid-to-high frequency range.

Conclusions and Forward Work

- Hybrid Transmission Loss calculations using VA One were verified using Lorch's Measured results were verified for a rib stiffened Isogrid Panel.
  - *Finite element model must include nodes at the center of each Cell.*
  - *Damping, Mesh Density, and frequency resolution , corresponding to the analytical solution were provided.*
- Demonstration of how the measured transmission loss from 1 flat panel might feed into a system assessment estimating internal cavity acoustic environments.
  - *Transmission loss is not total noise reduction.*
  - *Transmission loss can be used to help define the terms of a power balance equation, where all the loss factors are included.*
- When making use of TL from test verify that the test article and system architecture compare well to support the objectives for the test. Since Hybrid Transmission Loss Predictions are becoming fairly reliable, be sure to match your vehicle architecture when conducting breakout studies.

Conclusions and Forward Work

- Impact of Lorch's assumptions/ methodology on test setup's was explained. Placement of microphones is important:
  - *Goal is to measure diffuse field on reverberant side of panel. Microphones sample field at least 30 inches form walls and surfaces.*
  - *Goal is to measure plane waves amplitudes radiated on Anechoic side in Receiver room.. Microphones sample field at close spacing to the panel.*

- Forward Work:
  - *Account for Venting and Other Effects that make an actual vehicle compartment different that the simple cylinder assessed.*
  - *Develop better understanding of the Surface Absorption effects.*
  - *Develop understanding of Transmission Loss and Noise Reduction for such pressure fields as are present at Transonic and Max Q.*

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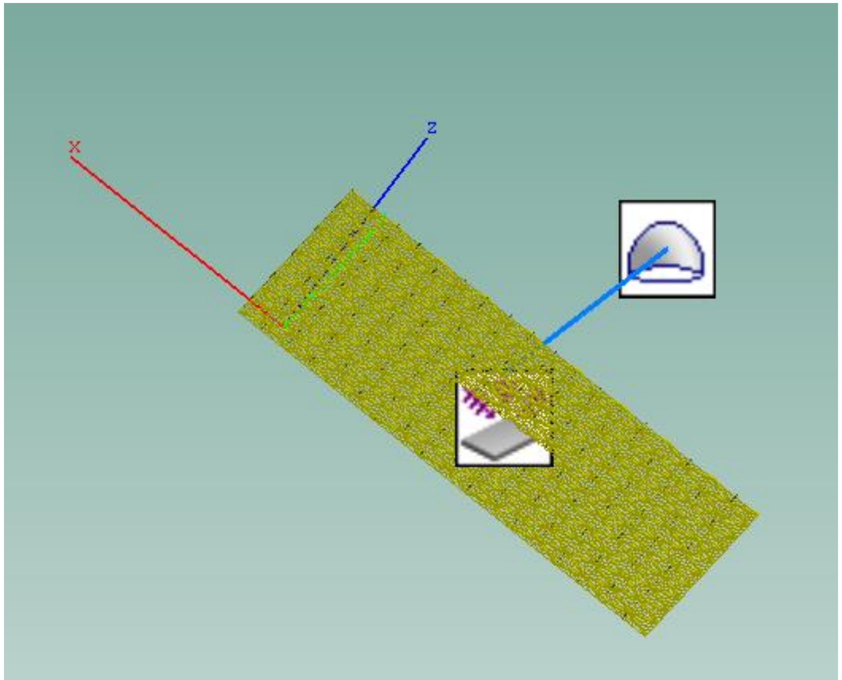
Backup Slides



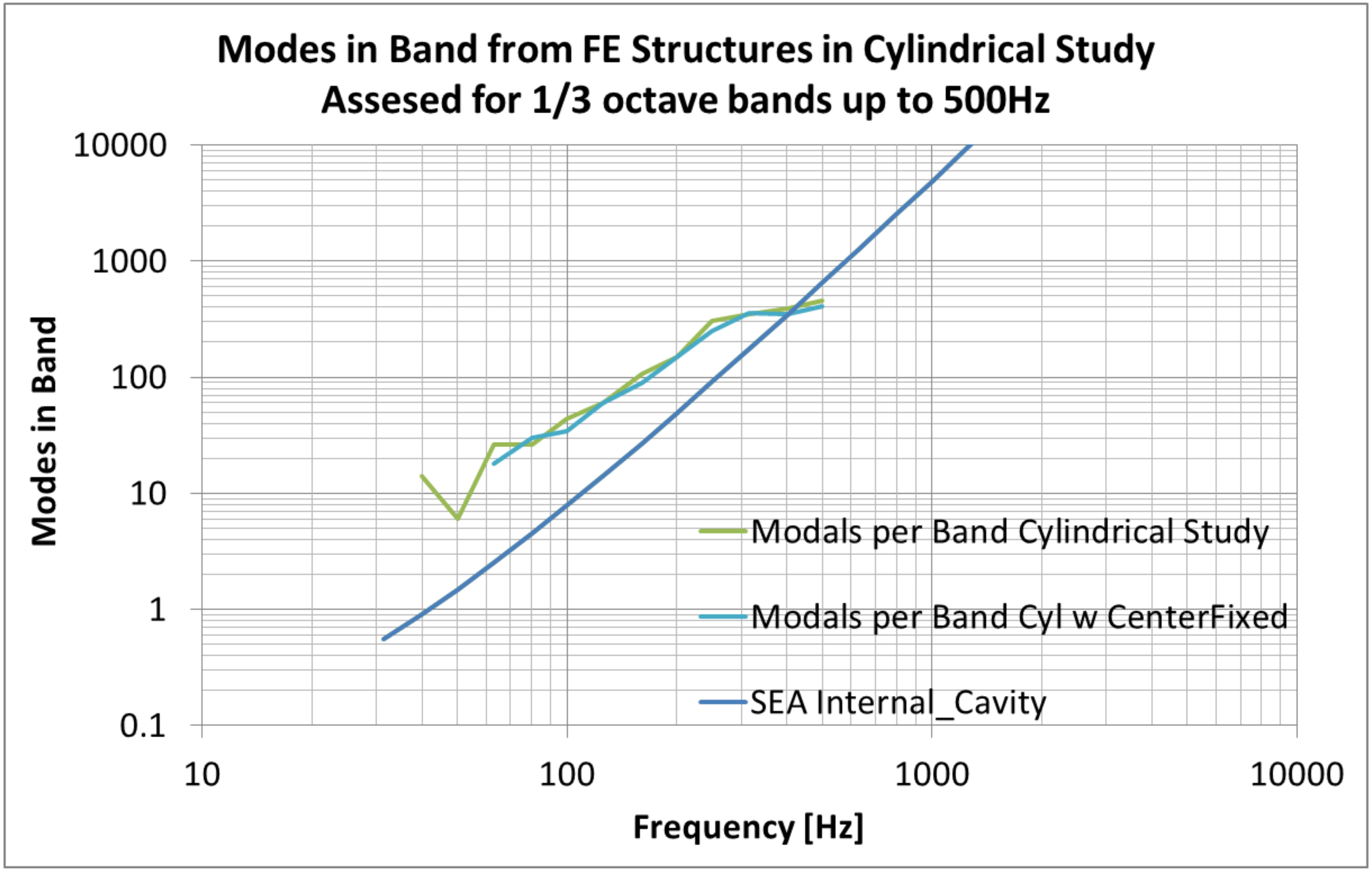
Hybrid Transmission Loss Studies are Simple Assessments:

- FE of Partition
- SEA DAF applied Excitation to one side
- SEA SIF Receiver attached to opposite side

Adaptable to more than Just Flat Panel studies.

Consider Hybrid Transmission Loss Studies for larger more complex subsystems.

Modes in Band for the Cylindrical Studies



"Validation of Transmission Loss Simulation Approach with Goal to Estimate Launch Vehicle Internal Cavity Acoustics"

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