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Structure-Acoustic Validation of an un-Pressurized Airplane Cabin Section Using MSC Nastran

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Abstract

To better understand the vibration & noise in passenger cabin, a typical fuselage section equipped with nearly full interior was tested and analytically studied using NASTRAN. The test results validated the FEM model predictions to 100 Hz that is more than twice the N1 engine speed for wide body aircraft. The results of this study validates that accurate vibro-acoustic predictions can be made using existing NASTRAN FEM capabilities. Such strong test-analysis agreement builds confidence in modeling of complete airplanes that are used to simulate the flight tests for structure-borne noise studies, and will remove some uncertainties in the structure-acoustic predictions.

Outline

- Introduction
- Models
- Analysis
- Conclusions
- Recommendations

Introduction

- Engine Vibration Related Noise (EVRN) is primarily structure-borne, caused by the engine unbalances and can create ride discomfort in terms of 'noise & vibration' in the passenger cabin
- A typical coarse grid FE model can be utilized to accurately predict the vibro-acoustic response in the cabin caused by EVRN type of excitation as long as the load paths of the primary and secondary structures and interface mechanisms to the fluid are properly modeled
- Proper modeling of the secondary structures such as stowage bins, trim panels and sidewall systems are important to achieve accurate results within this frequency range
- The cabin airspace acoustic model, on the other hand, can be relatively simple
- The modeling philosophy was based on typical dynamic modeling concepts within the NASTRAN standard environment. Therefore special DMAP, exotic techniques, and use of specialized third party software were not necessary to achieve accurate results.

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Boeing Interior Noise Test Facility (INTF)
Aft Section of typical airplane cabin

Cargo door, windows

Boundary Conditions (cradle foam)

Stowage bin, trim panels

End cap acoustic blankets

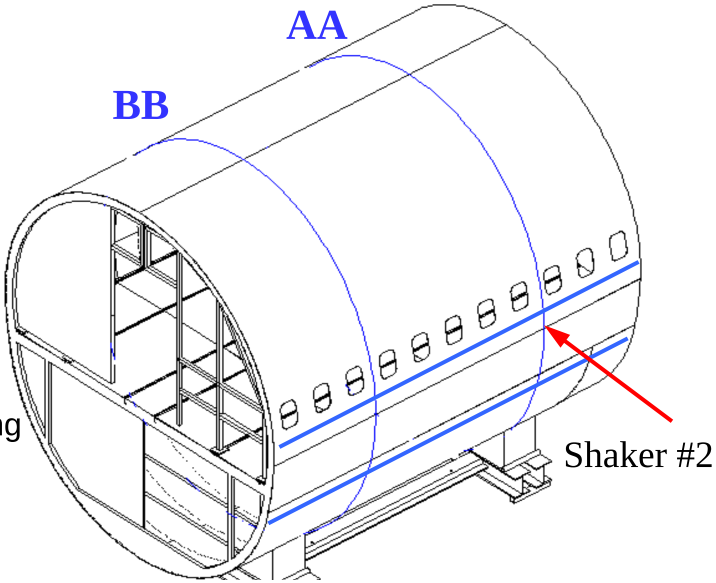
INTF Lab Setup (Boeing Anechoic Chamber)

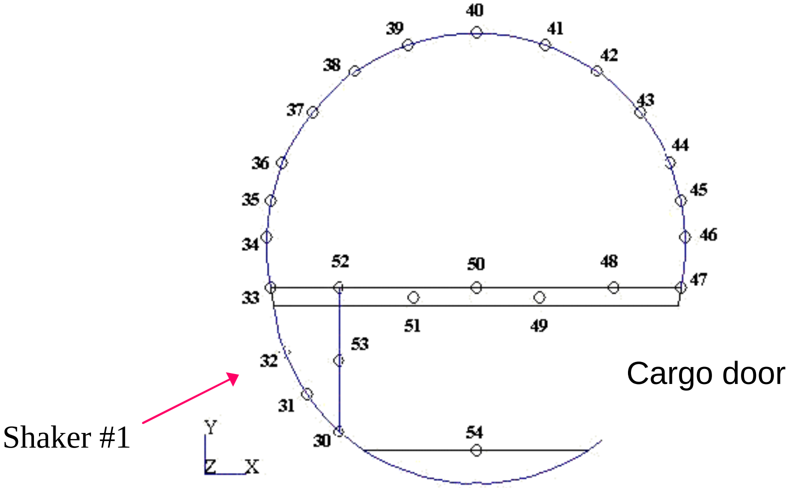
Test Article:

- Cut out Aft fuselage Sec 46
- 11 frame bays
- Seats were removed
- Unpressurized

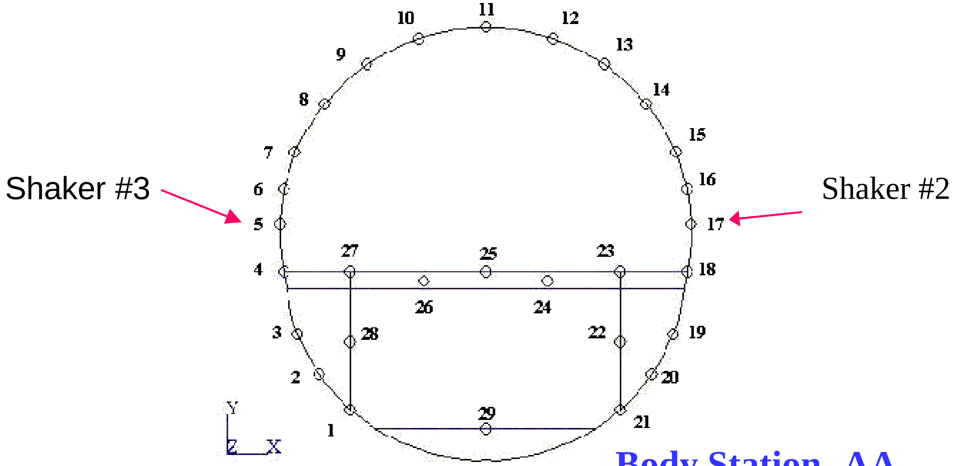
Anechoic Chamber: fiberglass acoustic absorptive wedges on walls and ceilings and floor isolated from rest of building

(58 ft long, 41 ft wide, 34 ft floor to tip of ceiling wedges)





Body Station - BB



Body Station -AA

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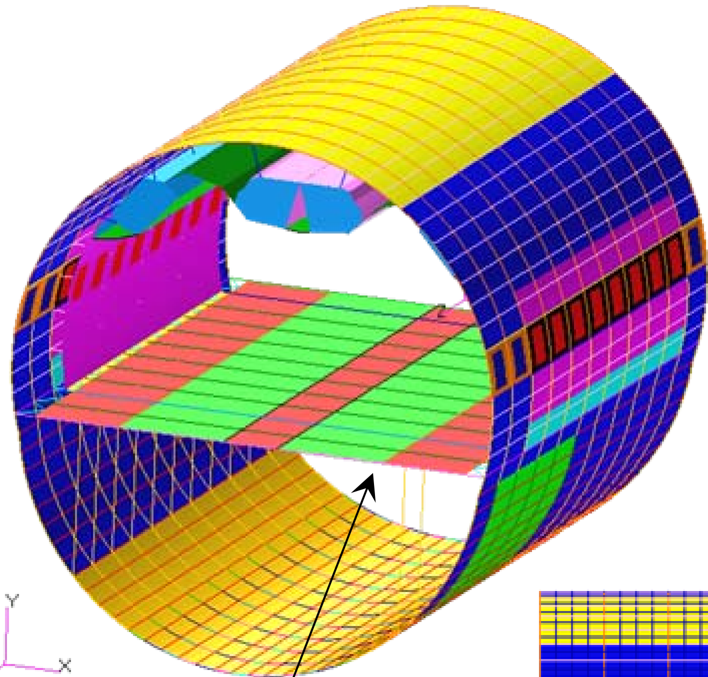
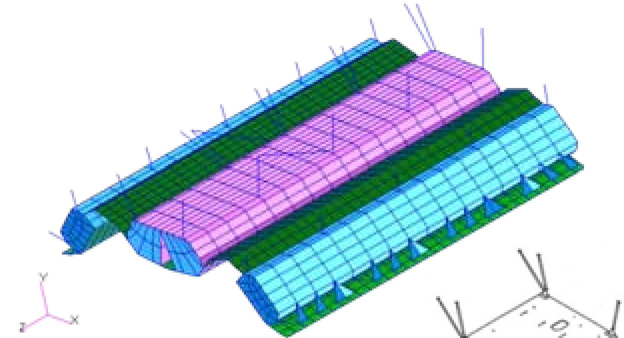
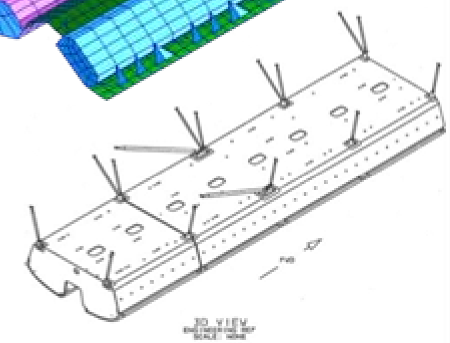
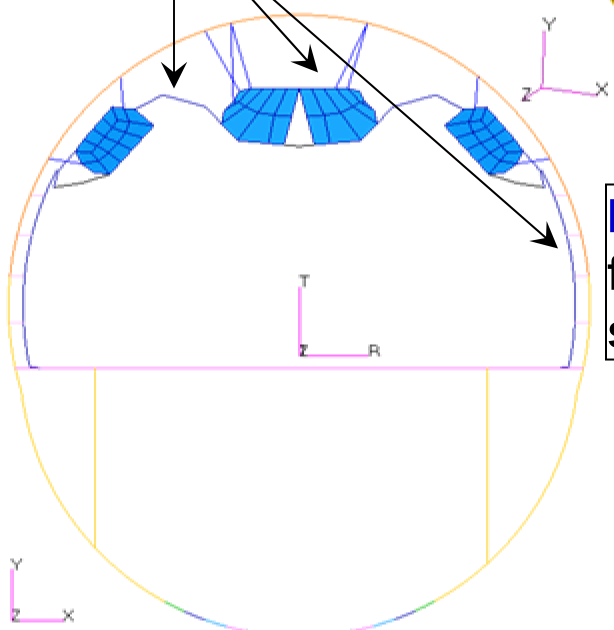
Structural Mesh



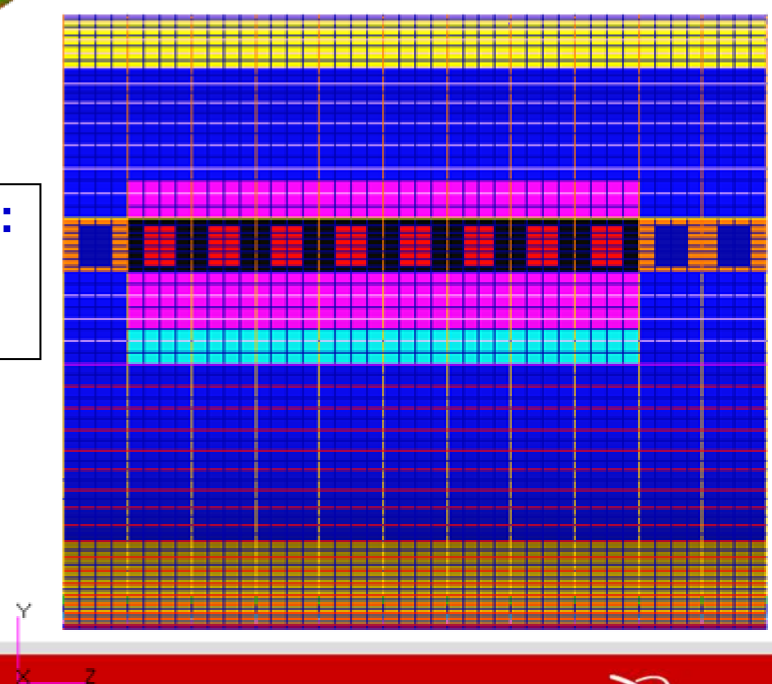




Secondary Structure:
OH bins, sidewall & ceiling trims



Primary Structure:
frames, skins, stringers, floors



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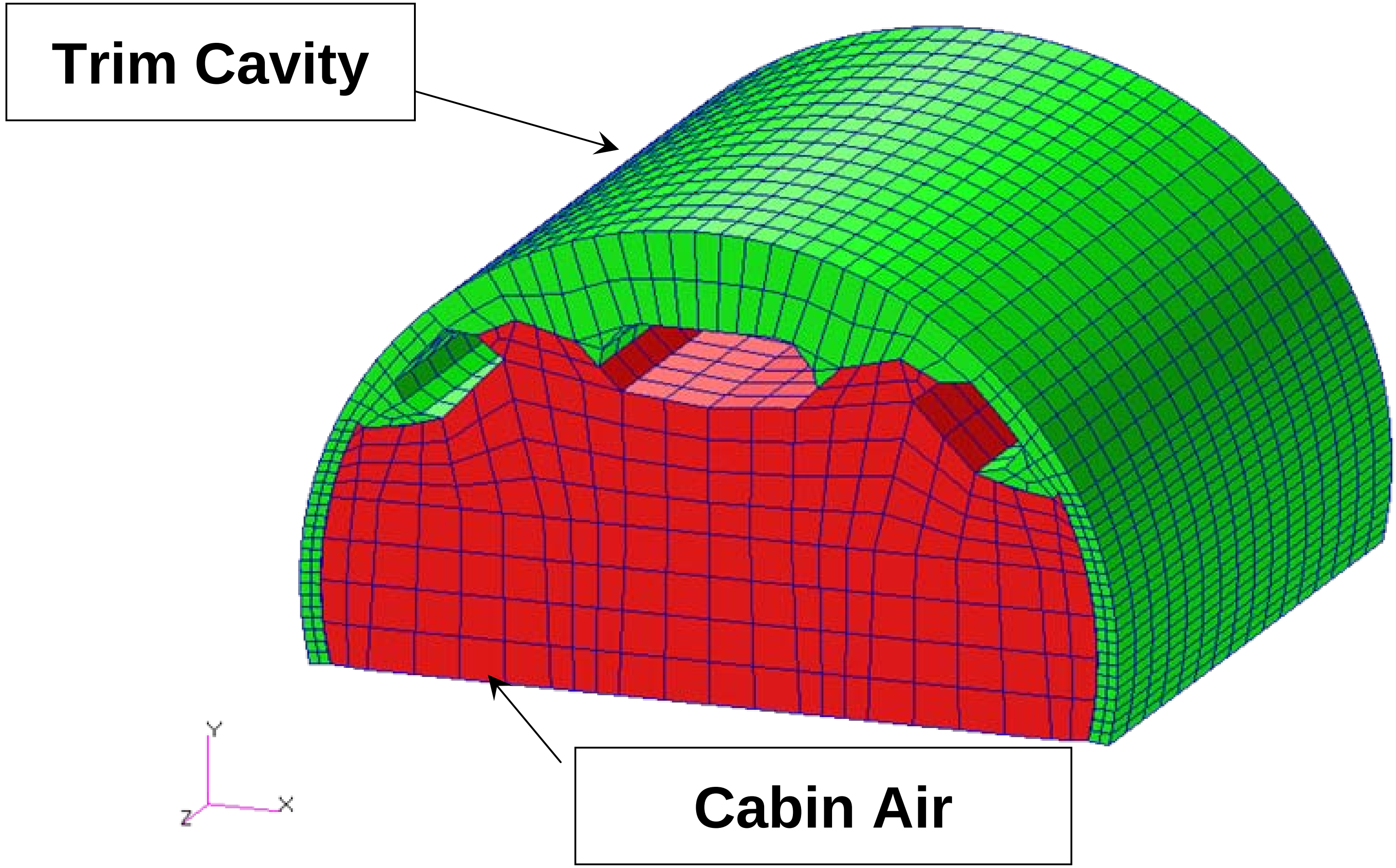
Acoustic Mesh



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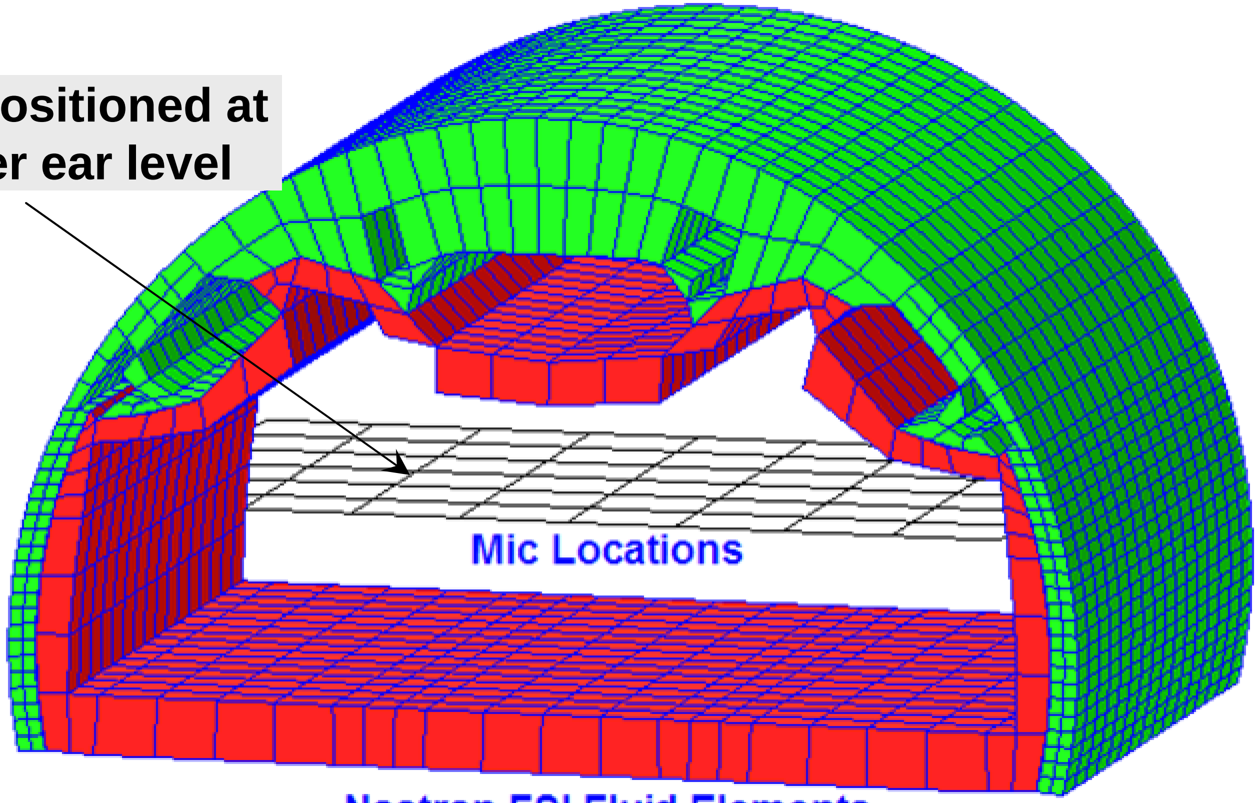
Fluid-Structure Interaction

63 Mic's -Positioned at passenger ear level



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Assumptions & Idealization

Boundary Conditions

Test: cradle foam / FEM: Free-Free

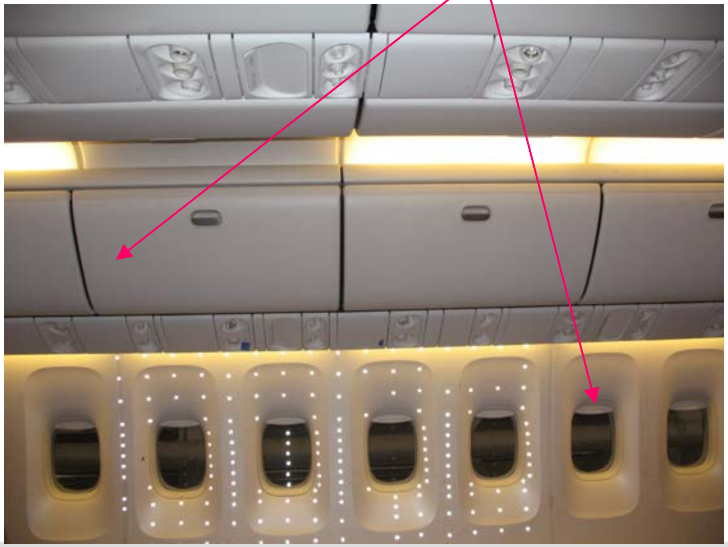
Primary Structure

Stiffness: PBAR, PSHELL

Mass: material density

Stowage Bins / Trims panels

Test: composite / FEM: PCOMP



End Caps

Test: Impervious blanket

FEM: Rigid walls

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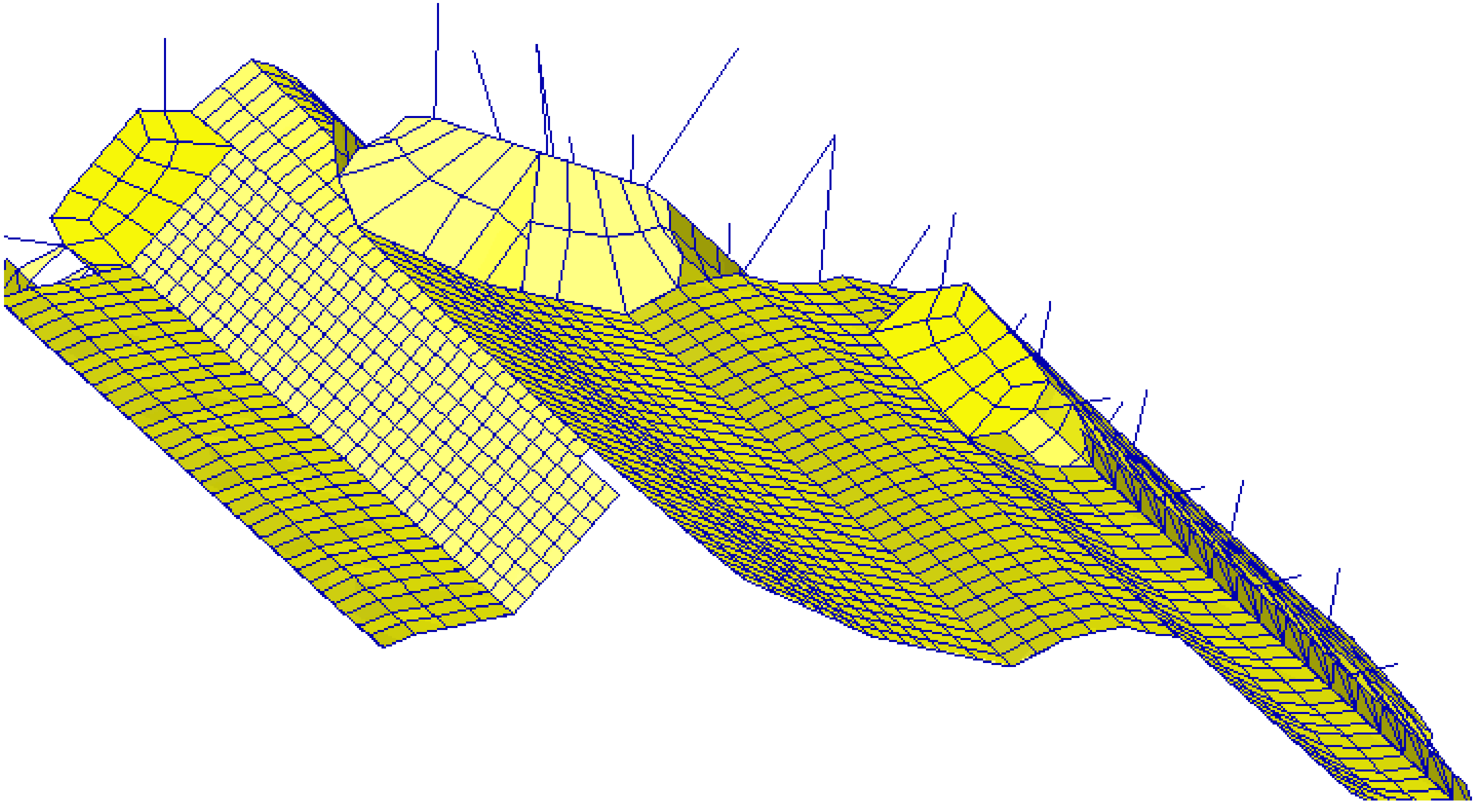
Modeling Simplifications

- No detailed cross section modeling of stringer, frame, floor, or fasteners was deemed necessary for frequency band of interest.
- Acoustic medium was made of simple solid fluid elements with only air property definition. Specific representation of carpets, acoustic treatment blankets, and effects of the end cap acoustic curtains in the test were ignored.

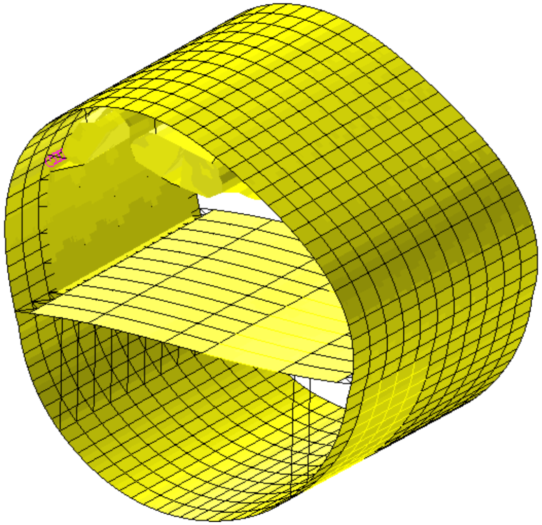
Overhead bins influence the acoustic response

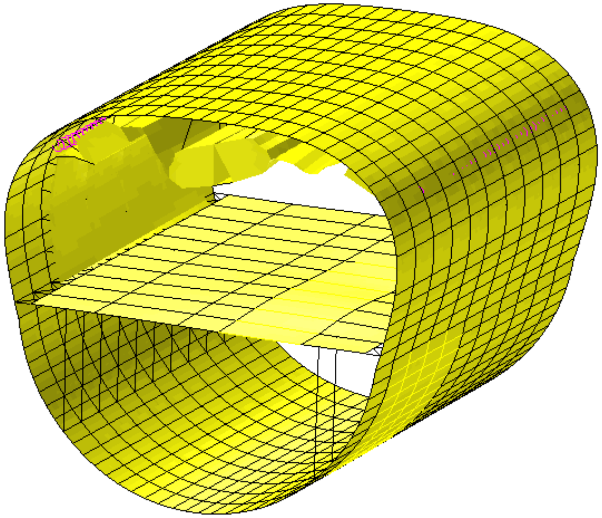
- •low frequency kinetic energy
- •higher frequency strain

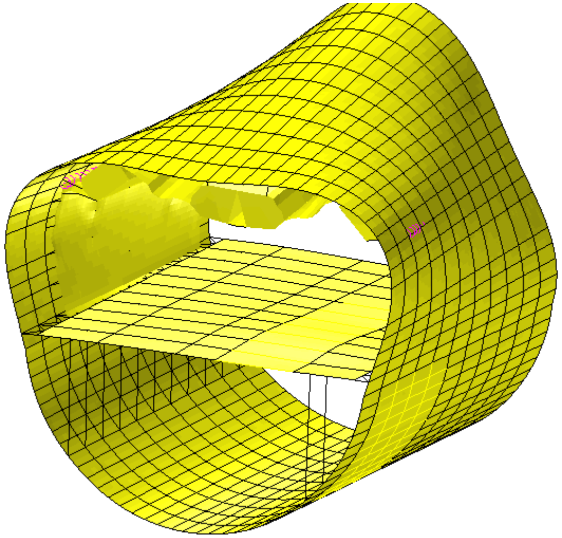


Structural Modes

Typical Low Frequency Structural Modes



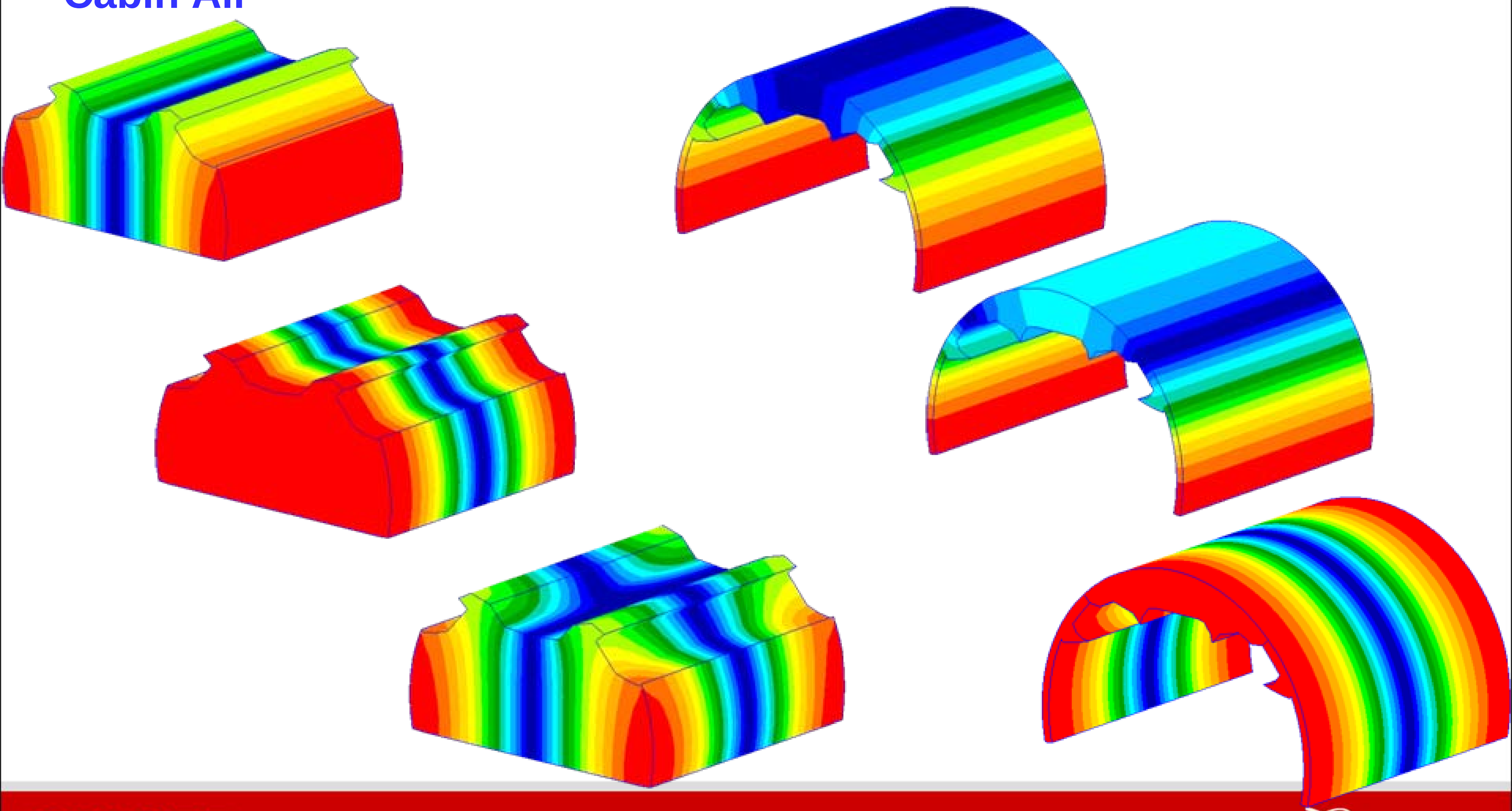




Acoustic Modes

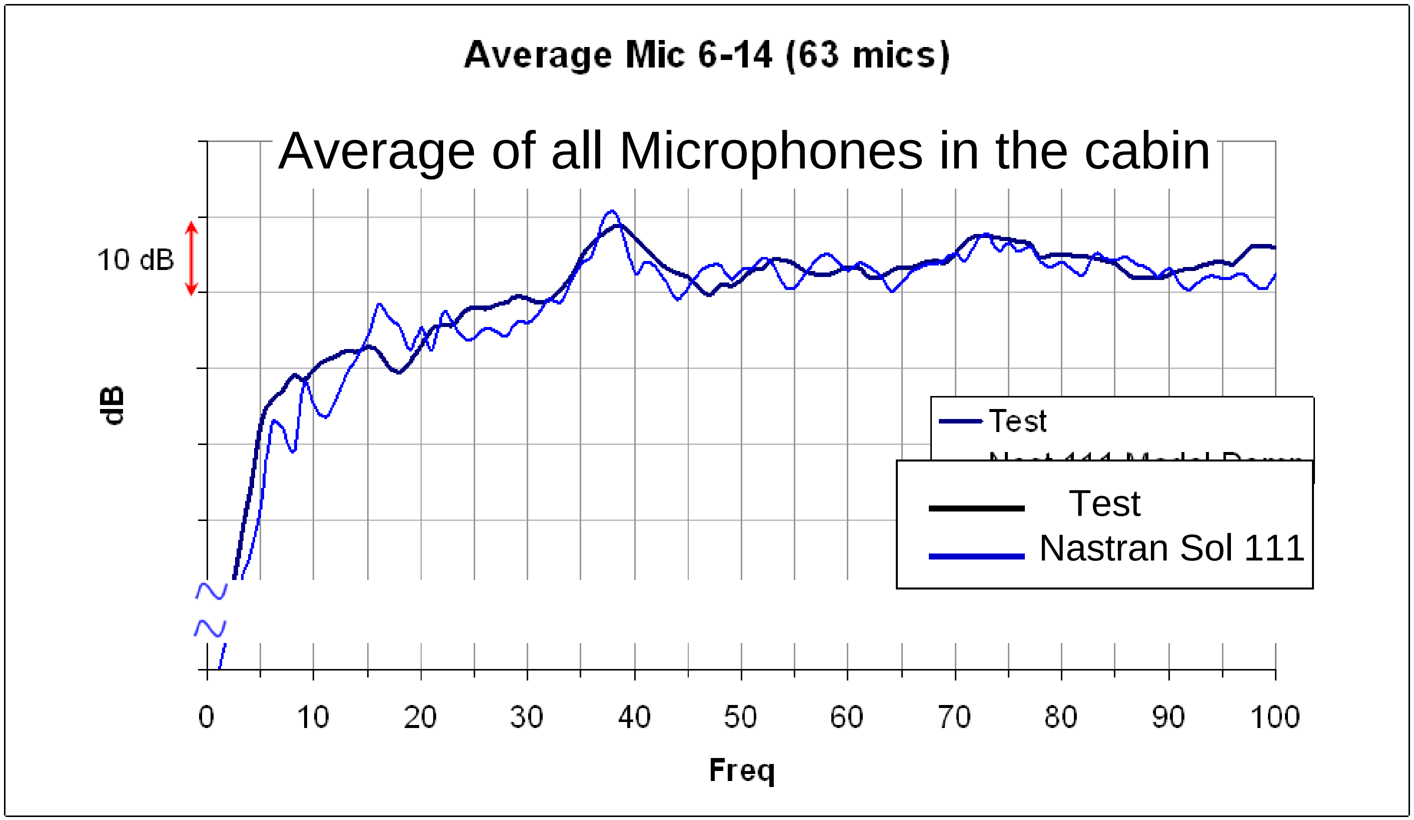
Trim modes & Cabin modes (pressure profile)

Cabin Air **Trim Air**



Passenger Cabin Acoustic Correlation

$$dB_{avg} = 10\log_{10}\frac{\sum_{i=1}^{N}\left(\frac{p_i^2/\Delta f}{p_{ref}^2}\right)}{N} \quad \text{where} \quad p_{ref} = 2.9e-9 \text{ psi}$$



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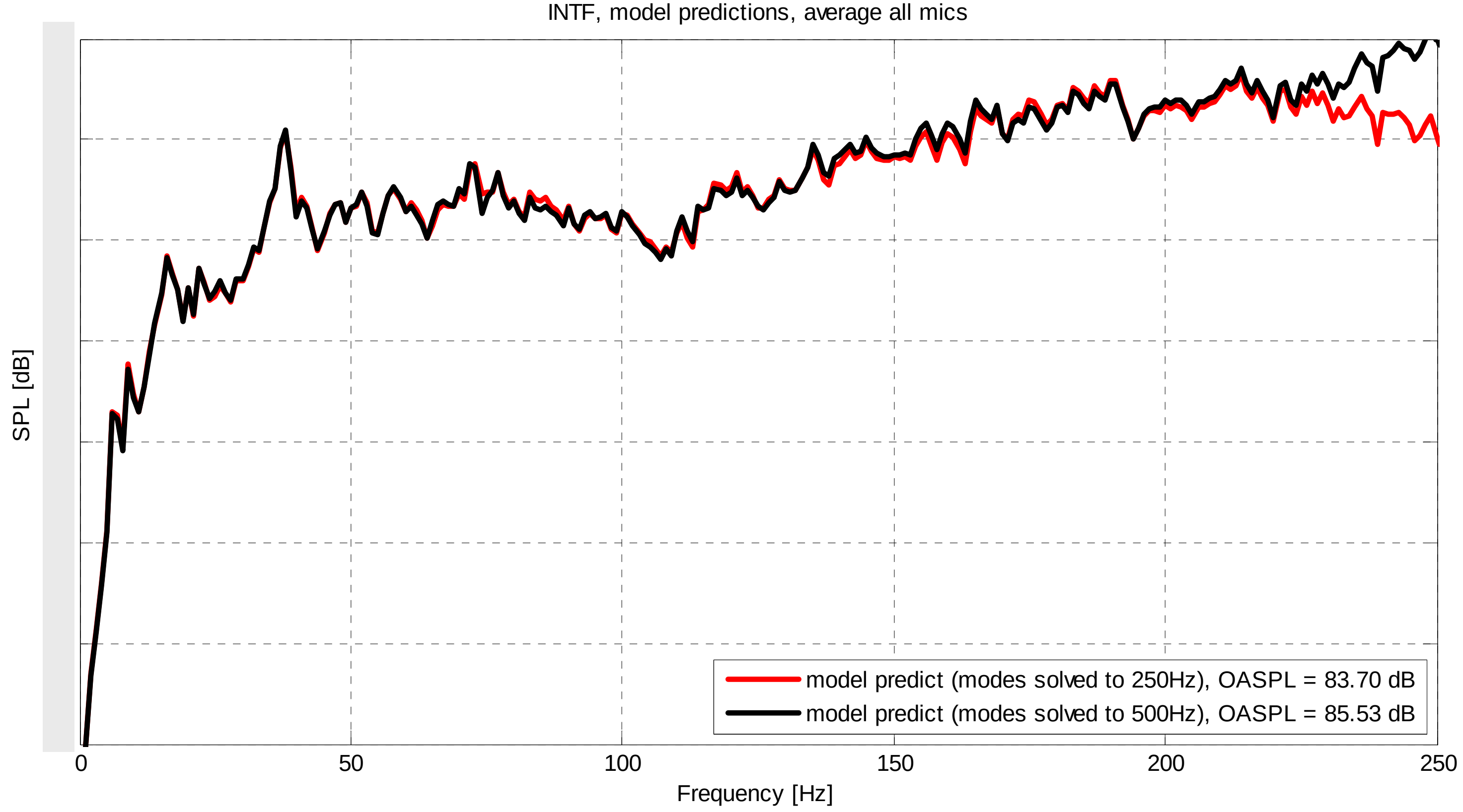
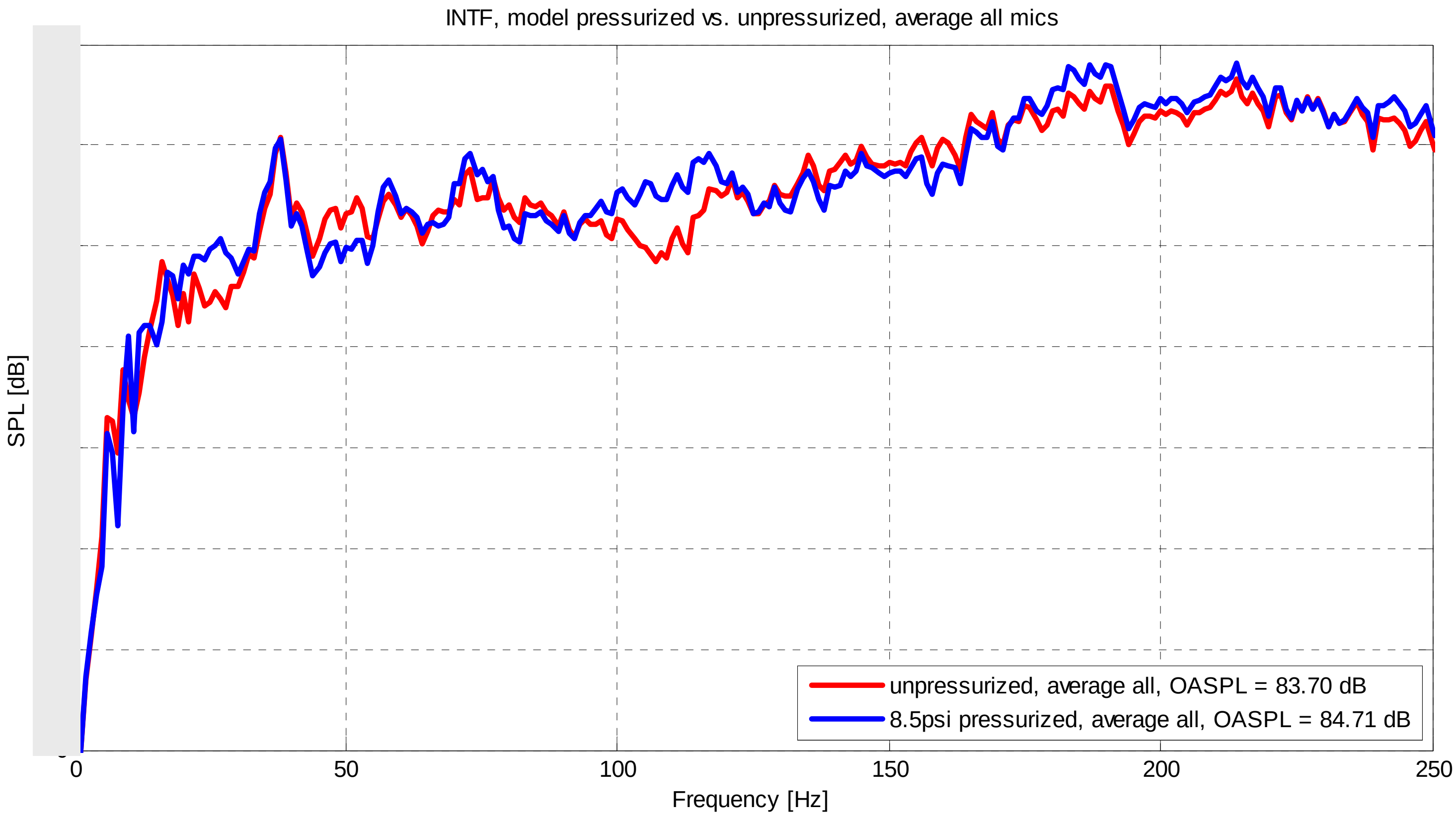
Modal Truncation effects on SPL results



Enough modes were captured in Sol 111 results to avoid modal truncation

Cabin Sound Pressure (pressurized vs. unpressurized)



Effect of pressurization is important to consider in future flight test studies

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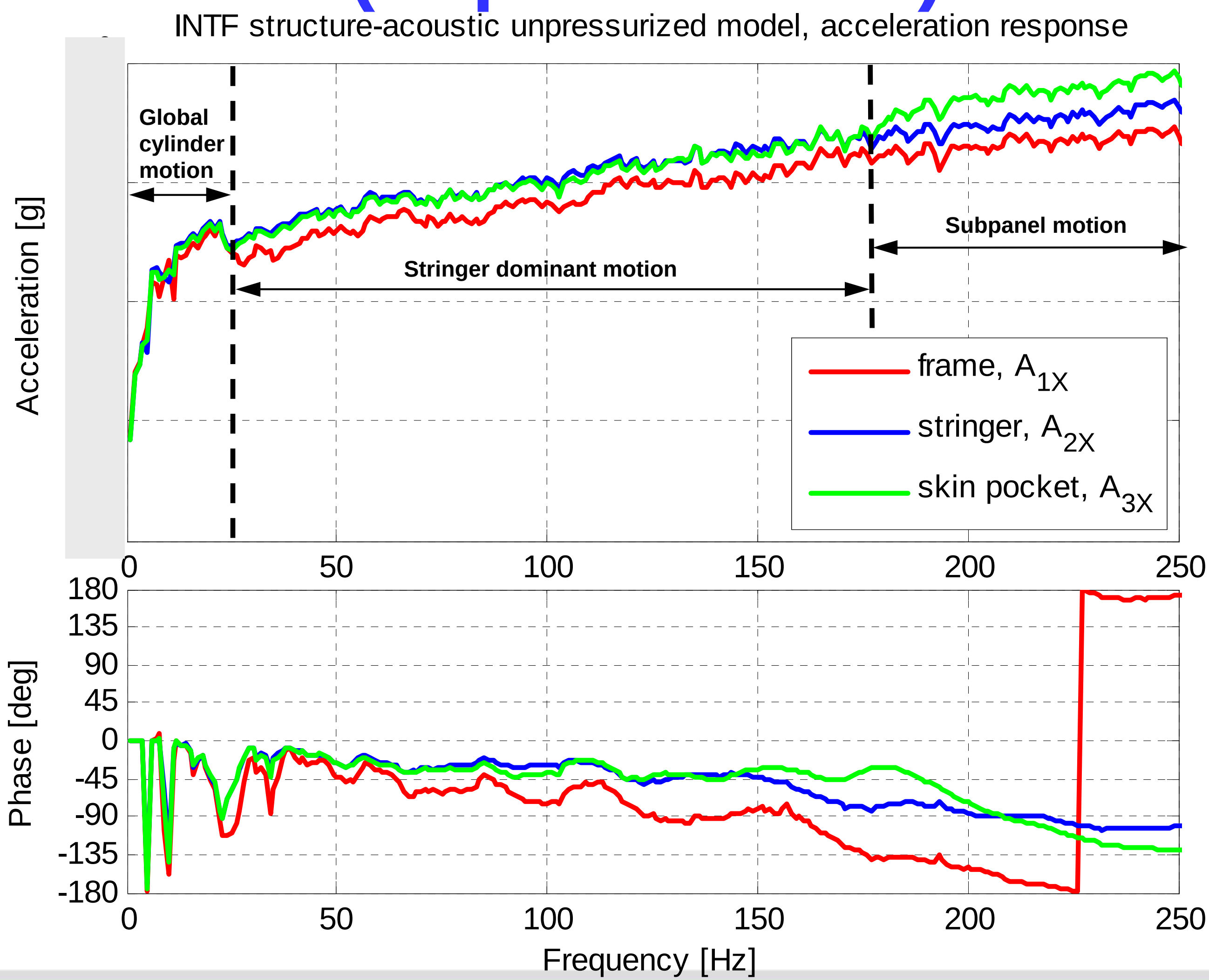
Structure acceleration results (unpressurized)



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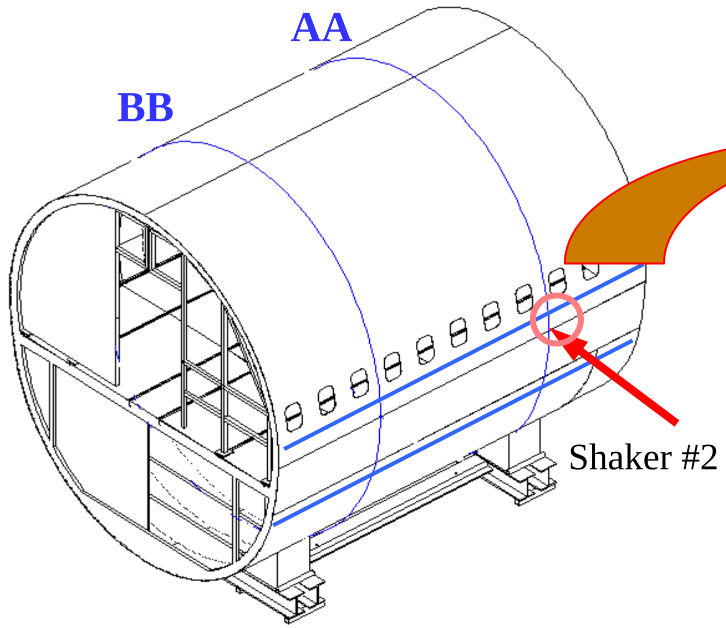
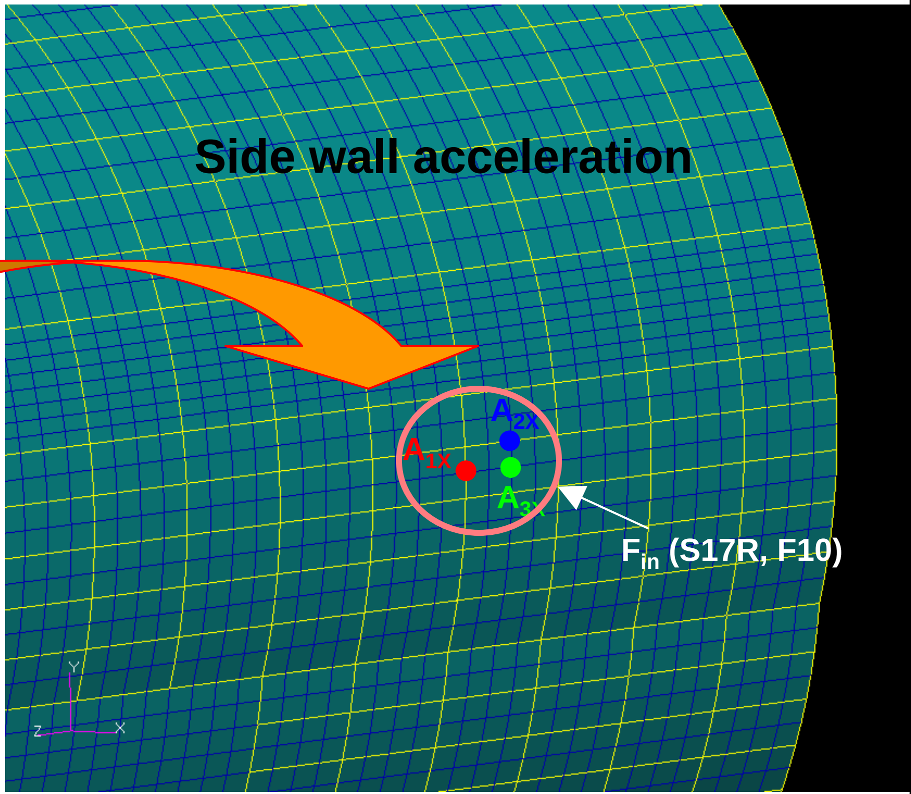
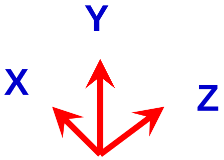
Structure acceleration results



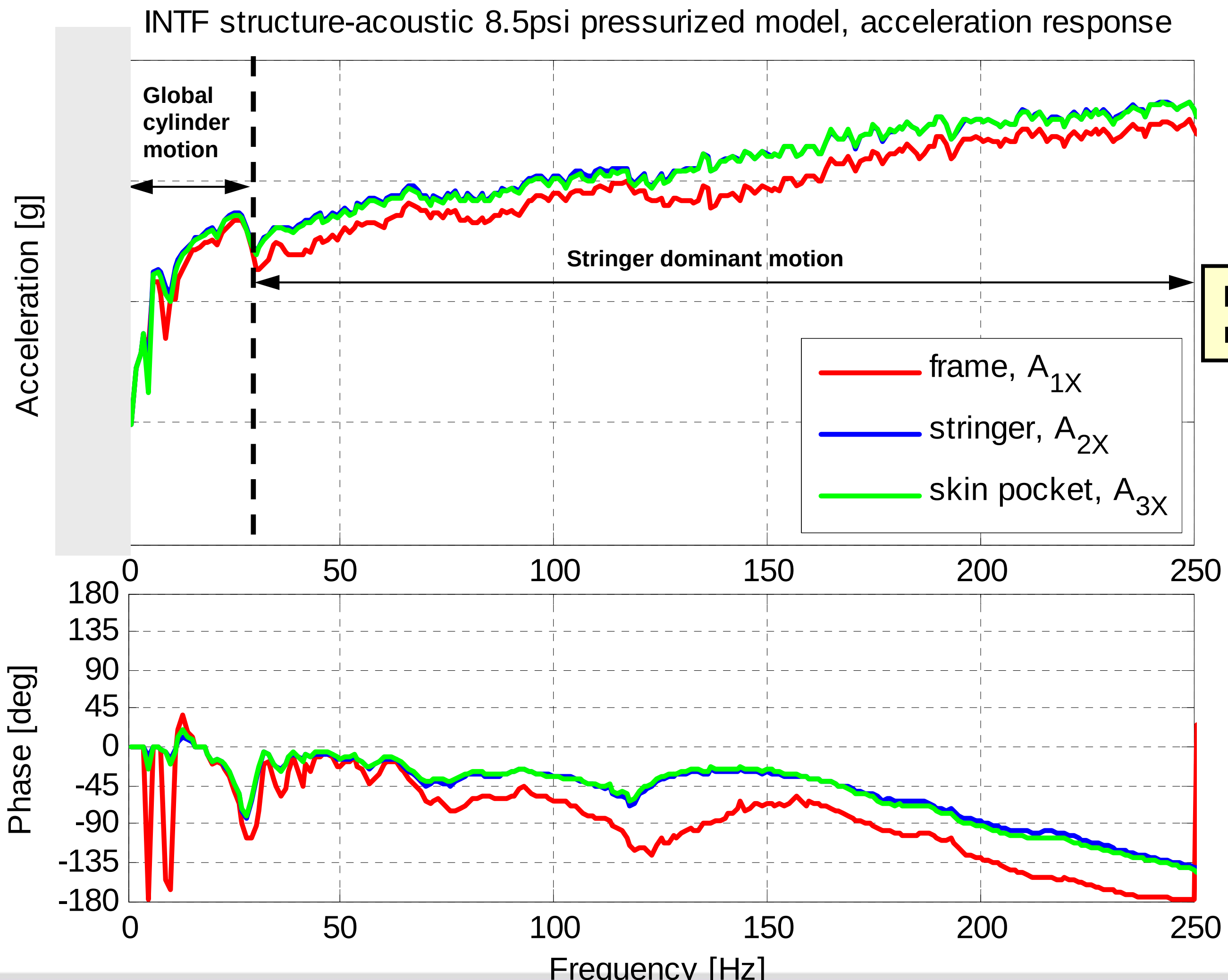




Acceleration results in Lateral Dir

A1x, A2x, A3x

Structure acceleration results
(8.5psi pressurized)



No Subpanel only motion under 250 Hz

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Conclusions

- The test results validated analytical model up to 100 Hz with great accuracy.
- The strong test-analysis agreement in this study can build confidence in modeling of complete airplanes in flight tests conditions.
- Highly detailed FEM is not required as long as the primary and secondary load paths are accurately represented with flexible element types.
- Standard dynamic modeling concept within the Nastran (MDR3 & V.2008) is adequate. Therefore special DMAP, exotic techniques, use of specialized third party software, or even use of any empirical data (other than damping) are not necessary to achieve accurate result.
- No detailed cross section modeling of the stringer, frame, floors, fasteners, or detailed modeling of sidewall system was deemed necessary for the frequency band of interest.
- The pressurization is important to include in the analysis and could help reduce some modeling detail for higher frequency requirements.

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Recommendations

- Future studies will be conducted to investigate and reduce the vibro-acoustic response of full airframe-engine in flight conditions.
- More modeling detail may be necessary to study the vibration of the engine N2 frequency (> 100 Hz) effects to the cabin environment, critical to narrow body airplanes.
- Study of the Engine Vibration Related Noise, requires close collaboration of the airframe and engine manufacturers to understand and reduce noise and vibration at engine/airframe architectural design phase.

Acknowledgement

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This work is the result of close collaboration between the Boeing company and MSC Software. Some detailed steps or selected results have intentionally been omitted, or represented by non-dimensional units in order to protect Intellectual Property.