



Boundary Element Method (BEM) Analysis of a Stiffened Composite Panel Transmission Loss Test

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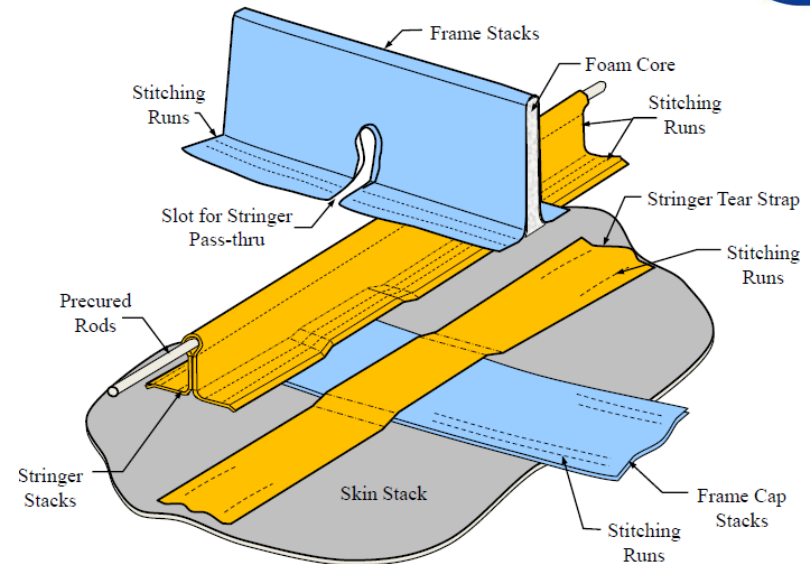
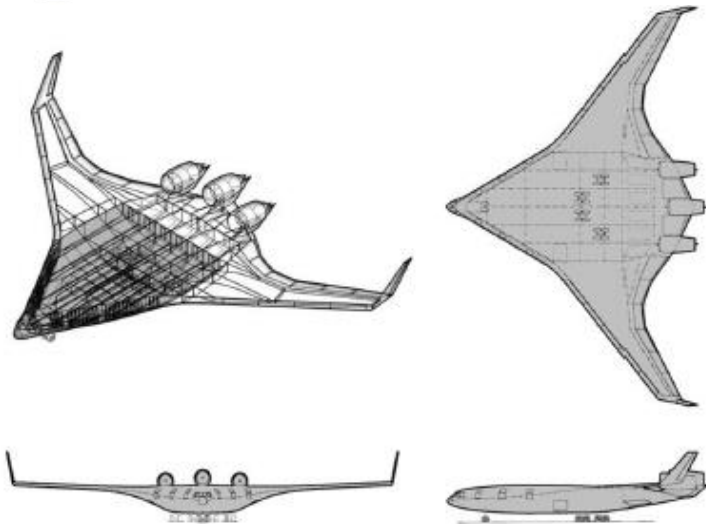




Purpose

- BEM analyses performed to study substructure radiation and scattering effects to validate assumptions of a previous model comparison of TL test data
- Grid BEM computation cost compared for varying models

Background

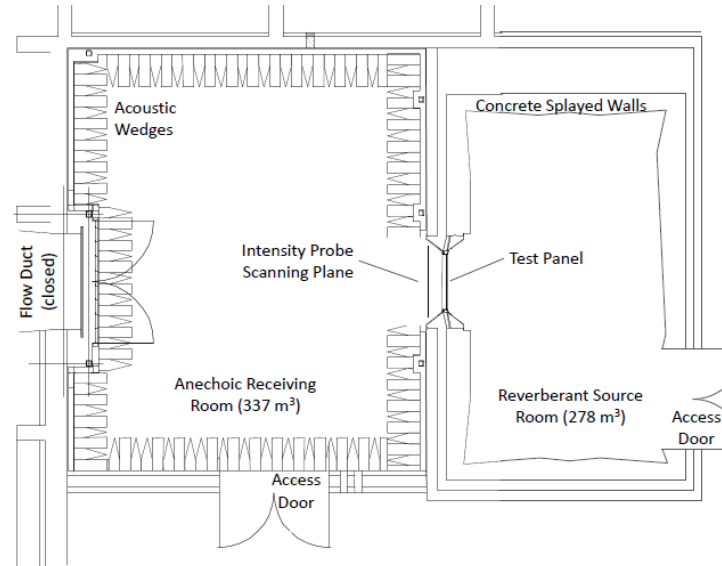
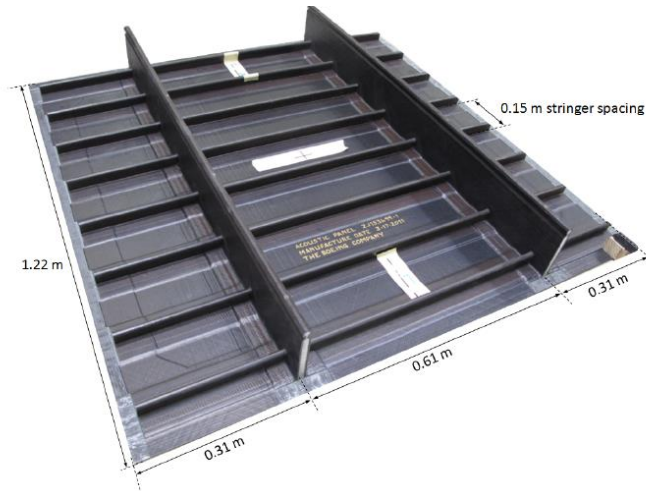


* Internoise 2012/ASME NCAD meeting, IN12-321, Aug,2012.

- Environmental Responsibility in Aviation (ERA) Project
 - New Airframe Designs: Hybrid Wing Body (HWB)
- Pultruded Rod Stitched Efficient Unitized Structure (PRSEUS)
 - Lighter, stiffer, co-cured composite design sufficient for demanding out-of-plane loading
 - Concerns over interior acoustic noise and structure radiation efficiencies
- Representative PRSEUS test panel was fabricated for radiated sound measurements from diffuse acoustic field (DAF)



Motivation



* Internoise 2012/ASME NCAD meeting, IN12-321, Aug,2012.

- Transmission Loss (TL) testing and model validation previously performed (Allen and Przekop, Internoise/ASME 2012)
 - Efficient finite element modal domain analysis accounting for planar radiation (**FE-PR**) impedance only (Rayleigh integral formulation)
 - Neglects effects of substructure radiation and scattering for computational efficiency
- Additional BEM analyses performed here to capture effects of the substructure radiation/scattering
 - Additional validation of the assumptions within the **FE-PR** code
 - Opportunity to perform BEM analysis for higher frequencies
 - Evaluation of BEM analysis computation cost (parallel processing tools)

June 3-5,2014



BEM Overview



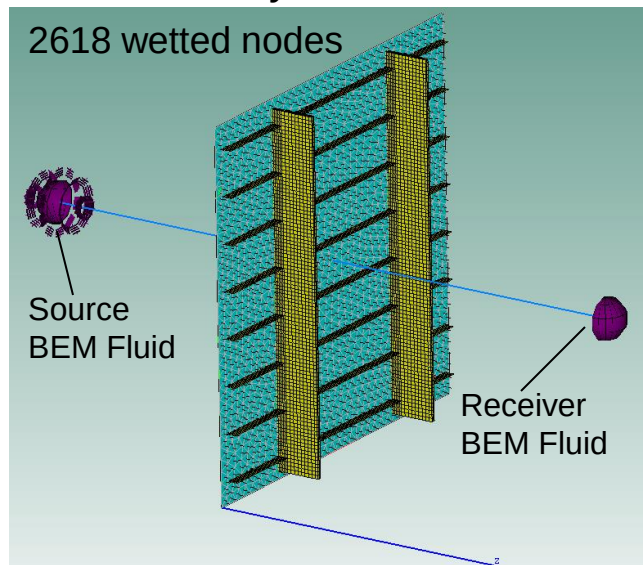
- Deterministic boundary representation of a fluid used to approximate coupled fluid-structure response
- Prediction of sound field in enclosed or open space (scattering/diffraction), vibration from acoustic field, sound radiation from vibrating structure
- Typically limited to low/mid frequency domain due to computation cost and feasible mesh fidelity



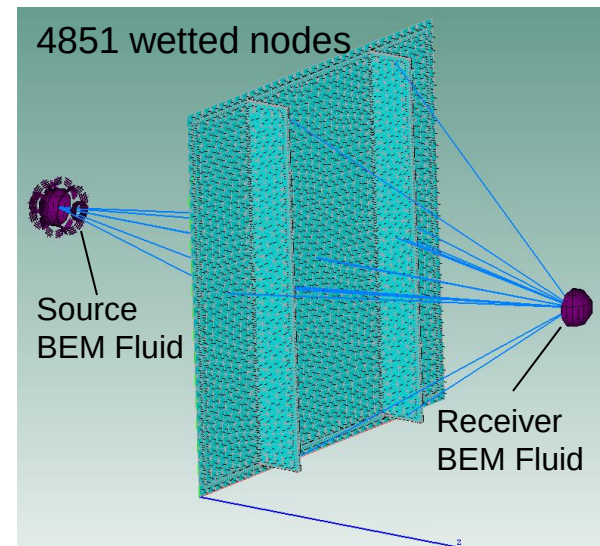
PRSEUS BEM Model Overview



Skin Only Radiation

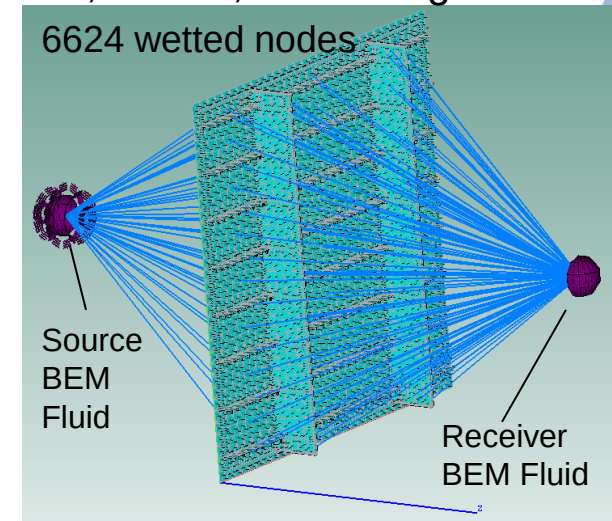


Skin and Frame Radiation



- TL configuration model (2 BEM's, Rigid Baffle) mimics the test configuration
- FE Face mesh 8 elements/acoustic wavelength at 1115 Hz (0.038 m)
- Imported PRSEUS panel structural modes from 200 – 4000 Hz
- Approximated DAF (1 Pa) on source BEM fluid by 50 plane waves

Skin, Frame, and Stringer Radiation

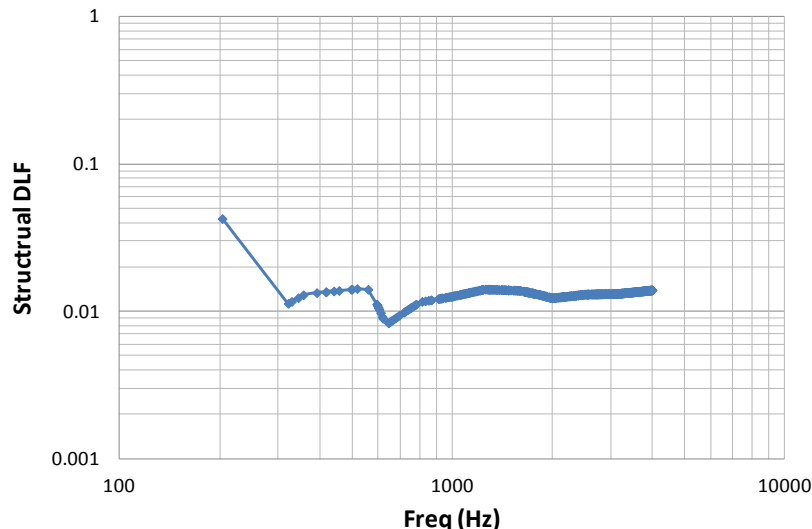




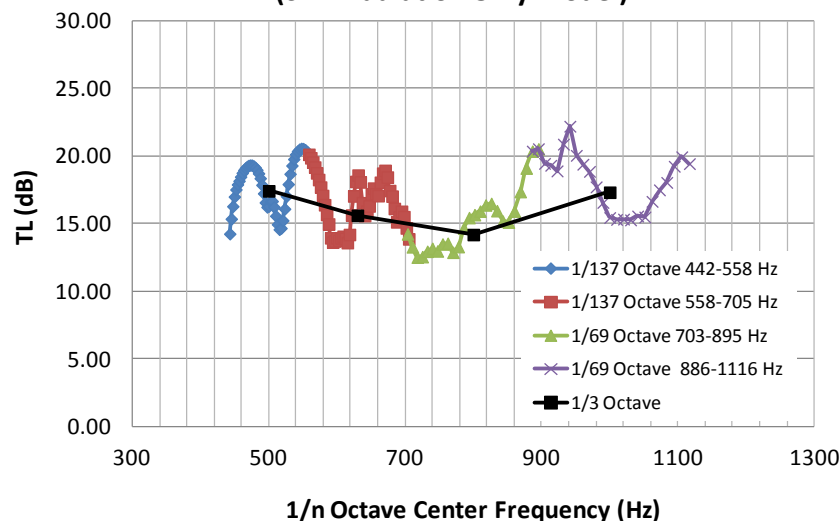
PRSEUS BEM Model Solution Parameters



PRSEUS Test Panel DLF Estimates



PRSEUS Panel VA One BEM Analysis
(Skin Radiation Only Model)



- DLF (η) schedule estimated from testing used in analysis
- BEM solution solved from 442–1115 Hz to produce 1/3 octave results

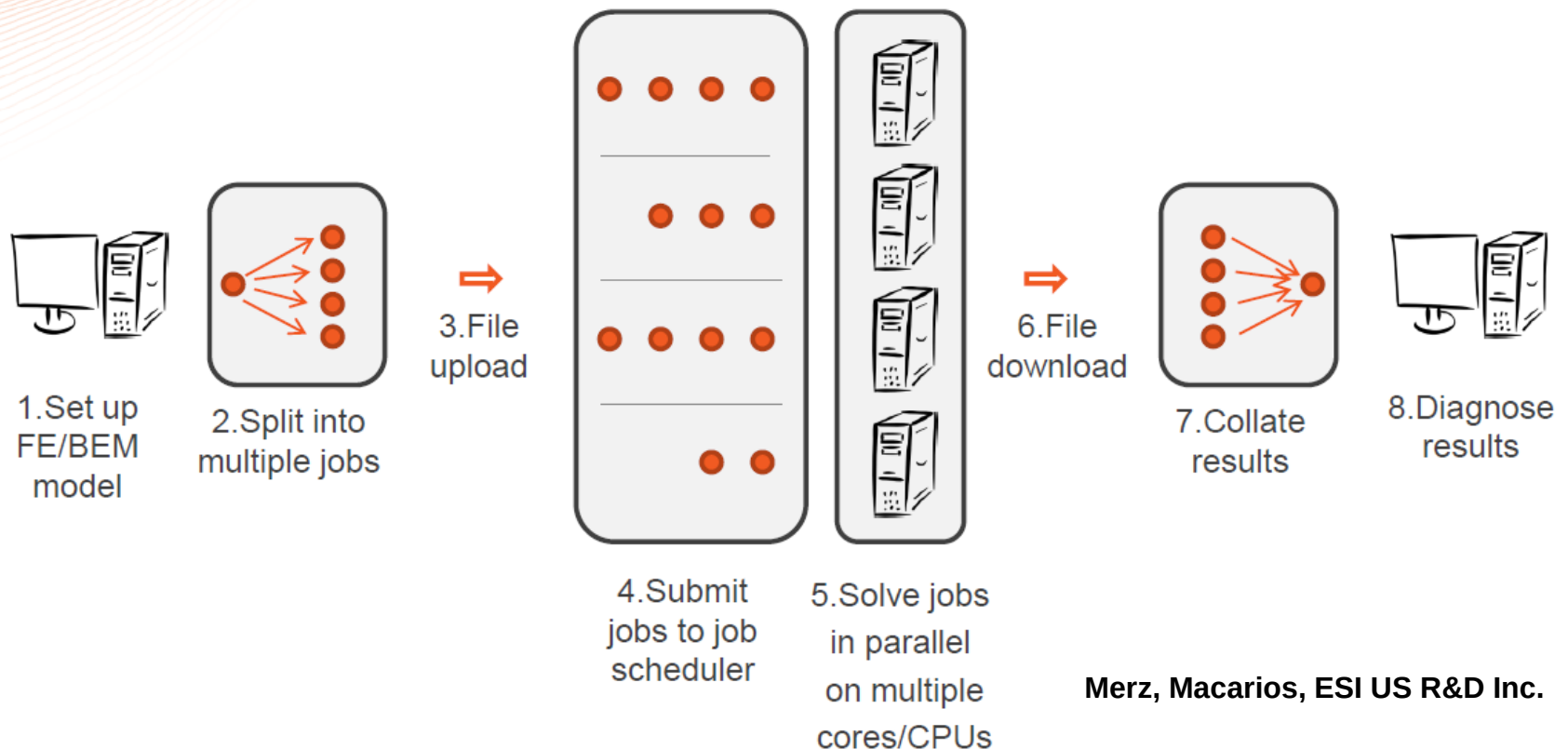
- 500 Hz band: 442-557 Hz solved at 1/137 octave
- 630 Hz band: 557-702 Hz solved at 1/137 octave
- 800 Hz band: 707-892 Hz solved at 1/69 octave
- 1000 Hz band: 884-1115 Hz solved at 1/69 octave

$$\Delta dB = 20 \log_{10}(\eta((1 - 2^{1/n})^2 + 2^{1/n} \eta^2)^{-1/2})$$

Larko, McNelis, and Gardner, SCLV 2010

- Utilized VA One grid BEM parallel processing (x8 processors)
 - Each frequency step can be solved on individual processor

BEM Parallel Processing



- VA One software Grid BEM module allows automation of the process
- PRSEUS BEM analysis was divided across 8 separate processors
- Benefits on next page



Computation Time Comparisons



Simple Model			
CPU #	Source BEM (1309 wetted)	Receiver BEM (1309 wetted)	Freq Solves/BEM
1	1:11:59	1:06:40	19
2	1:08:00	1:03:12	18
3	1:08:51	1:03:01	18
4	1:08:14	1:03:35	18
5	1:07:36	1:03:14	18
6	1:08:11	1:03:00	18
7	1:08:49	1:03:29	18
8	1:00:42	0:56:49	16
Sum	9:02:22	8:23:00	143
Comp. Time/Freq	0:03:48	0:03:31	
Grid BEM Time	1:12:35	1:07:18	
Total Computation Time (hr:min:sec)			17:25:22
Total Grid BEM Time x8 parallel cpu (hr:min:sec)			2:19:53

Intermediate Model			
CPU #	Source BEM (1926 wetted)	Receiver BEM (2925 wetted)	Freq Solves/BEM
1	3:49:31	13:44:54	19
2	3:38:48	12:52:24	18
3	3:35:56	12:40:57	18
4	3:36:58	12:49:30	18
5	3:35:48	12:53:14	18
6	3:35:46	12:52:46	18
7	3:34:20	12:47:34	18
8	3:04:07	11:37:16	16
Sum	28:31:14	102:18:35	143
Comp. Time/Freq	0:11:58	0:42:56	
Grid BEM Time	3:54:58	13:49:31	
Total Computation Time (hr:min:sec)			130:49:49 (5.5 days)
Total Grid BEM Time x8 parallel cpu (hr:min:sec)			17:44:29

Complex Model			
CPU #	Source BEM (2500 wetted)	Receiver BEM (4124 wetted)	Freq Solves/BEM
1	6:39:30	80:40:48	19
2	6:23:34	76:25:53	18
3	6:30:06	76:36:57	18
4	6:29:24	76:48:51	18
5	6:18:13	76:32:47	18
6	6:18:19	76:46:20	18
7	5:54:38	72:28:36	17
8	5:34:30	68:08:08	16
Sum	50:08:14	604:28:20	142
Comp. Time/Freq	0:21:11	4:15:25	
Grid BEM Time	6:55:01	80:52:39	
Total Computation Time (hr:min:sec)			654:36:34 (27.3 days)
Total Grid BEM Time x8 parallel cpu (hr:min:sec)			87:47:40 (3.6 days)

- Reduction in computation time using 8 parallel processors
- Inclusion of substructure radiation resulted in a large increase in grid BEM computation time ($O(n^3)$)
- Addition of Indirect BEM solvers increase computation time even more than the ($O(n^3)$)



TL Results Calculation



- Incident Power (W_{inc}) calculated from equation below, using BEM field pressure (P_f) response from VA One
 - W_{inc} calculated for each source side FE Face area (S) and summed to give total for the intermediate and complex models where skin is broken into multiple FE Faces.

$$W_{inc}(f) = \frac{P_f(f)^2 S}{4\rho_o c}$$

- The radiated Power (W_{rad}) recovered directly from the Receiver BEM input power response in VA One
- The W_{inc} and W_{rad} were averaged into 1/3 Octaves (band-limited avg), and the panel transmission loss (TL) is calculated from following equation

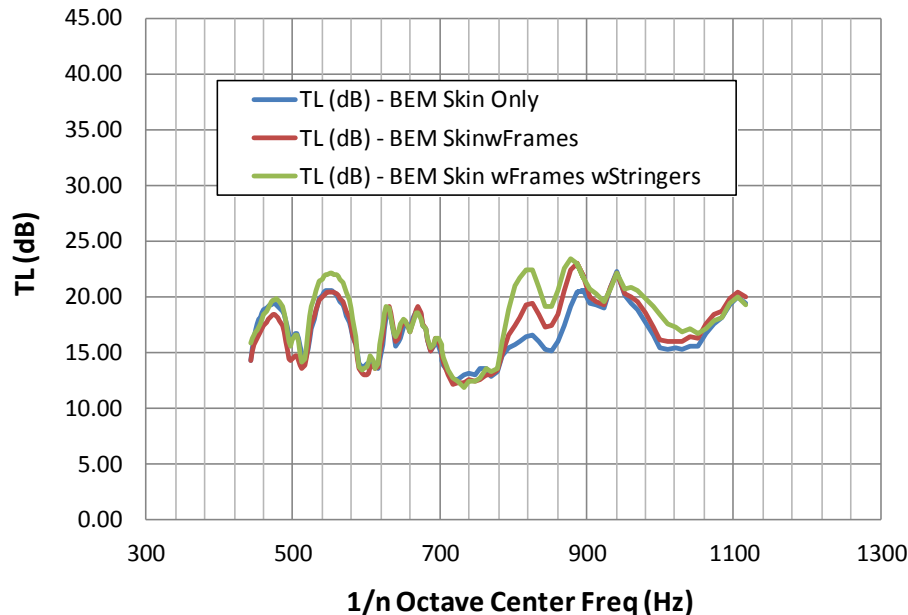
$$TL(f) = 10 \log \left(\frac{P_{inc}(f)}{P_{rad}(f)} \right)$$



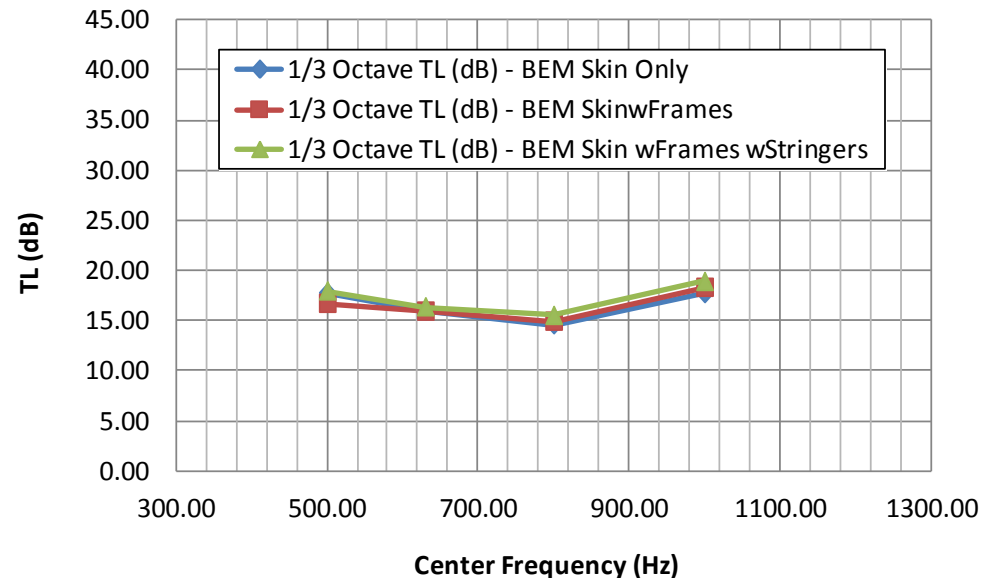
BEM Model Fidelity Comparison



PRSEUS BEM Model Transmission Loss



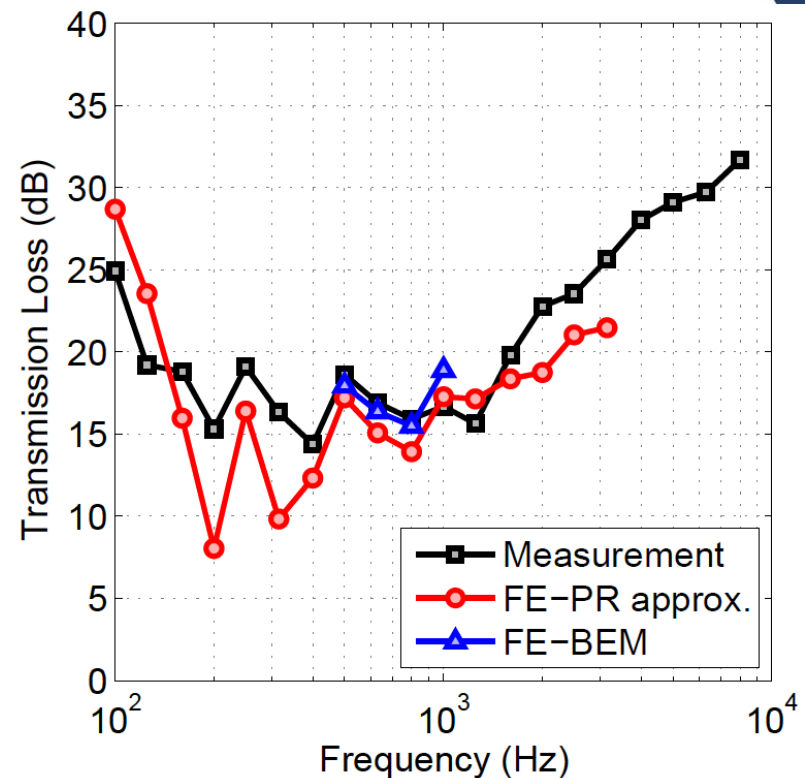
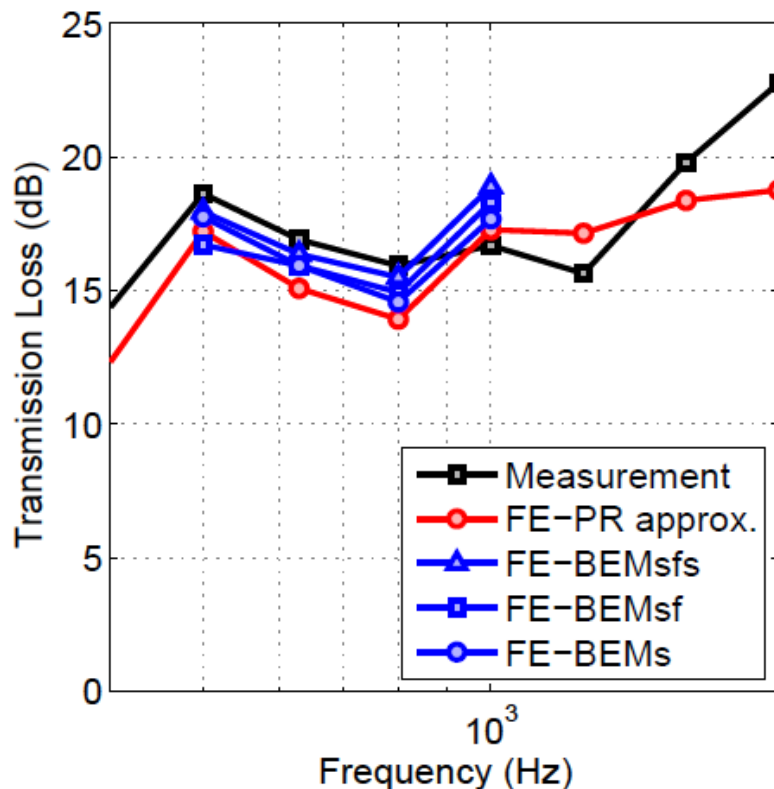
PRSEUS BEM Model Transmission Loss



- Comparison of the TL results for the BEM models show that the effect of substructure radiation of PRSEUS panel is minimal for DAF excitation at this frequency range
- Cost to benefit ratio is too large for this particular case
- High fidelity BEM models could become more worthwhile for narrowband excitation situations, perhaps at higher frequencies, and for other response quantities (i.e. field pressure)



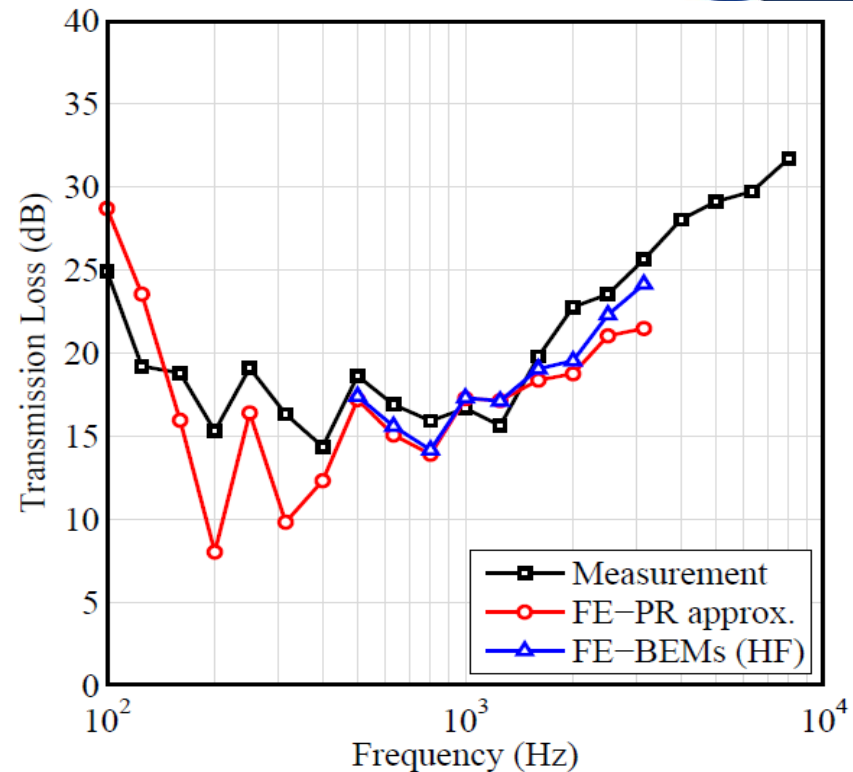
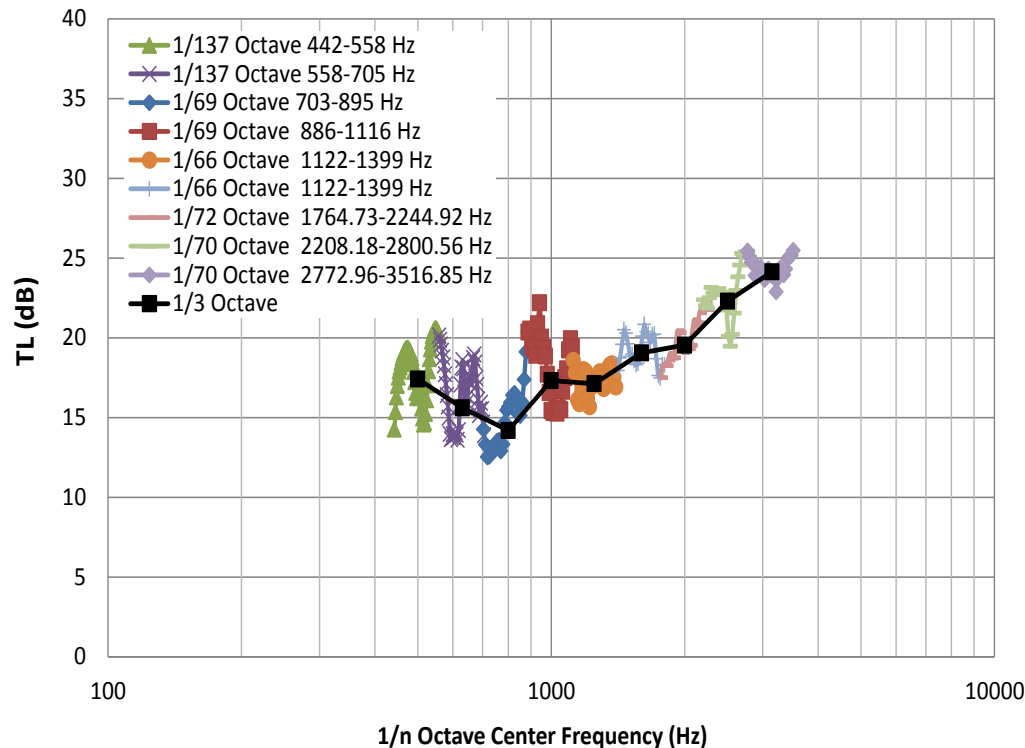
BEM Model Comparison to Test and FE-PR Code



- Simple BEM Model (FE-BEMs) compares well with FE-PR code
- Substructure radiation effects captured in intermediate (FE-BEMsf) and complex models (FE-BEMsfs) shows negligible differences from the simplified analyses



Higher Frequencies?



- BEM model (skin radiation only) FE Face mesh refined for higher frequencies (FE-BEMs (HF))
 - Solved from 419-3516 Hz using same methodology
- Comparison at higher frequencies shows:
 - Good BEM comparison to test
 - Potential convergence issues with FE-PR code



Conclusions



- BEM analysis of PRSEUS panel substructure radiation performed at three different levels of fidelity
 - Panel Skin, Skin/Frame, Skin/Frame/Stringer Radiation
 - Skin Radiation shown to be sufficient for validation with test data
- Computation times of the models were compared for grid bem parallel processing
 - Cost of additional substructure effects too large vs. benefits for this application
 - Grid BEM allowed large reductions in computation time
- Analysis results of the three models showed negligible differences and validated the more efficient FE-PR code for this application
- Additional BEM analysis at higher frequencies showed improved agreement with test data, and identified possible convergence issues with FE-PR code



Questions