



Risk Reduction Project in Pad Abort-1 Launch Vehicle Loads & Dynamics

Sasan Armand, Ph.D.

NASA Langley

01/05/2011



Overview

- History of PA-1 coupled loads analyses, including late impact of a static firing
- Risk reduction techniques used to reach flight qualification levels
- Lessons learned



PA-1 Coupled Loads Analysis History

- In a period of about two years, nine Coupled Loads Analyses (CLA) were performed and loads were provided for component design and testing
 - Fabrication of Crew Module hardware started before CLA-1
 - Design of Launch Abort System (LAS) based on MSFC DAC-1 loads analysis, which did not include abort loads
- The large (unusual) number of load cycles for PA-1 launch vehicle was due to fluidity in:
 - Design – Finite element models
 - External environments – AM thrust and acoustics
 - Trajectory – dynamic pressure and angle of attack
 - Intermediate test data – damping from random vibration tests



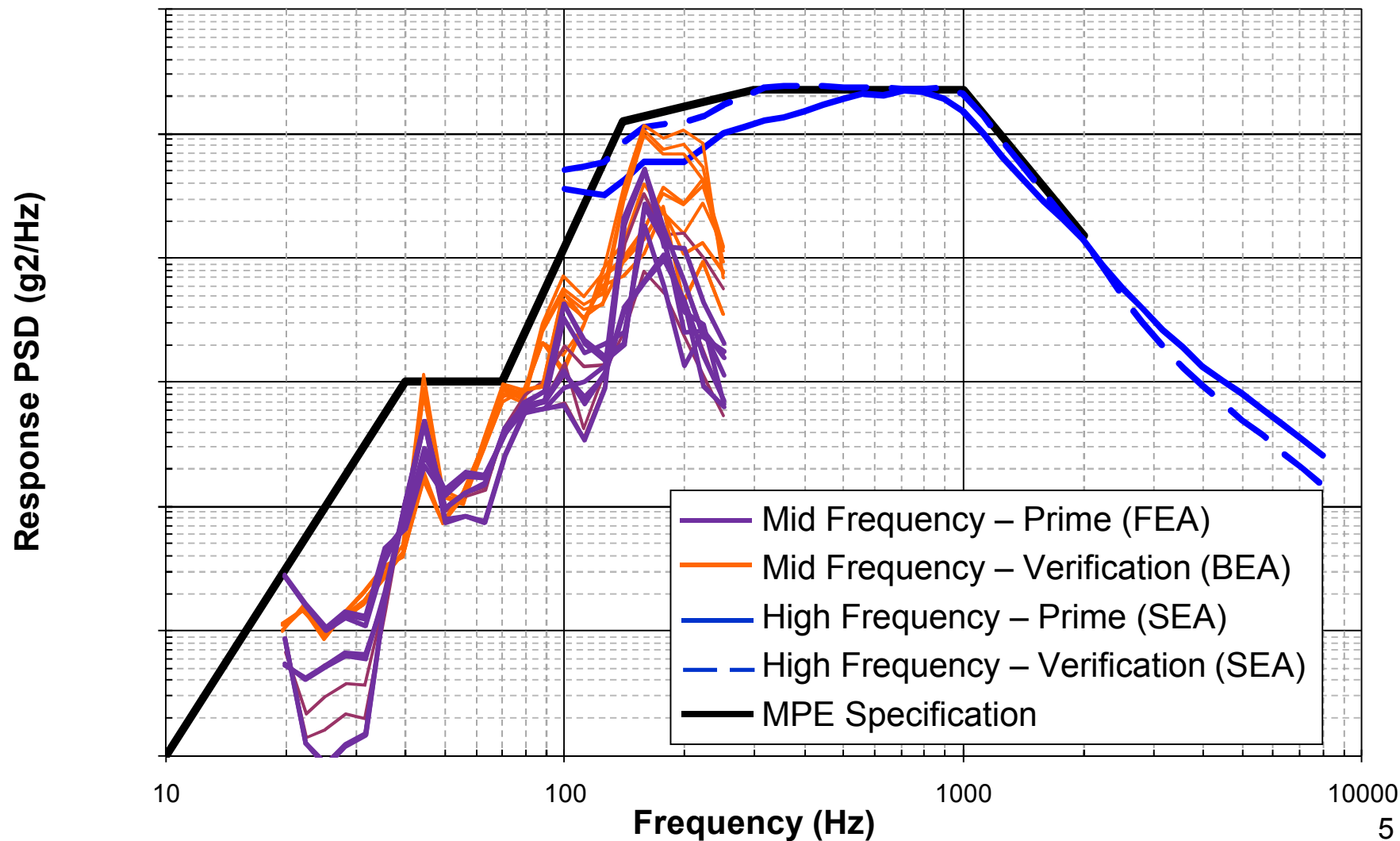
PA-1 Coupled Loads Analysis

- Low-Frequency Transients Analyses (<100Hz)
 - Integrated Finite Element Model
 - Launch Abort Motor & Adapter Cone (Lockheed Martin)
 - Crew Module (LaRC)
 - Transient analysis up to 100Hz based on combined IOP, AM & ACM Thrusts, and aerodynamic
- Vibroacoustic analyses based on Abort Motor plume acoustics & structure-borne vibratory inputs
 - Mid-Frequency Analyses (20Hz – 250Hz)
 - Finite Element Analysis (LaRC - Prime Loads)
 - Boundary Element Analysis – (LaRC - Verification Loads)
 - High-Frequency Analyses (100Hz to 8kHz)
 - Statistical Energy Analyses – (Cambridge Collaborative, Inc. – Prime Loads)
 - Statistical Energy Analyses – (LaRC – Verification Loads)
 - Vibroacoustics Maximum Predicted Environment (20Hz – 2KHz)
 - Combined (overlaid) the mid and high frequency analyses
 - Enveloped all four analyses to derive the design and test specifications



PA-1 CLA-6C Sample I/F Specification

DFI Pallet/CM I/F Response (Vehicle Lateral)





Test Summary

- Data from the following tests were used in CLA5B
 - Modal survey test of LAS with a mass-simulated CM
 - Correlated LAS FEM
 - Identified damping values
 - Subassembly random vibration tests
 - Identified Isolator damping
- Data from AM static test firing test was used in CLA6A and CLA6B
 - AM airborne and structure-borne environments
- Attempted to use data from the following tests in CLA6C
 - Shaker test of CM and adapter cone
 - Damping, TF's, and scaled responses
 - Acoustic test of CM and adapter cone
 - Damping, TF's, and scaled responses

ST-1 (Static Test -1)

- Static firing (conducted by ATK) of the Abort Motor was conducted after the completion of CLA5B (Launch – approximately 12 months)
- Prior to start of CLA6, the majority of design, evaluation and testing was already conducted
- External vibroacoustic levels from test were higher than those used in CLA5B introducing a risk to the vehicle qualification





Risk and Risk Reduction Steps

- Initial steps to reduce the risk
 - CM shaker test
 - CM acoustic test
 - Measure damping and develop TF's for subassemblies
- Final steps to reduce the risk
 - Lower AM operating temperature
 - Lower thrust
 - Lower acoustics
 - Remove cross talk caused by AM structure-borne inputs
 - Reexamine all uncertainty factors
 - Research damping for bolted structures

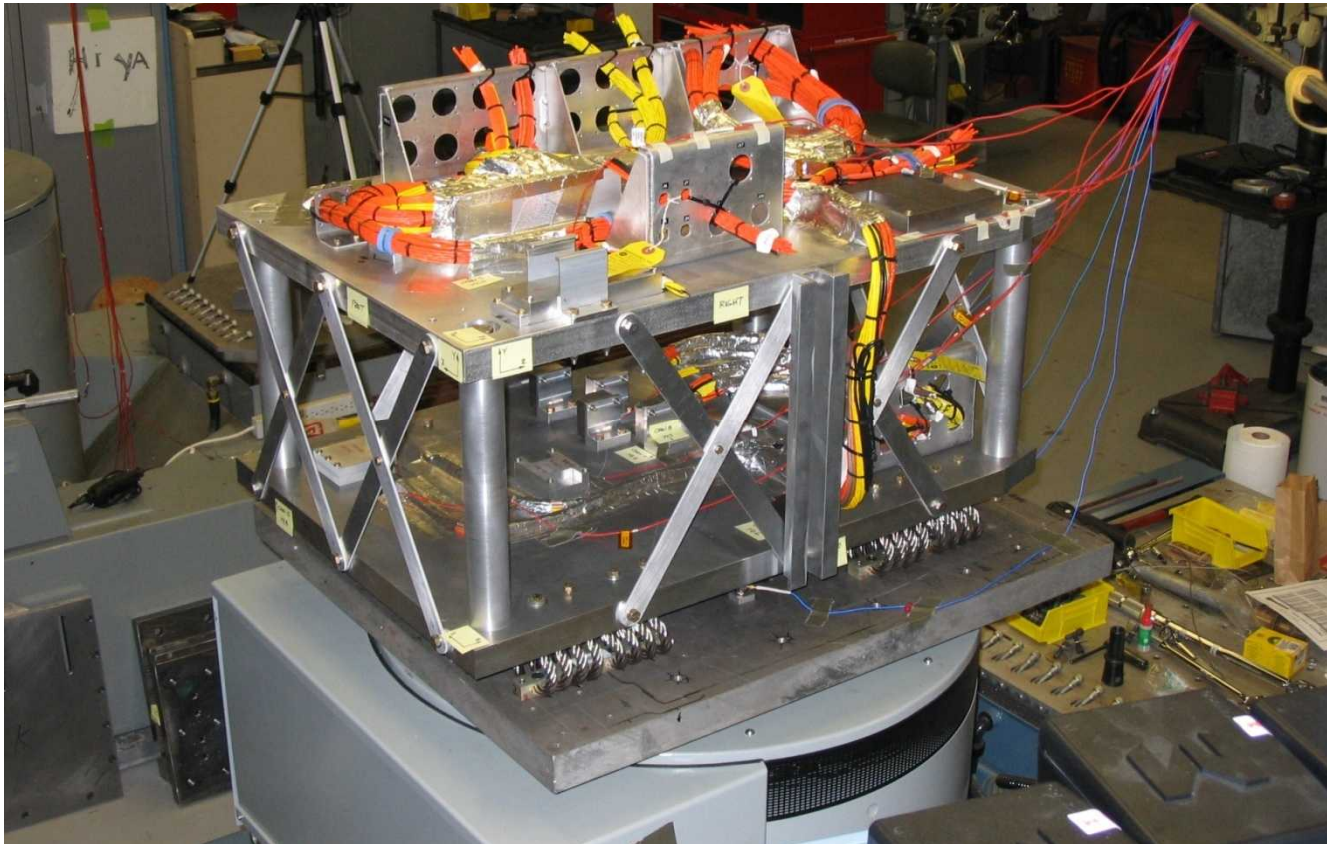
LAS Modal Survey Test

STRUCTURAL AND THERMAL SYSTEMS BRANCH

- Two Goals of the Test (conducted by Orbital and ATA Inc.):
 - Test-correlated FEM
 - Identify damping values

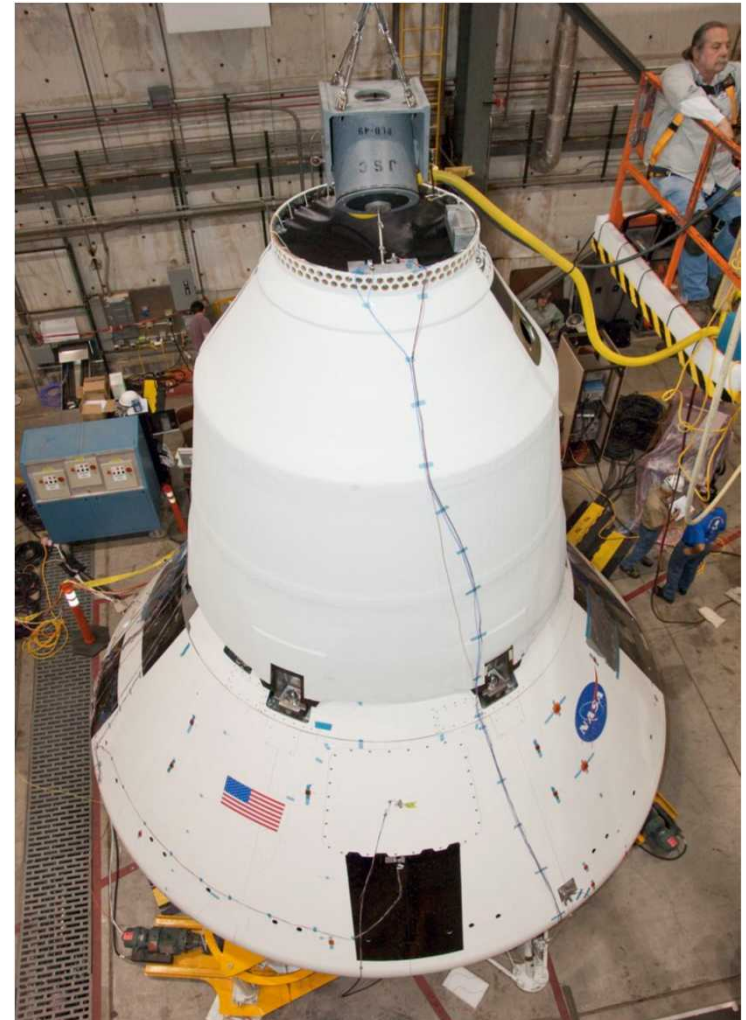


- Goals of Random Vibration of Pallets
 - Identify damping provided by isolators
 - Produce qualification levels for mounted equipment
 - Verify structural integrity of subassembly



CM Shaker Test

- Test conducted by NASA Dryden
- Goals:
 - Provide Transfer Functions between interface environments and component vibration response
 - Identify global damping values for loads models
- Results:
 - Identified unexpected (<2% Critical) damping at lower frequencies
 - Could not exercise CM at high levels
 - Highly isolated subassemblies
 - Used only for validation of CM FEM

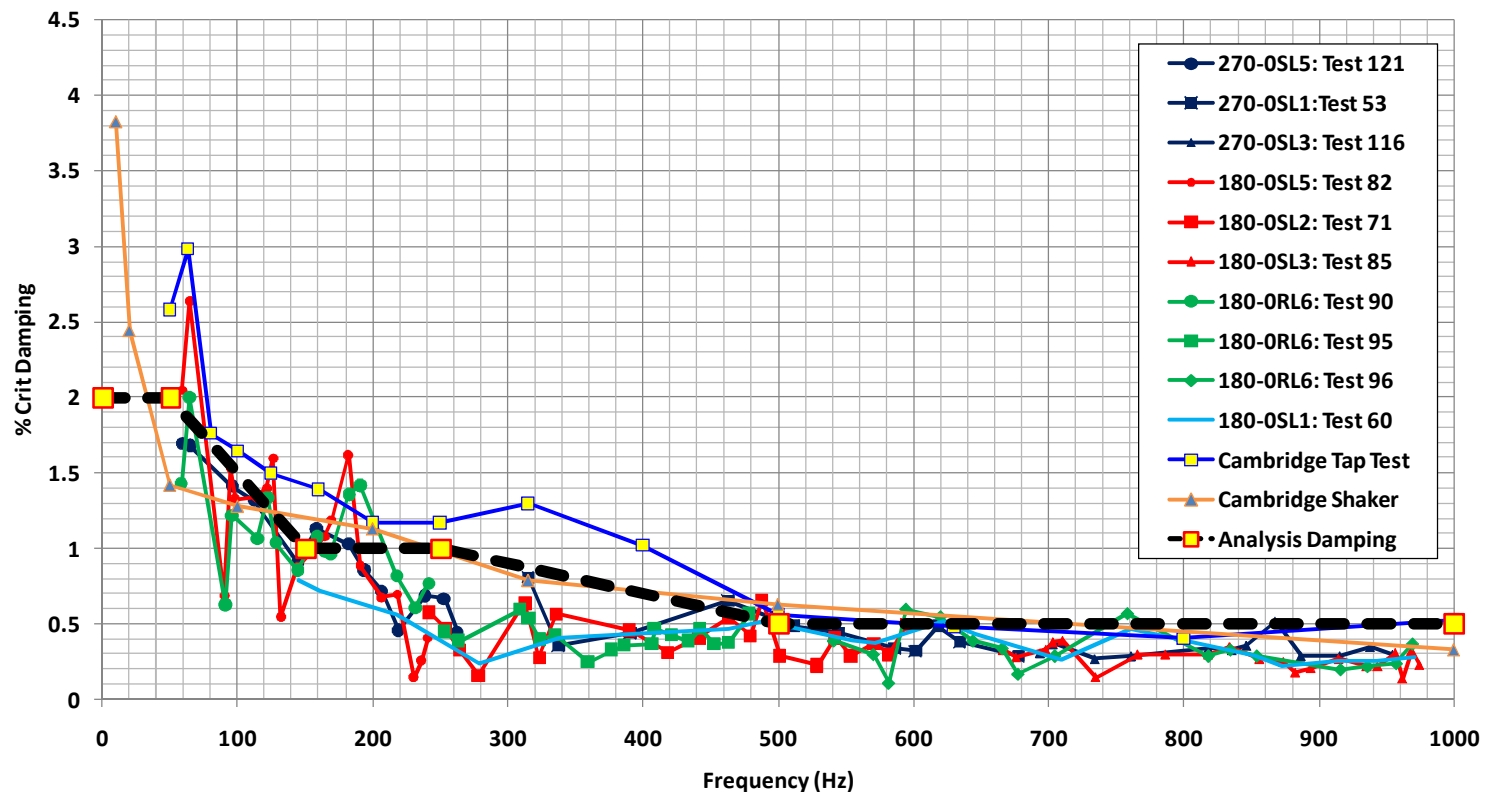




CM Shaker Test – Measured Damping

- The test damping values (by Cambridge Collaborative & Quartus) from the CM shaker test were unexpectedly smaller ($< 2\%$ critical) than the values used in all CLA's

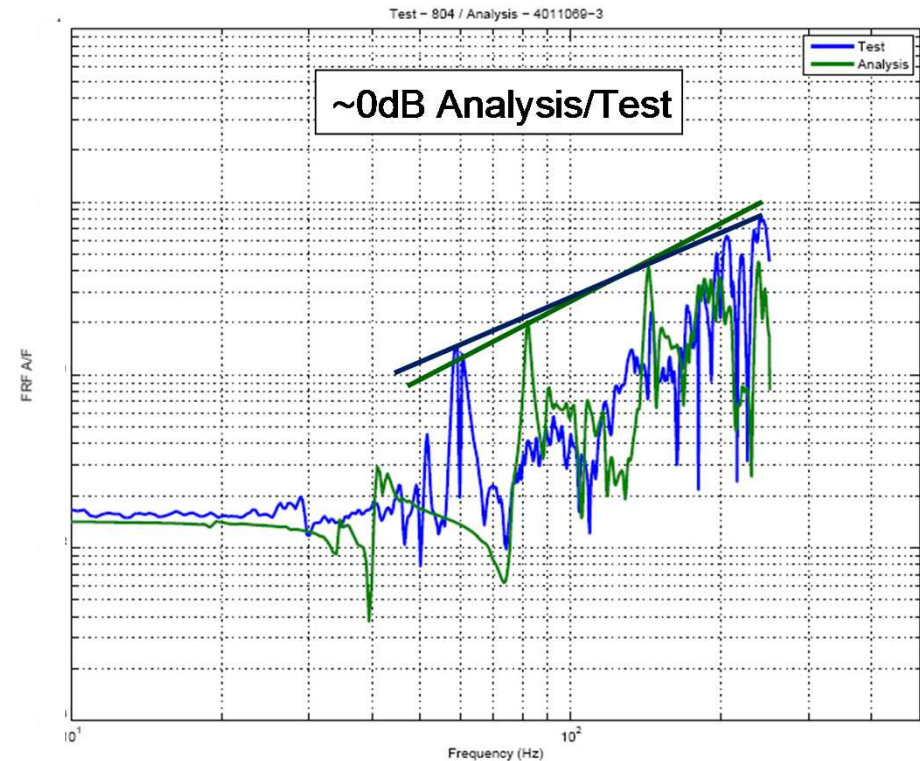
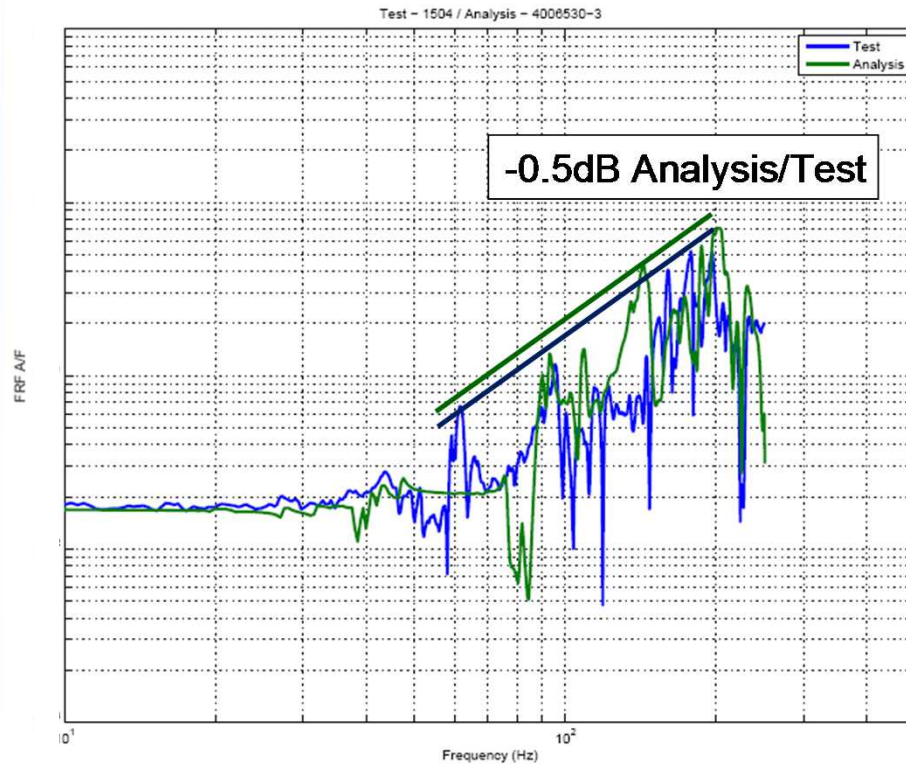
Modal Damping vs Frequency





Validation Portion of Shaker Test

Validation of FEM (by Quartus Inc.)



CM Acoustic Test

STRUCTURAL AND THERMAL SYSTEMS BRANCH

- Test conducted by Cambridge Collaborative Inc.
- Goals:
 - Provide transfer functions between acoustic excitation and vibration response
 - Validate the responses for equipment underneath FBC
- Results
 - TF's not used since low input levels (50 dB less than flight levels) resulted in low damping values
 - Used only for validation of the CM SEA model, i.e. with reduced damping

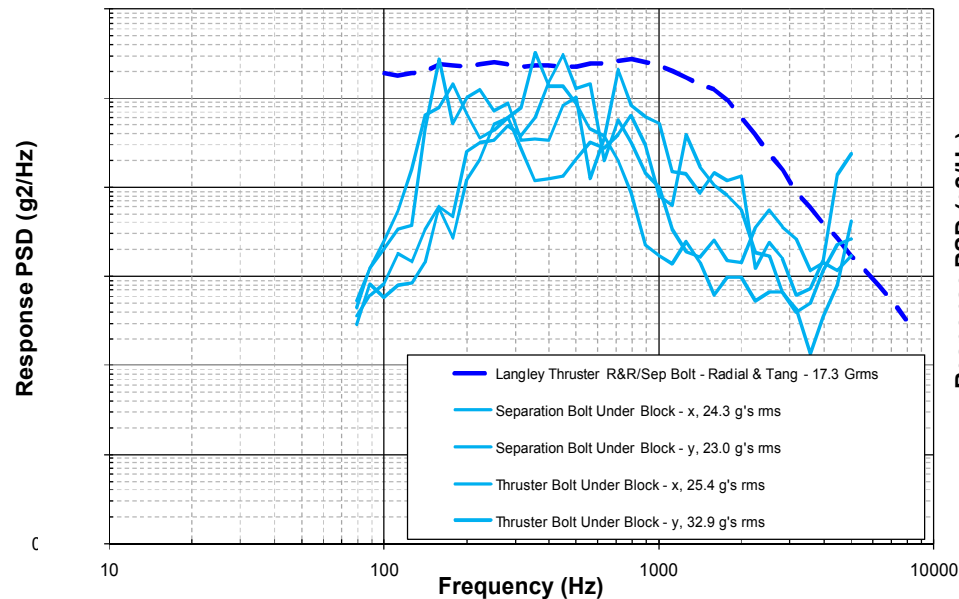




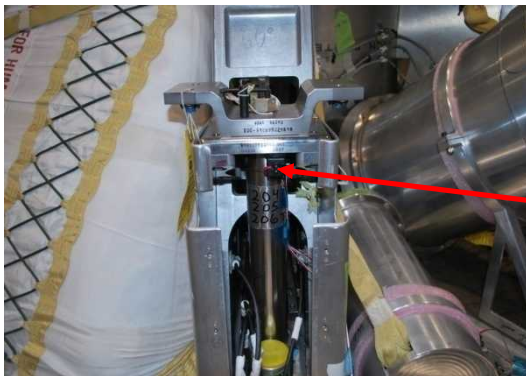
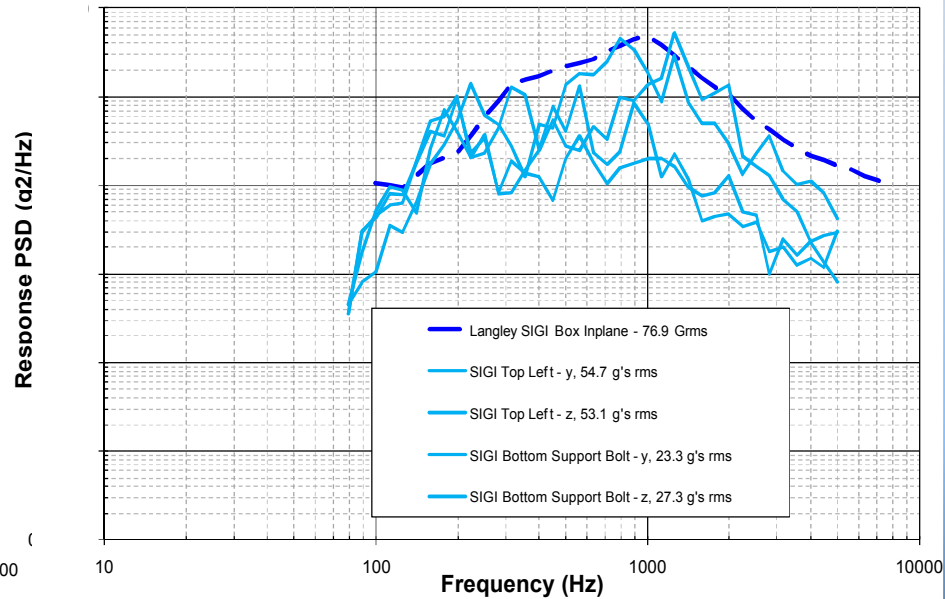
Validation Portion of Acoustic Test

- Validation of SEA Model (by Langley and Cambridge Collaborative)

Thruster & Sep Bolt I/F Response (Vehicle Lateral - Combined Load)

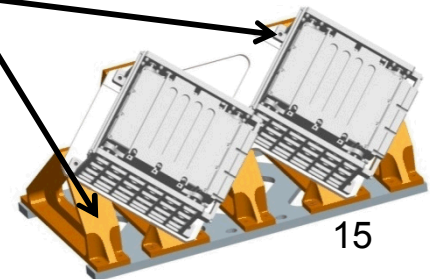


SIGI Box I/F Response (Inplane - Combined Loading)



Thrusters
Location 60°:
S-2a:4 (A) = 204
S-2a:5 (R) = 205
S-2a:6 (T) = 206

SIGI (Avionics) Box Interface





Summary of Risk Reduction Final Steps

Green: favorable**Red: not favorable**

	Risk Reduction Steps	Results/Findings
1	Examined all uncertainty factors on acoustic and structureborne environments	Considered necessary to use proposed uncertainty factors on input environments
2	Examined Launch Abort Motor (AM) for thermal conditioning to 60 degree F	Reduced AM thrust and lowered lift off acceleratoins
		CFD analysis by JSC CAP and plume & constituent study by ATA showed no reductions in acoustic environment
3	Calculated structureborne forcing functions at Abort Motor interfaces	Eliminated cross-talk between input AM interface excitations
4	Researched damping literature & test experience for bolted joints	Continued use of 2% critcal damping for all bolted structures



Environments Uncertainty Factors

Environment	Uncertainty	Rationale
AM Thrust	None	ST-1 measured and corrected for operating Temp.
ACM Thrust	None	Max thrust that can be produced. Rise time has not made any difference
Aerodynamics	None	Model validation against wind tunnel tests data
IOP	None	A second verification analysis should have been conducted to establish this factor. It is nearly impossible to guess at this factor.
Airborne	3dB	NASA Standards and TIM
Structure-Borne	5.2dB	NASA Standards and TIM

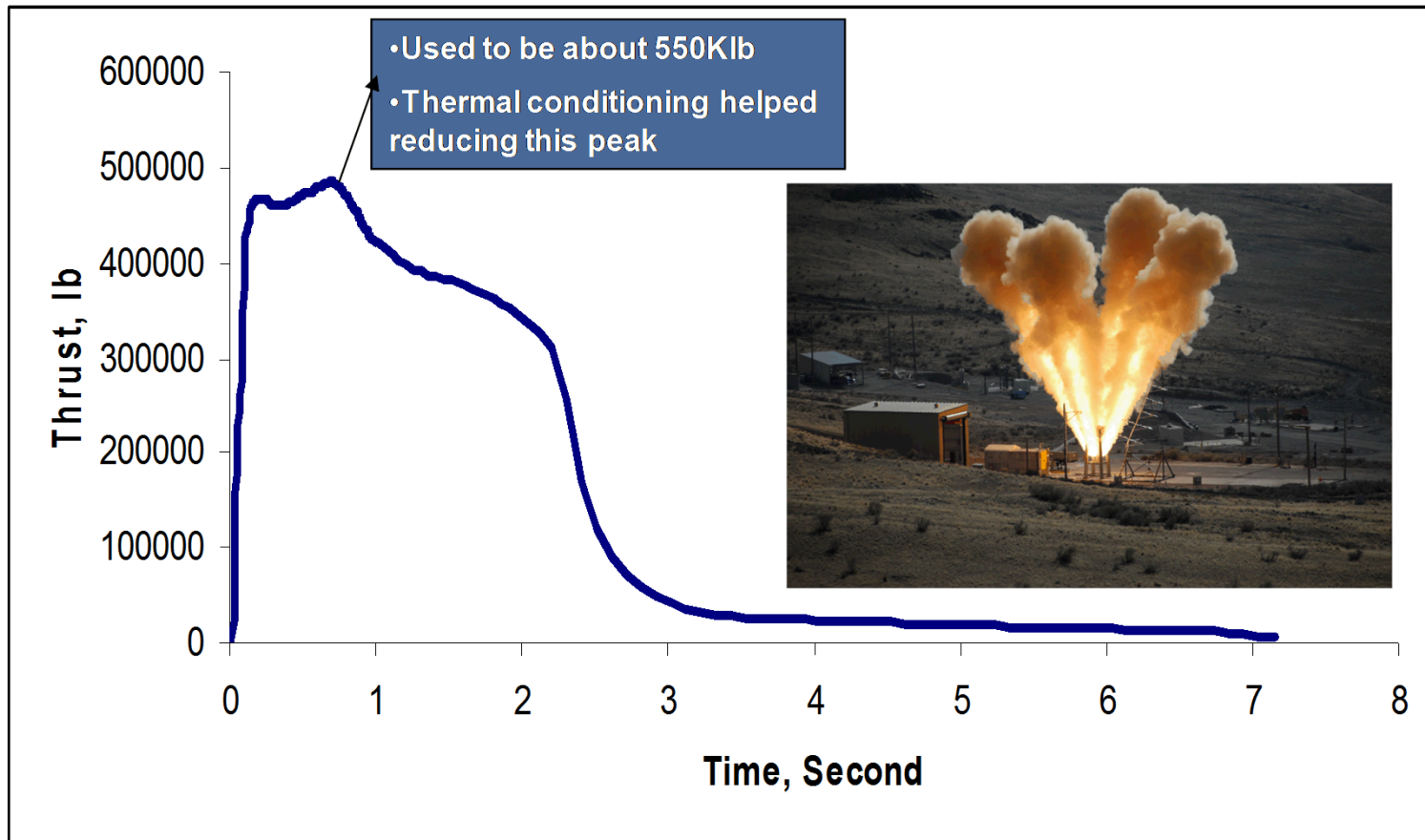


Analysis Uncertainty Factors

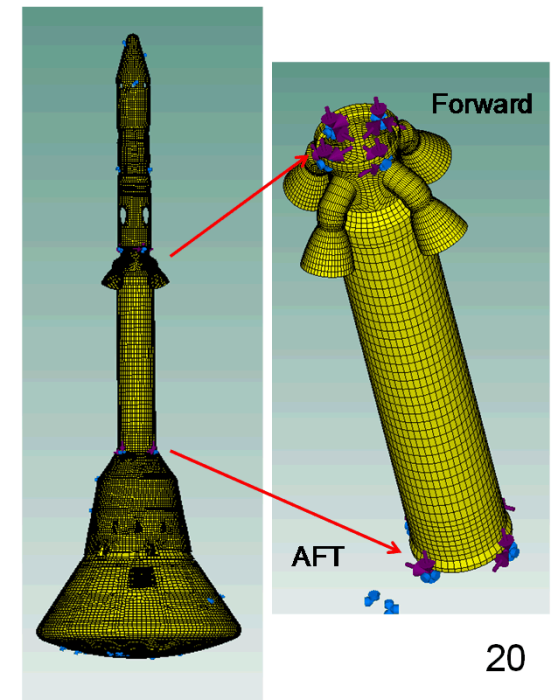
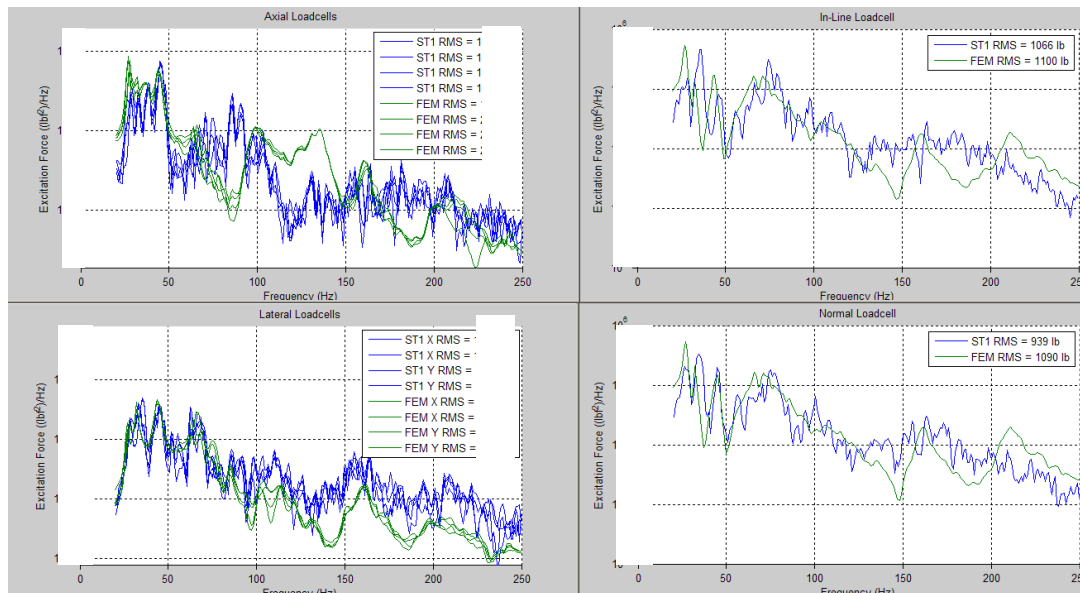
Analyses	Uncertainty	Rationale
Liftoff & Ascent Transients Loads	DUF=1.1	The individual hardware assemblies (CM & LAS) have been tested, and the FEMs represent the CAD models
SEA Prime Loads	None*	Good verification against acoustic test and verification loads
SEA Verification Loads	None*	Good verification against acoustic test and verification loads
BEA Prime Loads	None*	Good verification against acoustic test at 200Hz and above
FEA Verification Loads	None*	Relatively good agreement with BEA at below 100Hz

*Although no uncertainties were used on the individual mid- and high-frequency analyses, the vibroacoustic specs enveloped all analyses data

AM Thrust Reduction



- First developed time-domain FF to 330 Hz, then derived PSD forces/pressures from the time-domain FF (by ATA Inc.)
- The derived FF's are comprised of (by ATA Inc.):
 - ST-1 internal chamber pressures applied directly to the FEM internal chamber
 - ST-1 nozzle port pressures scaled appropriately to derive point forces applied to each nozzle





Lessons Learned

- Using AM pressure data (i.e. as opposed to envelop which caused cross-talk) had the most significant effect on vibroacoustic loads
- Using a damping value of 2% reduced the vibroacoustic loads significantly
- Cooling the AM reduced the static loads