Ares 1X Hybrid Modeling with Comparisons to Flight Data

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Integrated Loads, Structures, and Mechanisms
10 June 2010

Outline

- Ares 1X Flight Summary
- Ares 1X Data Summary
- Model Descriptions
- Model Comparisons to Flight Data
  - *Liftoff*
  - *Transonic*
  - *RCS Firings*
- Observations and Lessons Learned

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Ares 1X Test Flight

October 28th, 2009

- Flight objectives included characterization of acoustic and random vibration environments
- Assessment of the vibroacoustic modeling methods possible

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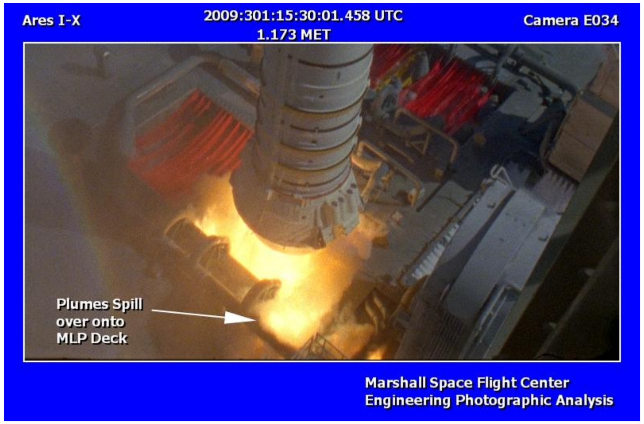
Significant Flight Events

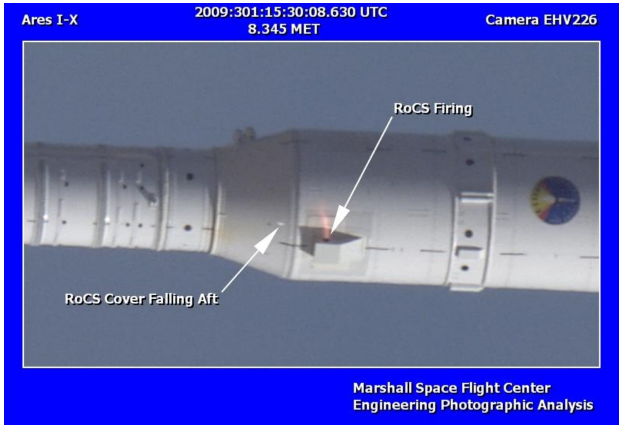
Possible Environment Drivers

Transonic

Liftoff



Roll Control Firings



- Peak Liftoff Pressures occurred at T = 3-5 sec
- Transonic occurred at T = 22-39 sec
- Roll Control Firings occurred 11 times throughout flight

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Ares 1X Flight Data Summary

- Low Frequency Channels (up to 100-150 Hz)
  - *Under review: 42 accelerations and 243 pressures*
- High Frequency Pressures (up to 1250 or 2500 Hz)
  - *5 of 60 channels did not produce good data*
- High Frequency Accelerations (up to 1250 or 2500 Hz)
  - *3 of 21 channels did not produce good data*
- Data Validity and Filtering for HF Channels
  - *An anti-aliasing filter was applied to the raw data at 4x the sample rate*
  - *Data for the ~5200 samples/sec channels are good to about 1000-1250 Hz*
  - *Data for the ~10400 samples/sec channels are good to about 2500 Hz*

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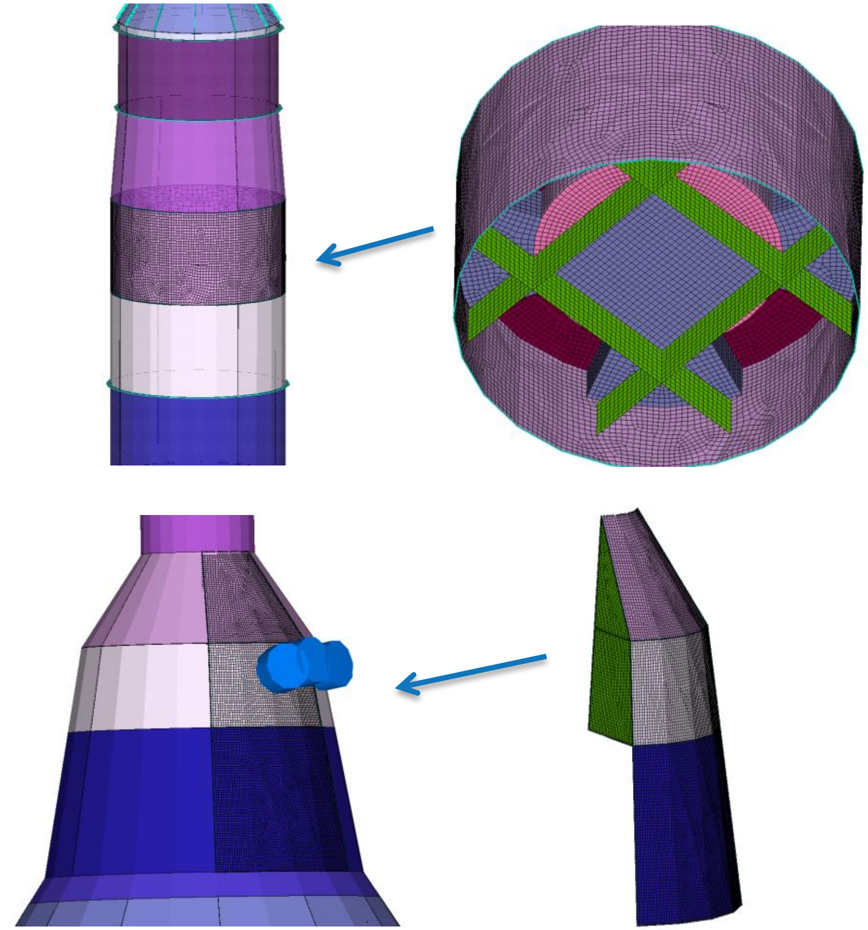
SEA and Hybrid Models

Multi-model approach

- SEA Models built from FEM as a preflight exercise
- External Pressure Loading
  - *Representative flight pressures applied*
- Standard Damping
  - *1% loss factor*
- Standard Cavity Absorption
  - *1% absorption*
- SIF Applied to All External Surfaces
- Hybrid models built with local detail then integrated into full-stack SEA models
- Hybrid Connections
  - *Manual hybrid line connections used at FE/SEA I/F*



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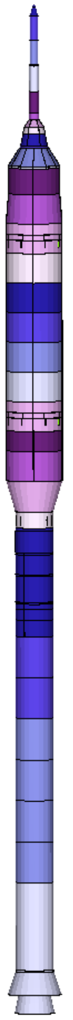
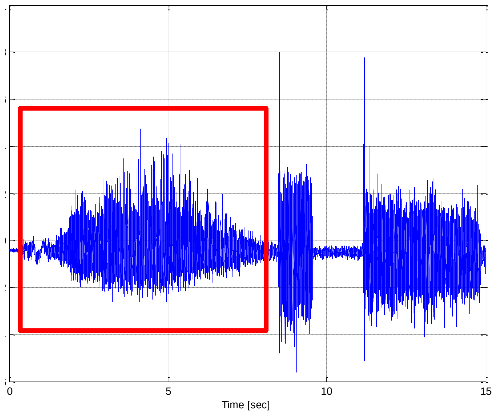
Liftoff Reconstruction Analysis

Flight time 4 to 4.5 seconds

- SEA and SEA/FE hybrid model results compared to processed flight data (20-1000 Hz for 5200 sample rate, 20-2000Hz for 10400 sample rate)
- Processed flight data for pressures and accelerations at the 4 – 4.5 second interval
- Applied flight pressures to the model and recovered accelerations at the locations corresponding to the flight instrumentation
- No adjustments to the models or modeling parameters were made post flight



Pressure Time History



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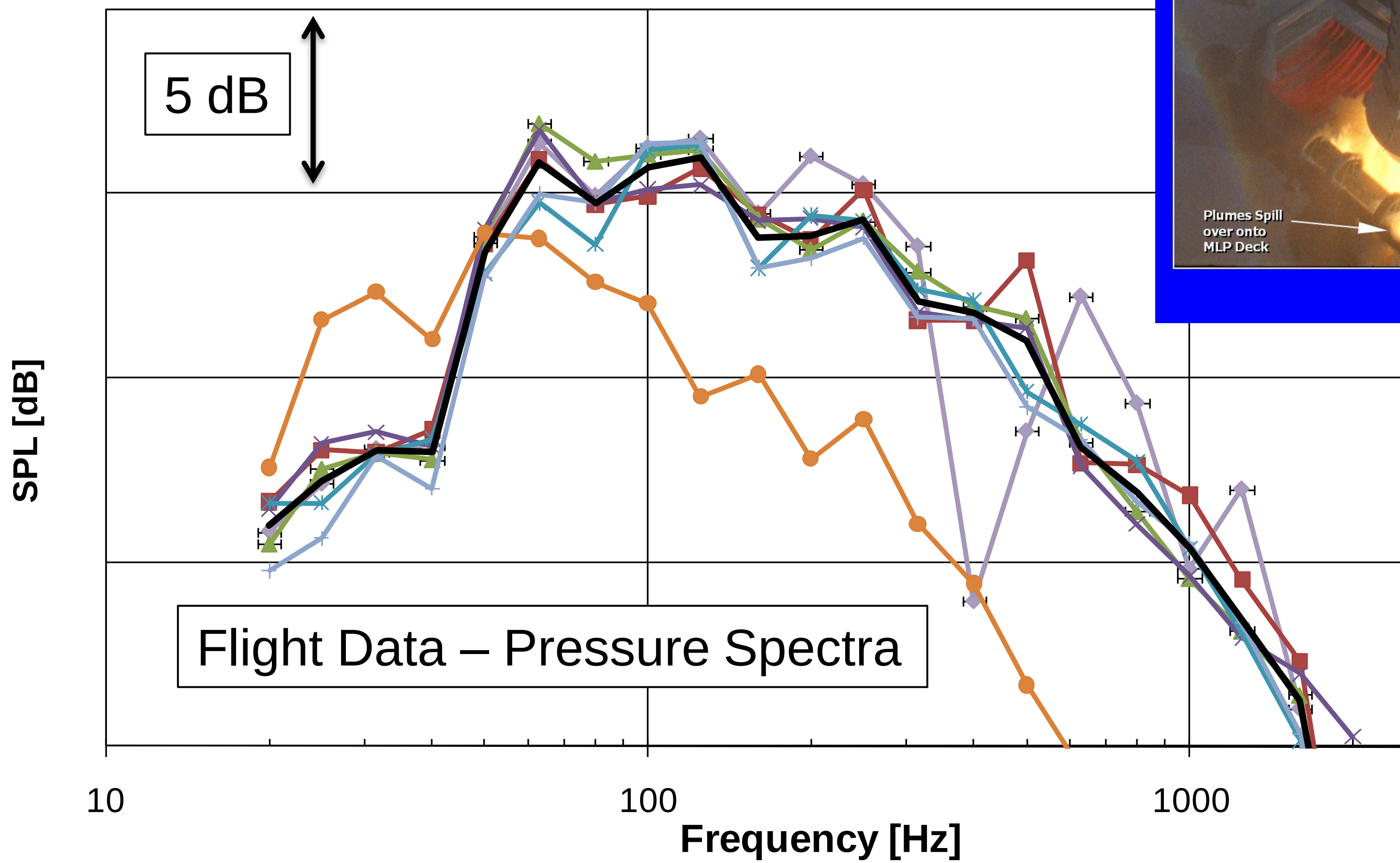
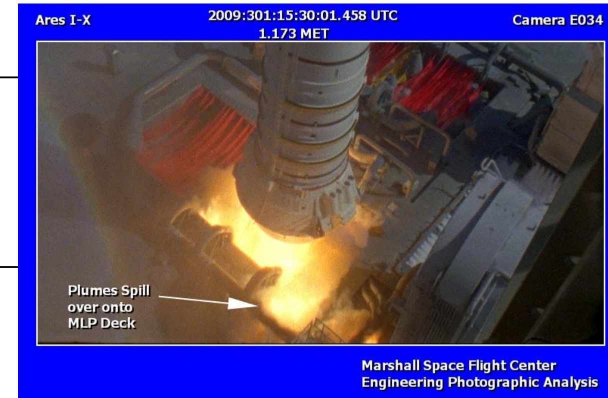
Liftoff PSDs (T = 4-4.5s)

Forward Vehicle Section





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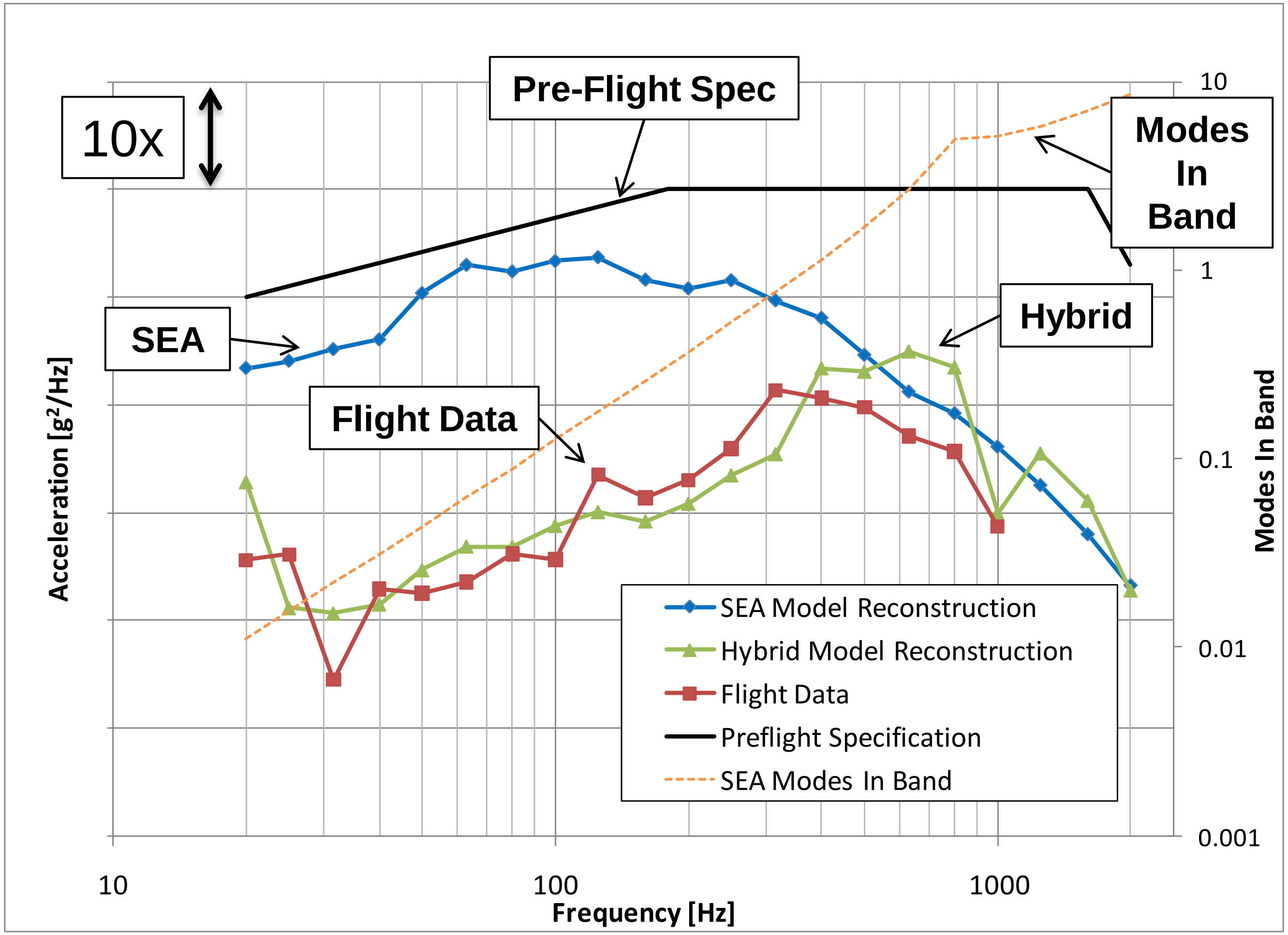
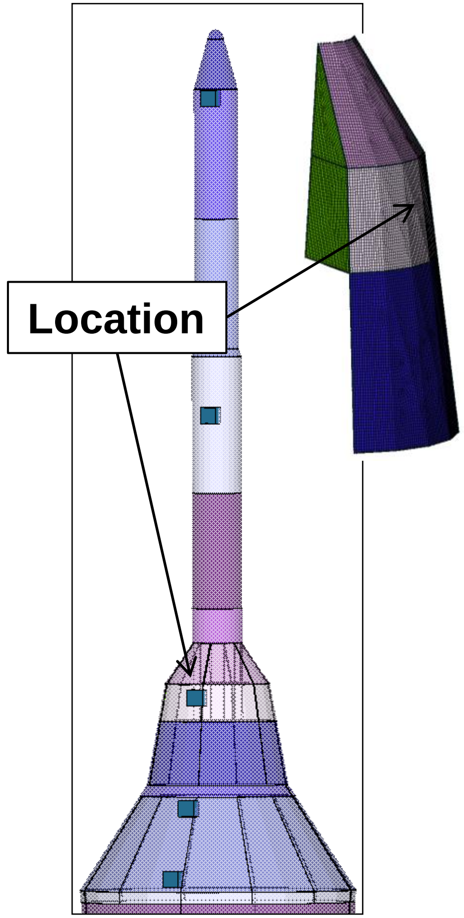
Liftoff Response Comparison

Model vs. Flight Data





SEA greatly over predicts at frequencies of low modal density, whereas the hybrid model is very accurate by accounting for the discrete modes

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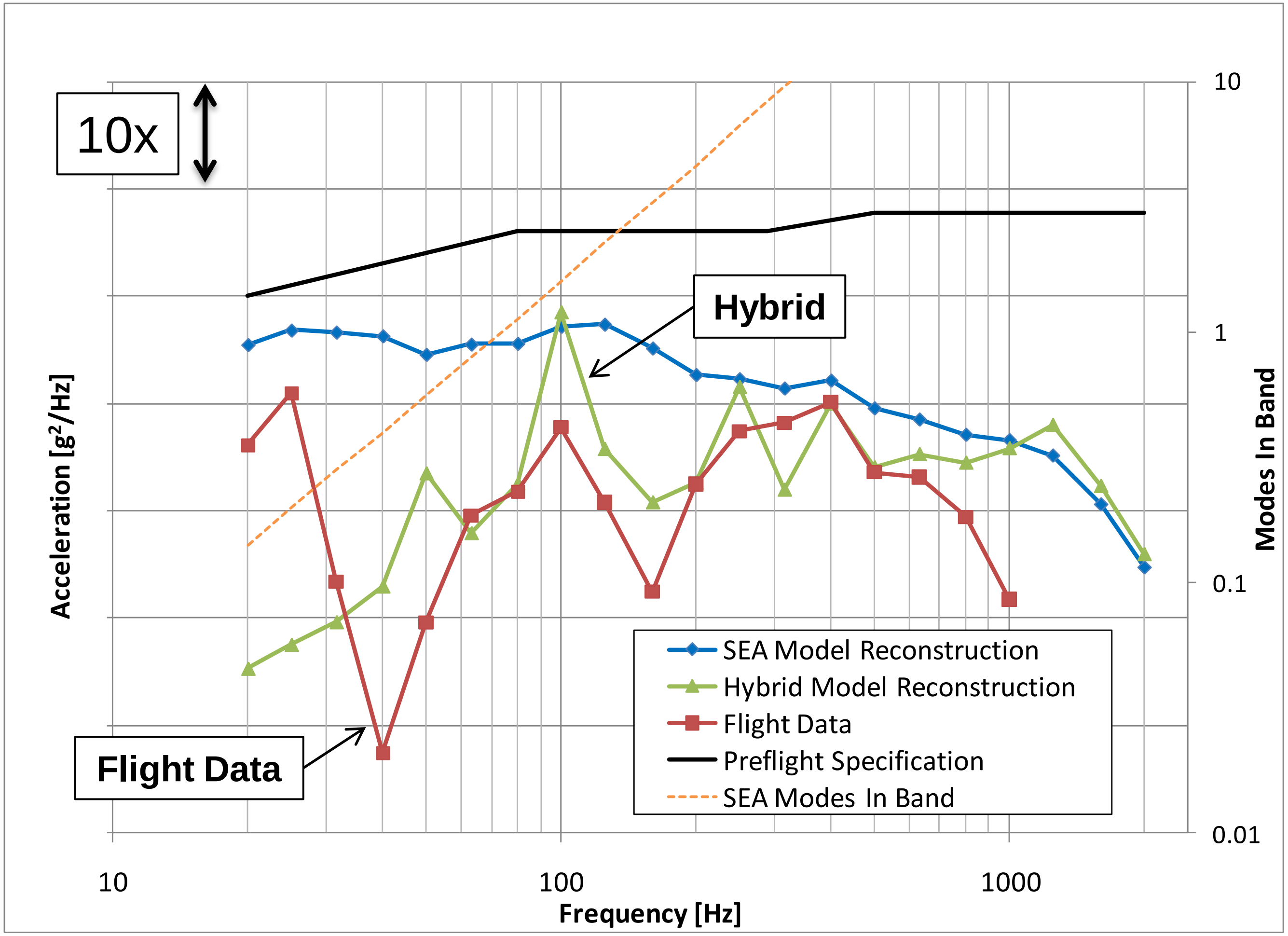
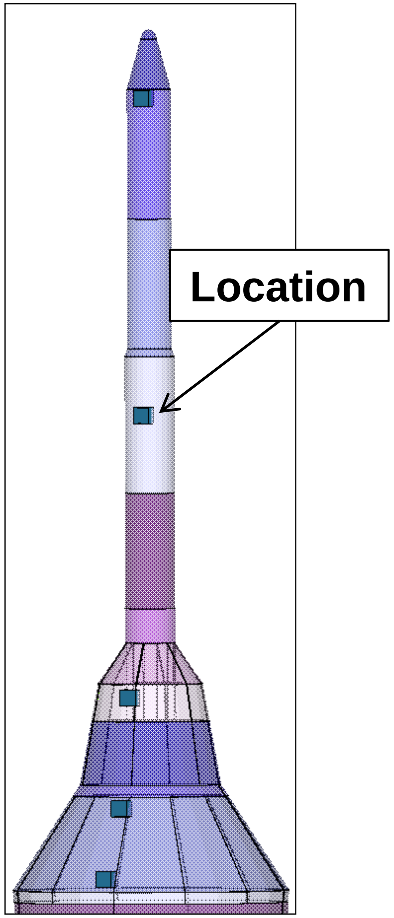
Liftoff Response Comparison

Model vs. Flight Data





Lack of FE model fidelity is most likely the cause of the poor correlation <50Hz

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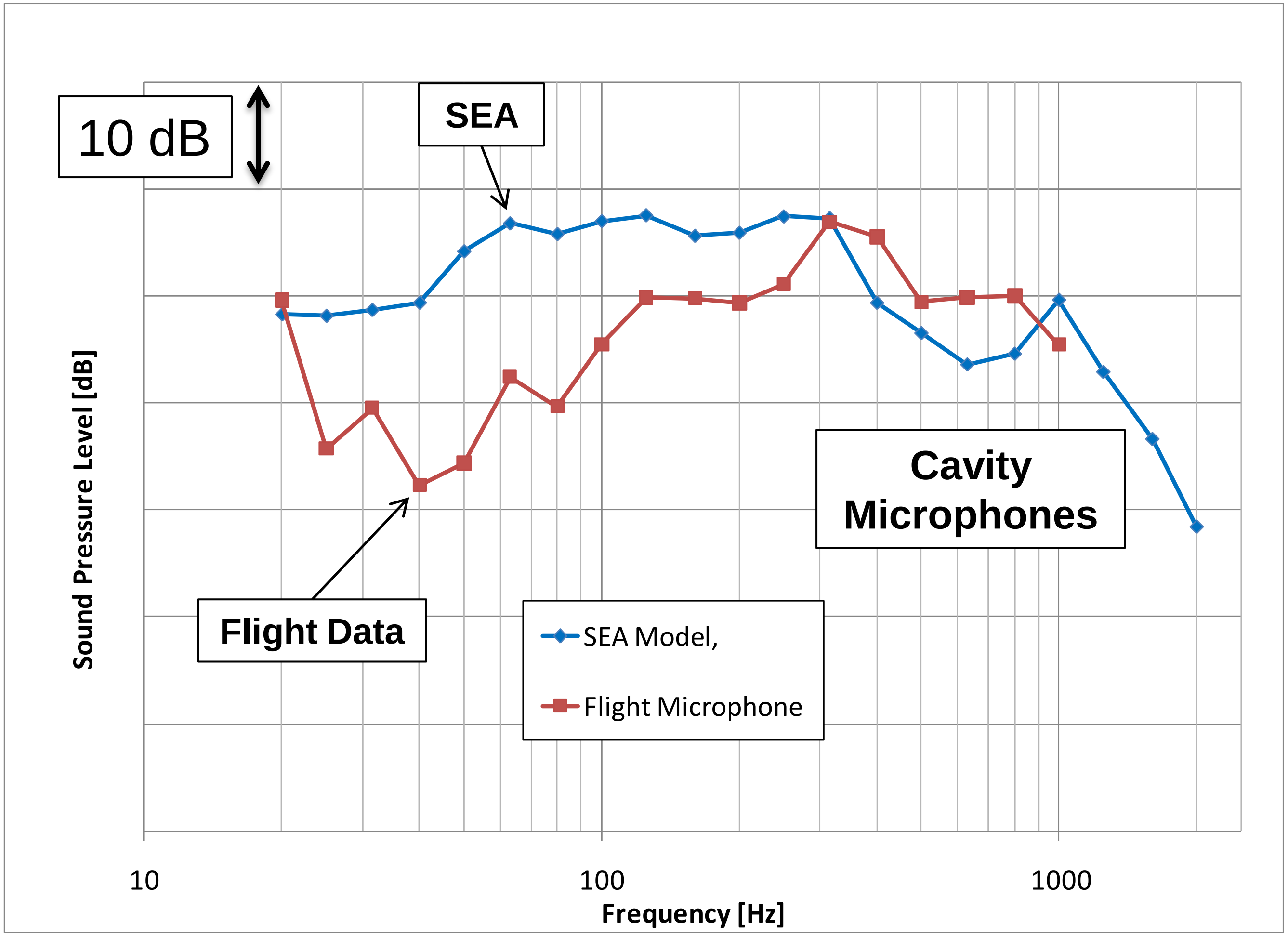
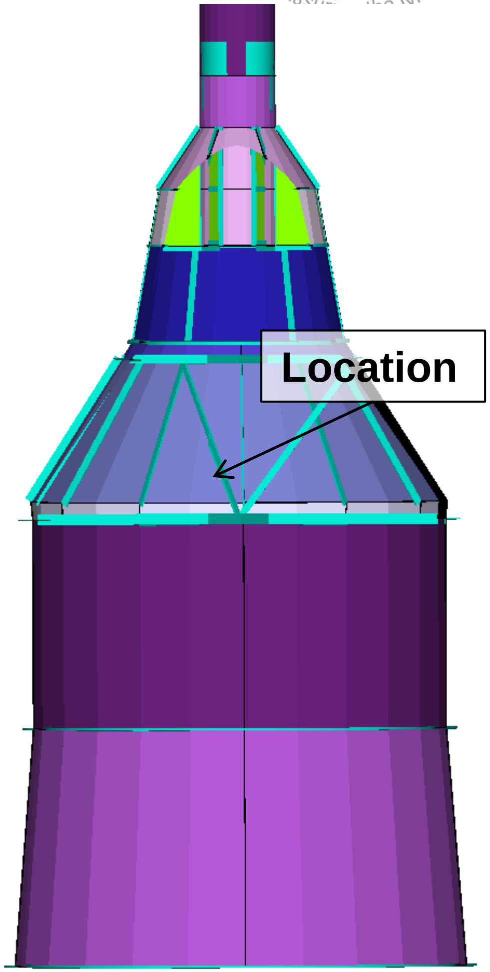
Liftoff Response Comparison

Model vs. Flight Data





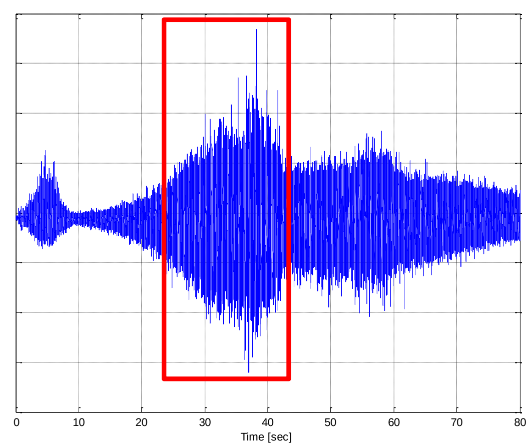
Poor correlation most likely from the inability to capture correct CM Panel response

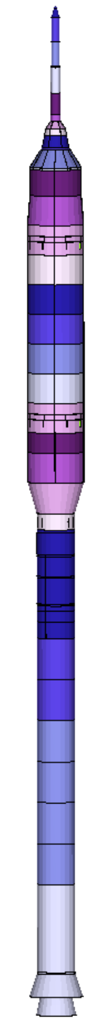
Transonic Reconstruction Analysis

Flight time 35.5 to 36.0 seconds

- SEA and SEA/FE hybrid model results compared to processed flight data (20-1000 Hz for 5200 sample rate, 20-2000Hz for 10400 sample rate)
- Due to the widely varying pressures and minimum and maximum pressure level were used
- Applied TBL loading for M=0.85 with default parameters
  - *Distance from leading edge modified to the distance from the vehicle nose*

<u>*Pressure Time History*</u>





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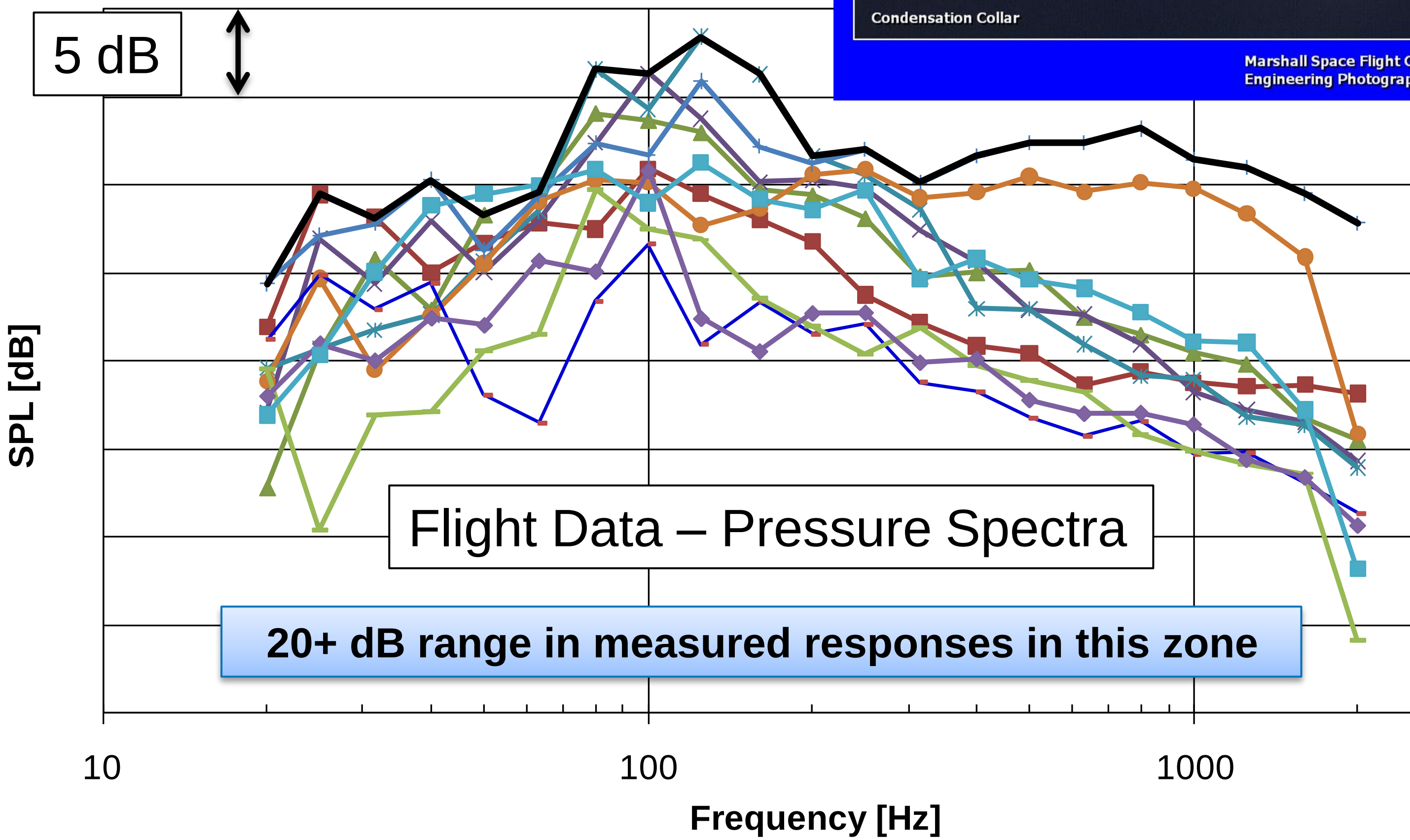
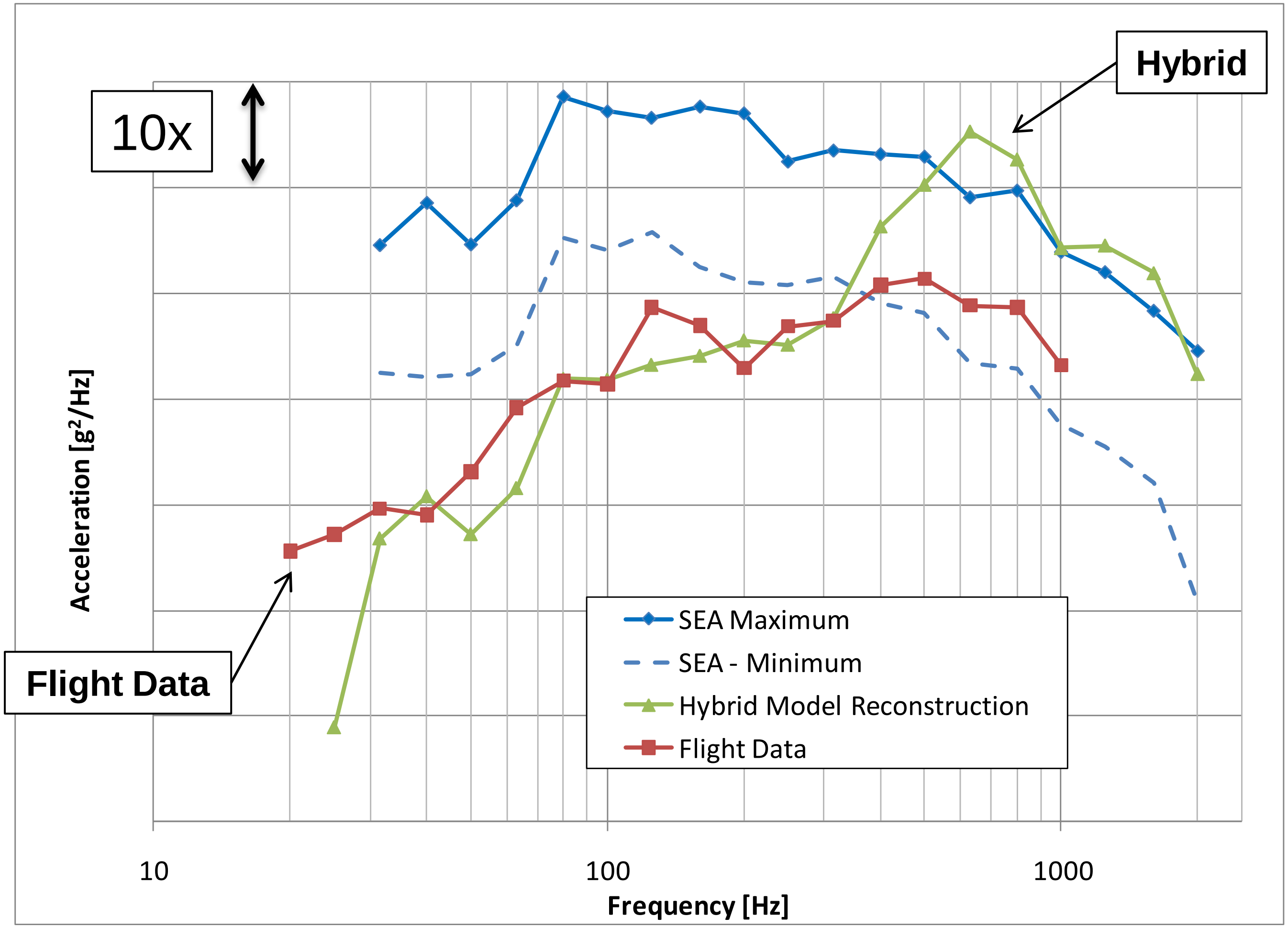
Transonic PSDs (T = 35.5-36.0s)

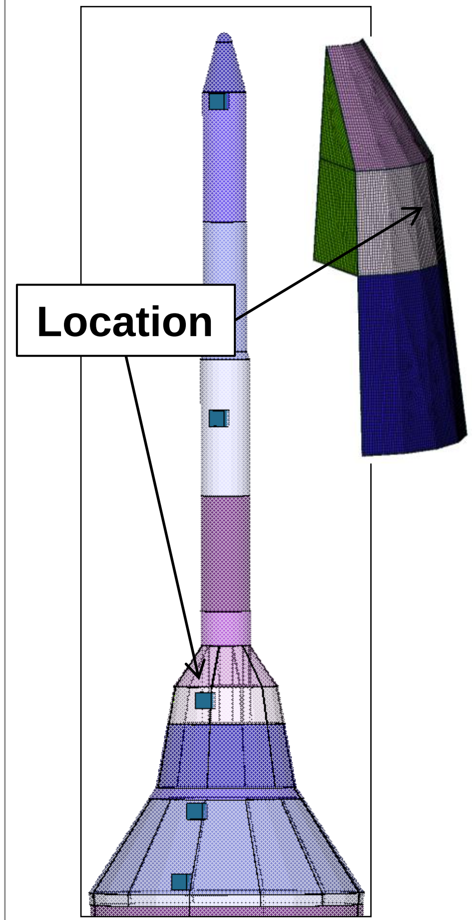
Forward Vehicle Section



Transonic Response Comparison

Model vs. Flight Data





High frequency over prediction occurs just above the ring frequency of the panel

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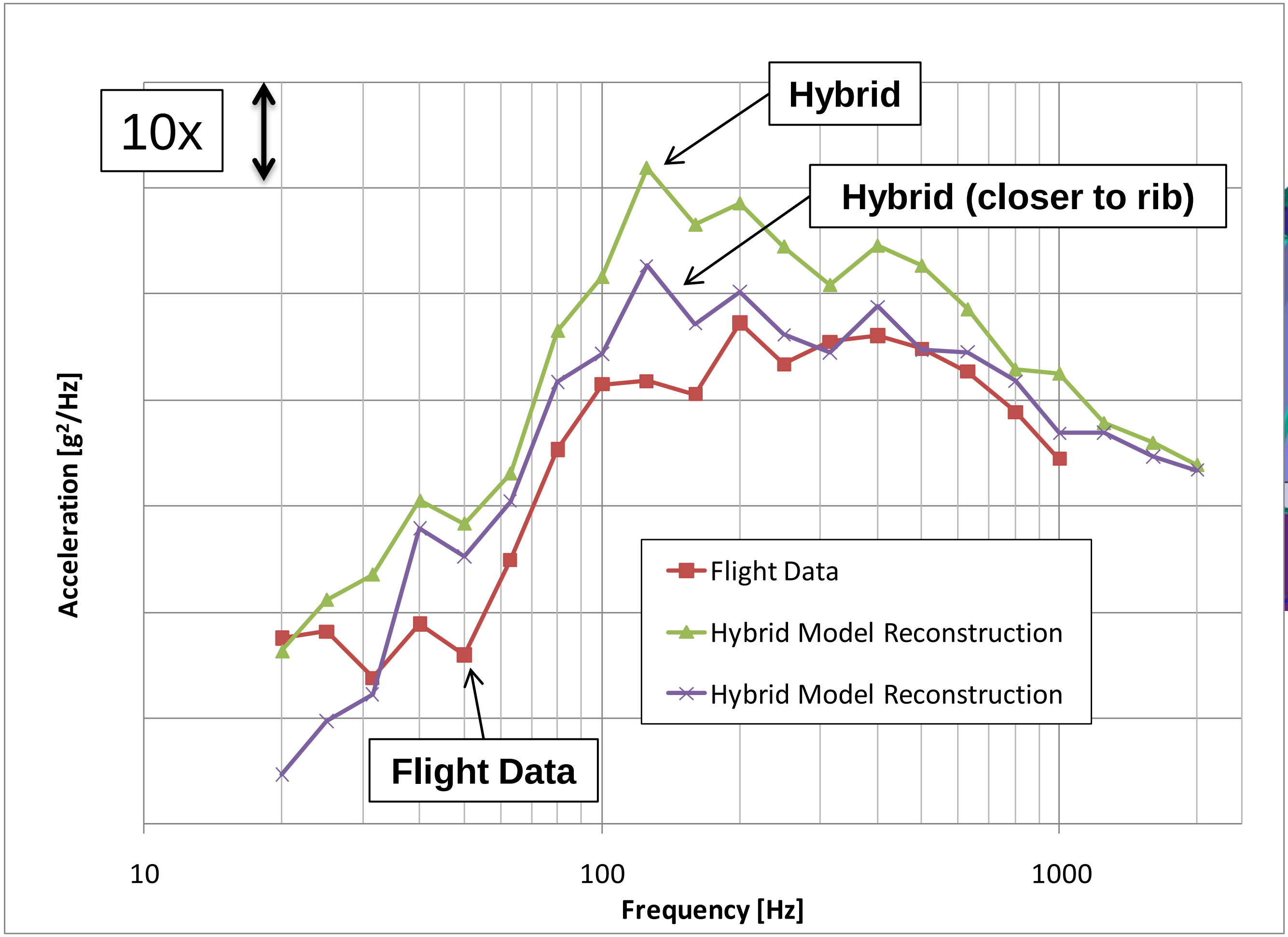
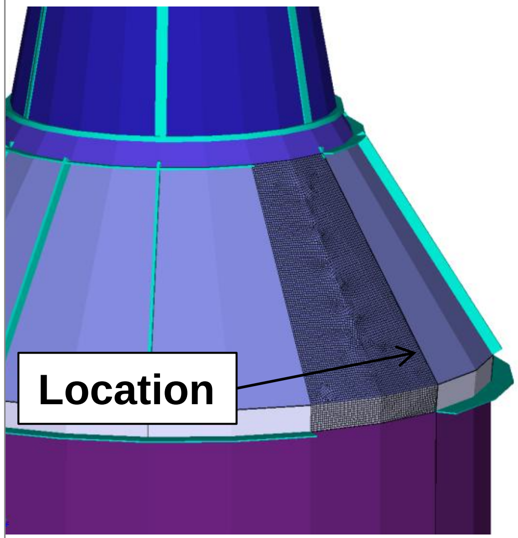
Transonic Response Comparison

Model vs. Flight Data





Instrument location is a significant factor in assessing the accuracy of the model predictions

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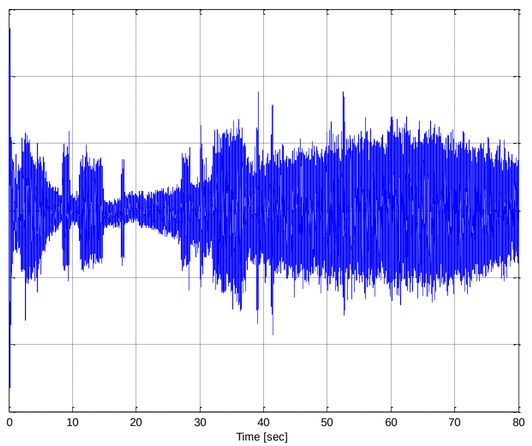
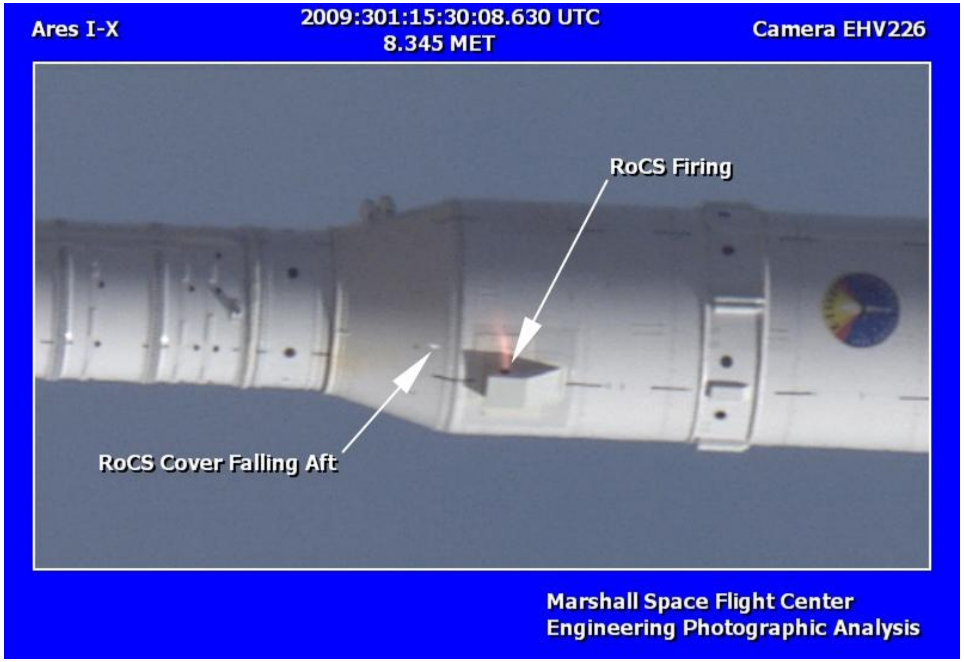
Roll Control Thruster Firings

Flight time 8.5 seconds

Acceleration Time History





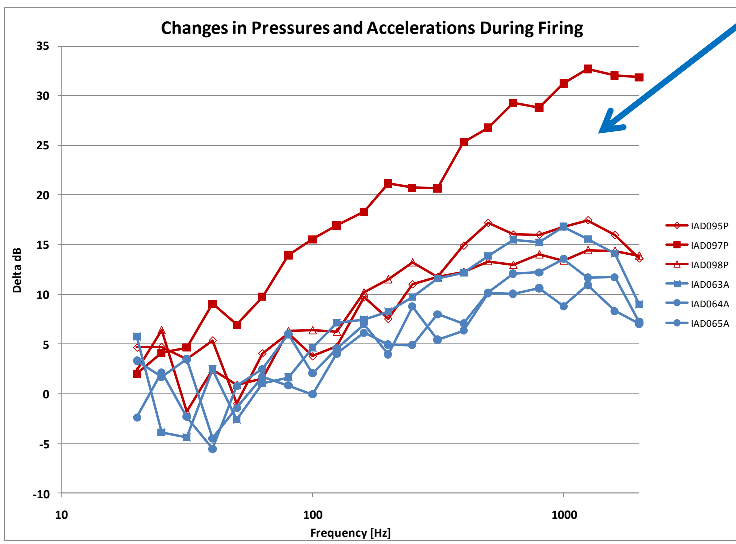
- Thruster firings induced significant vibrations in the first and upper stages
- Data and modeling assessment completed to determine the source of the vibration and the ability to simulate the event

Acoustic or Mechanical Driven?

Data Assessment

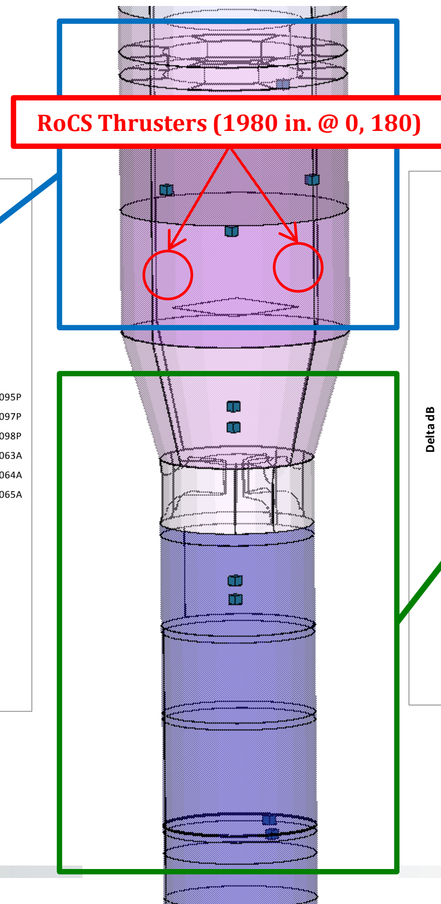
- The trend of the pressure increase equal to or greater than the increase in acceleration response, implies that most of the response is <u>thruster plume acoustic driven</u>

Delta dB increase when thrusters fire
Upper Stage

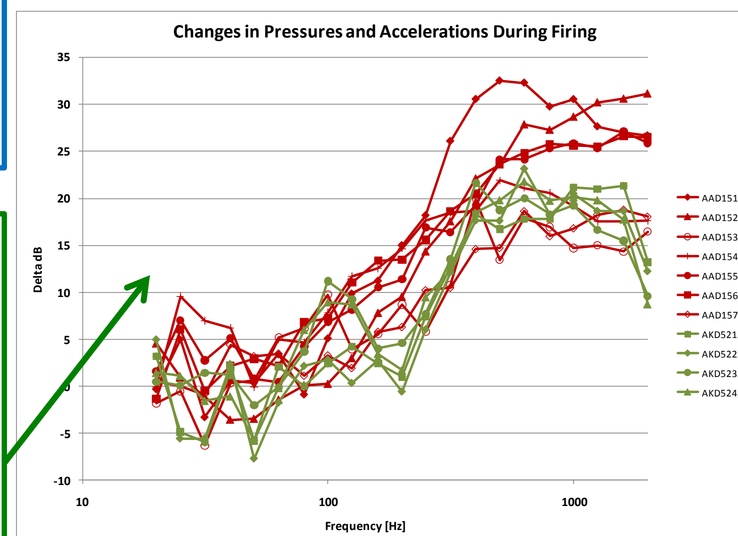


Red are <u>pressure</u> response deltas

Blue are <u>acceleration</u> response deltas



Delta dB increase when thrusters fire
First Stage



Red are <u>pressure</u> response deltas

Green are <u>acceleration</u> response deltas

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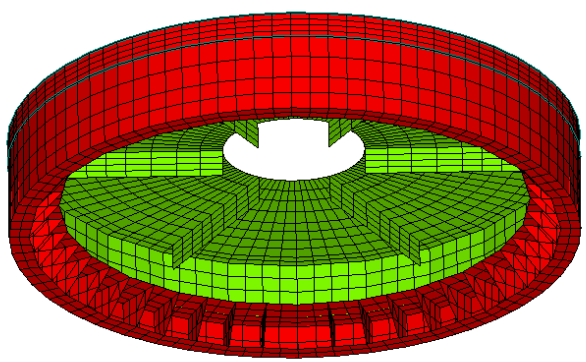
RCS Firing SEA/Hybrid Modeling

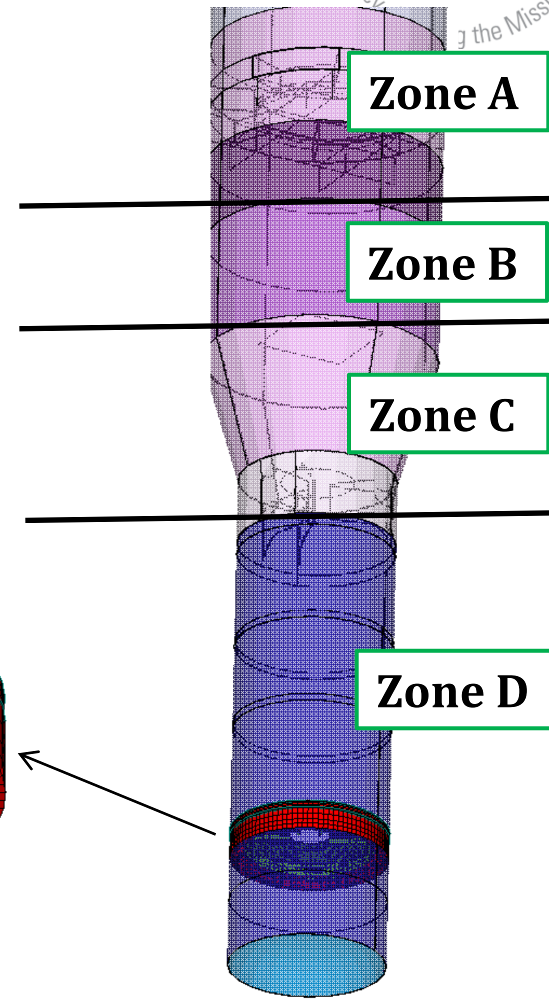
Multi-model approach

- Model First Stage Avionics Module (FSAM) location during a time while RCS is firing and a time without
- Apply the time consistent pressures and compare the change in predicted response to the flight response
- Partially integrated model broken into 4 loading zones

FSAM CAD



FSAM FE Section



Hybrid Model

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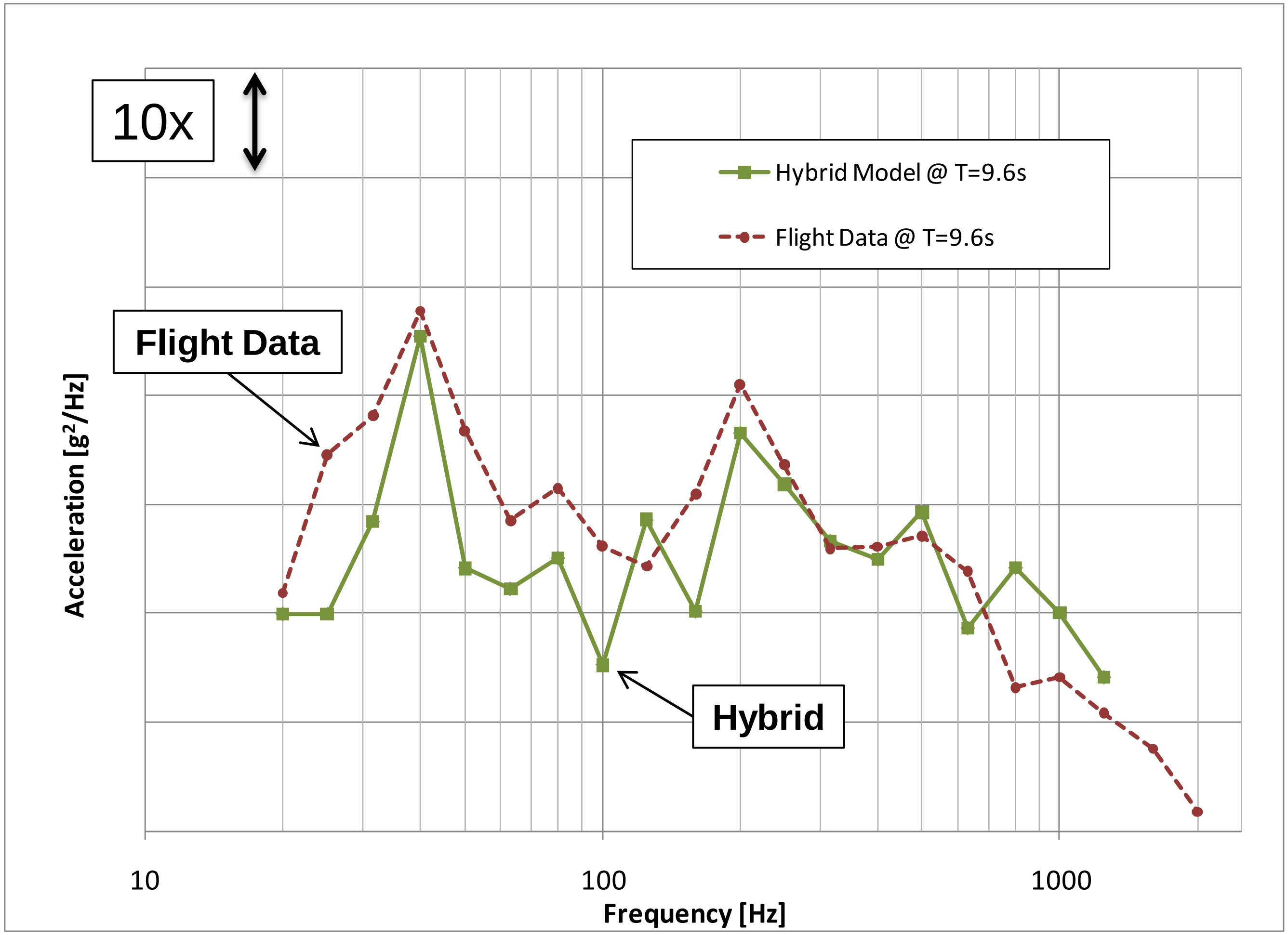
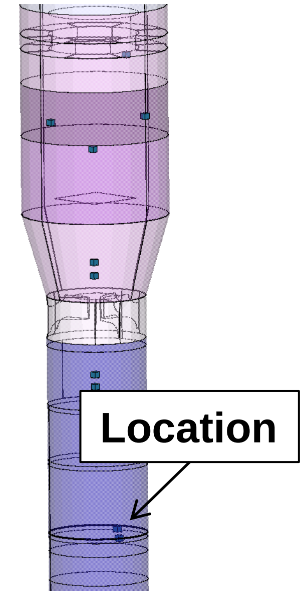
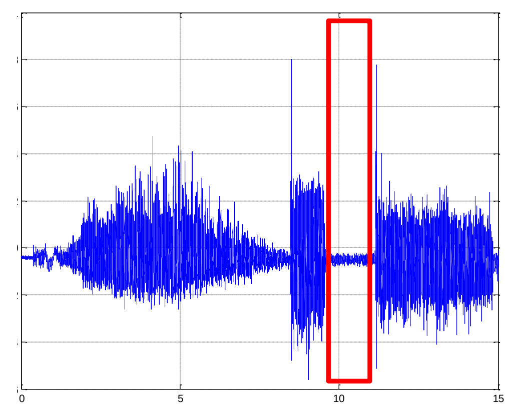
Nominal Flight Response Comparison

Model vs. Flight Data



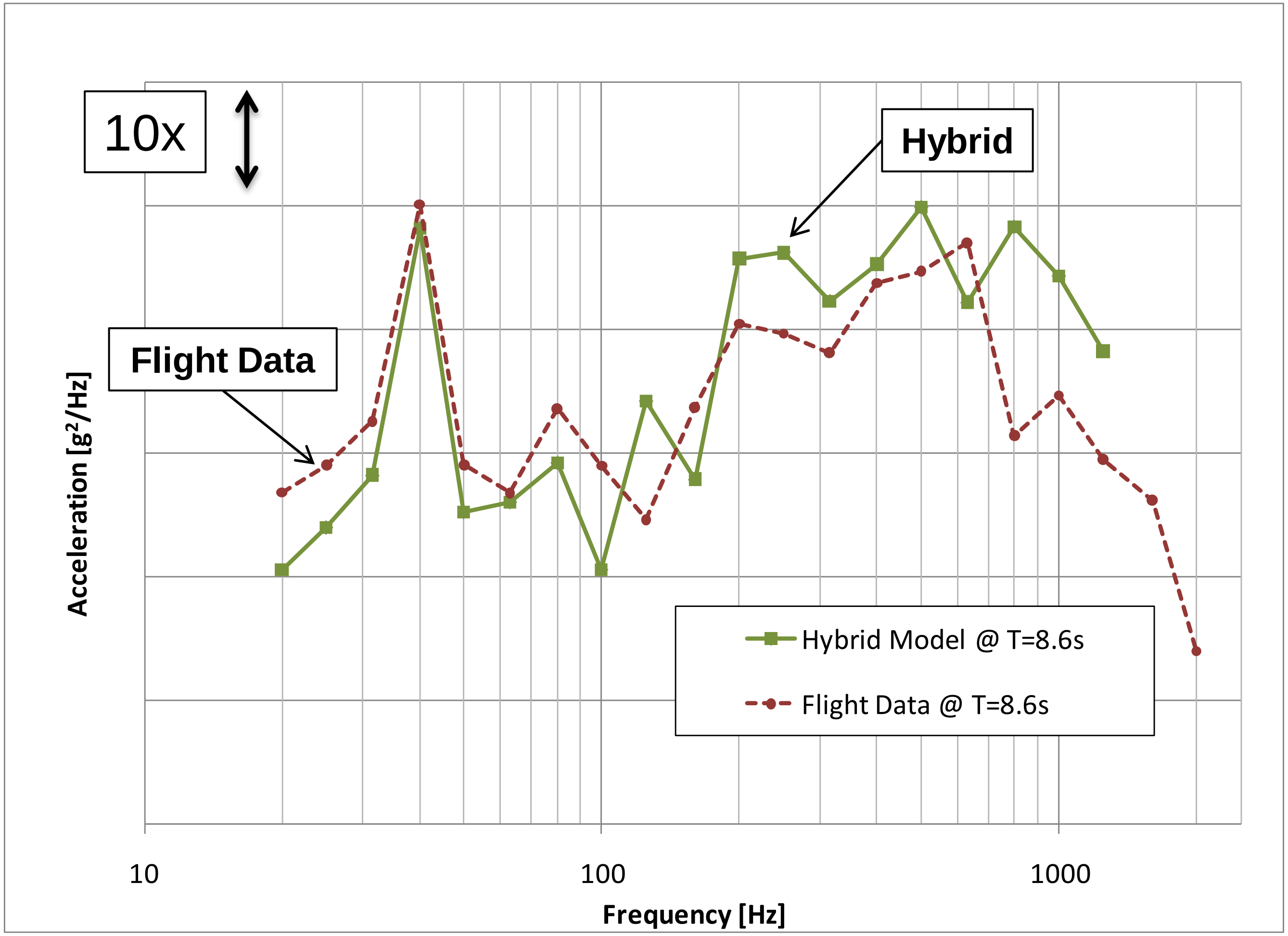


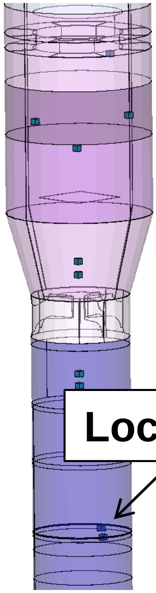


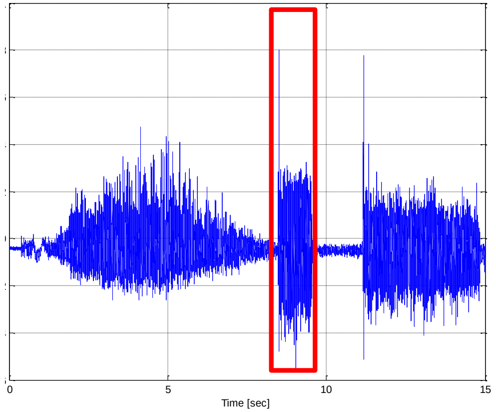
SEA alone has difficulty modeling the structural characteristics of the FSAM

RCS Firing Response Comparison

Model vs. Flight Data







Given that the simulation is linear, the increase in pressure captures the correct response…the firings can be modeled!

Observations and Lesson Learned

- Multi-model hybrid method
  - *Quick model set-up with an attractive computational cost when compared to full vehicle FEM or BEM*
  - *Hybrid results matched well with full vehicle FEM on another program*
  - *SEA not valid in the bulk of the frequency range of interest in many cases*
- Building Experience
  - *Model fidelity was a key player in the degree of correlation to test data*
  - *Instrumentation location during flight or in tests critical for model correlation*
  - *Correlating models for vibrations due to aero-acoustics may require a more controlled environment than the flight test*
  - *RoCS events are significant for random vibration and they can be predicted though modeling*

This flight has provided tremendous knowledge on modeling launch vehicle vibroacoustics and much more like it need to occur

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Thank you

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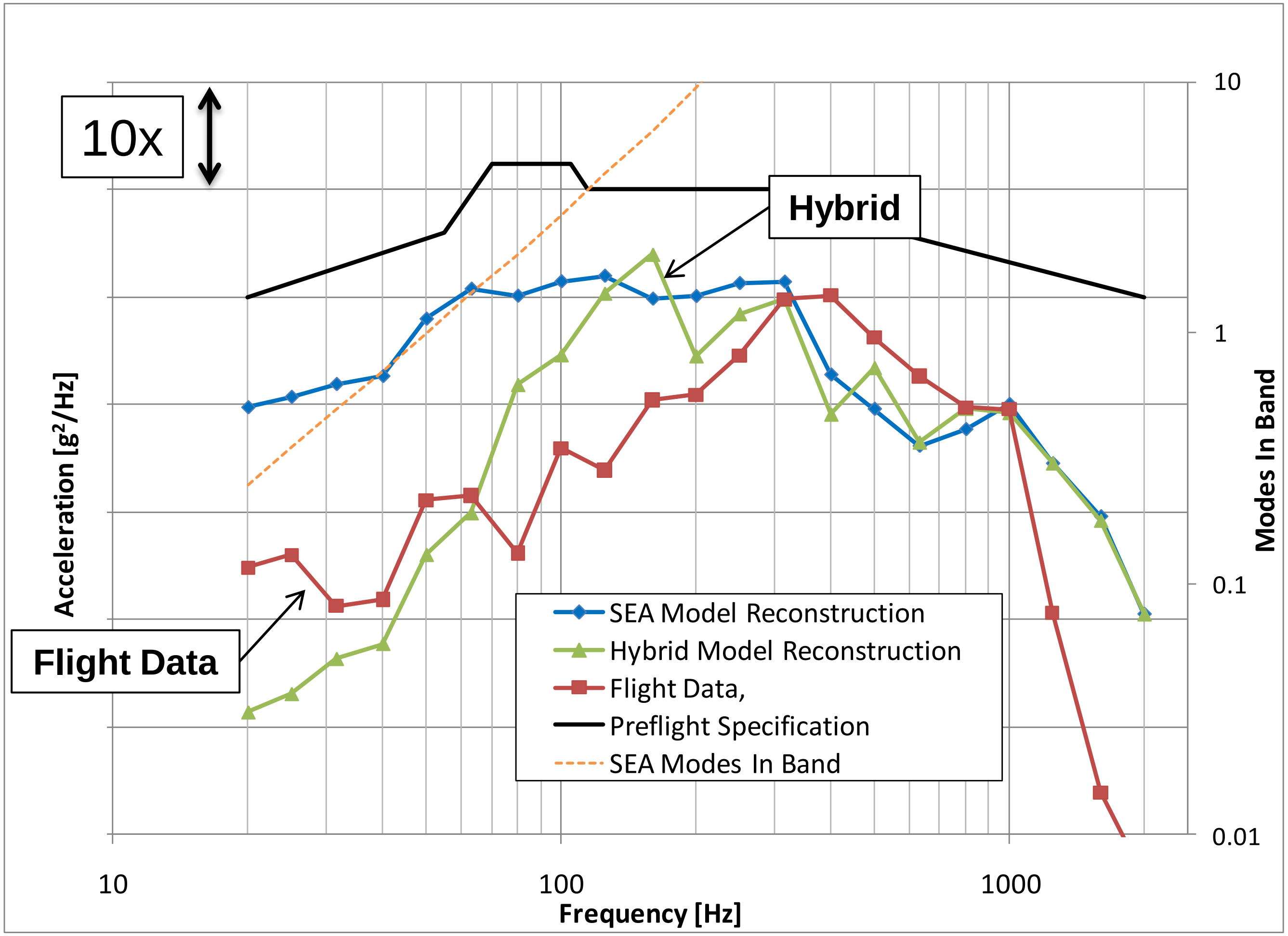
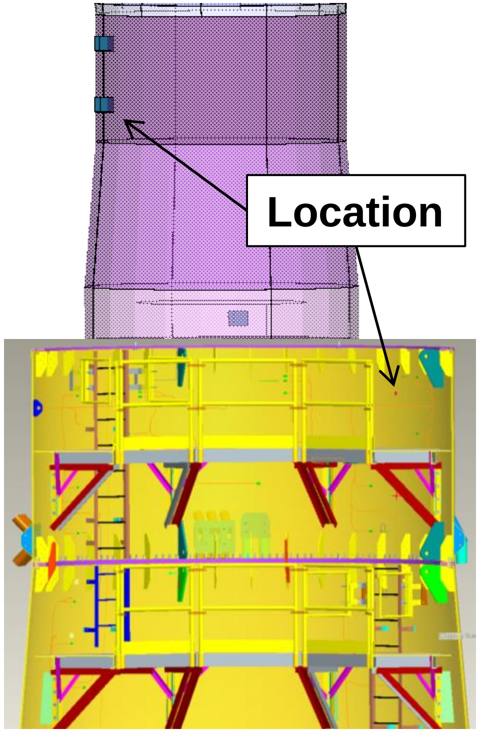
Liftoff Response Comparison

Model vs. Flight Data





The SM area is modeled as a simple panel and it is evident from the CAD picture that there is much more structure required for an accurate prediction

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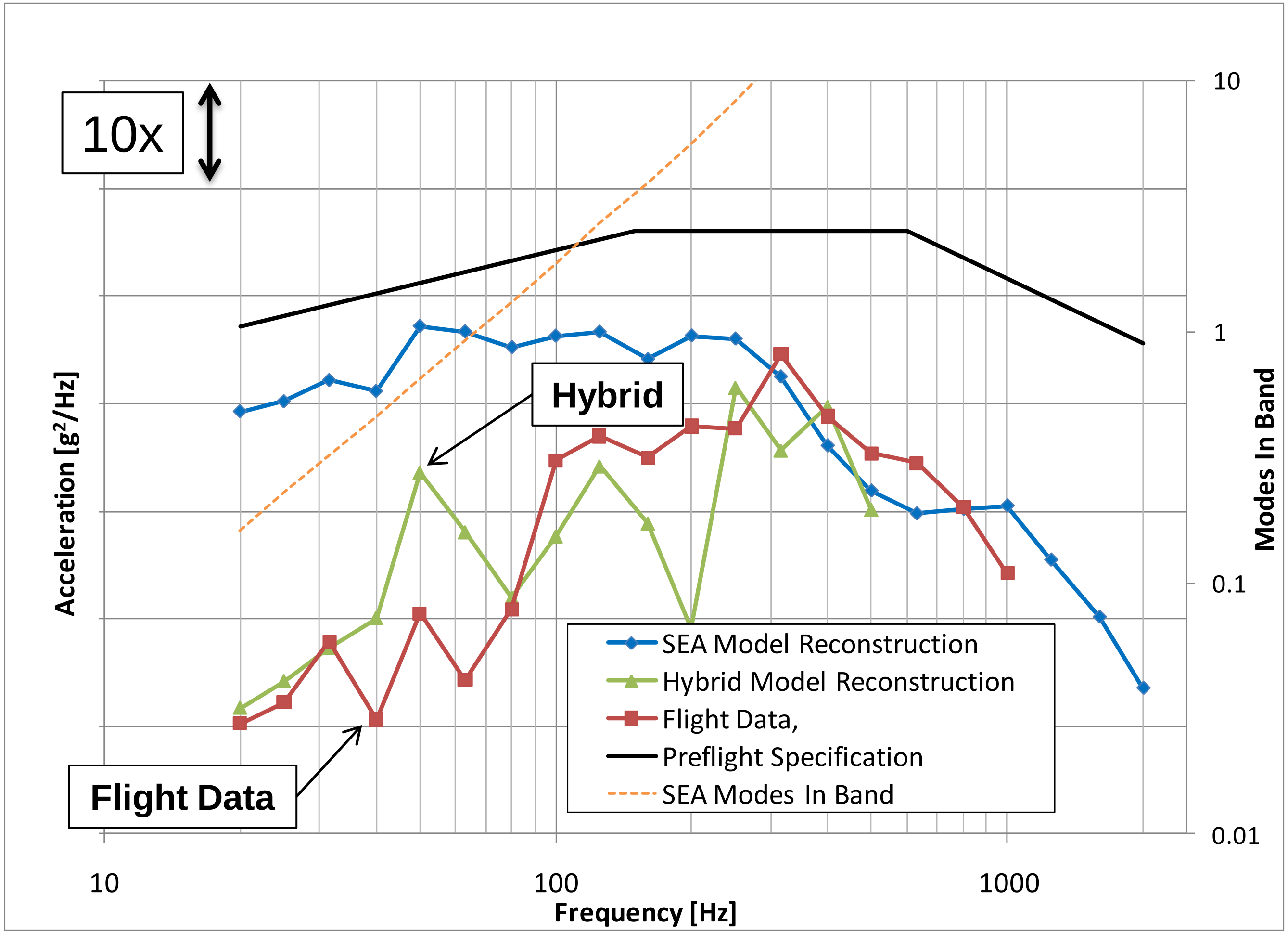
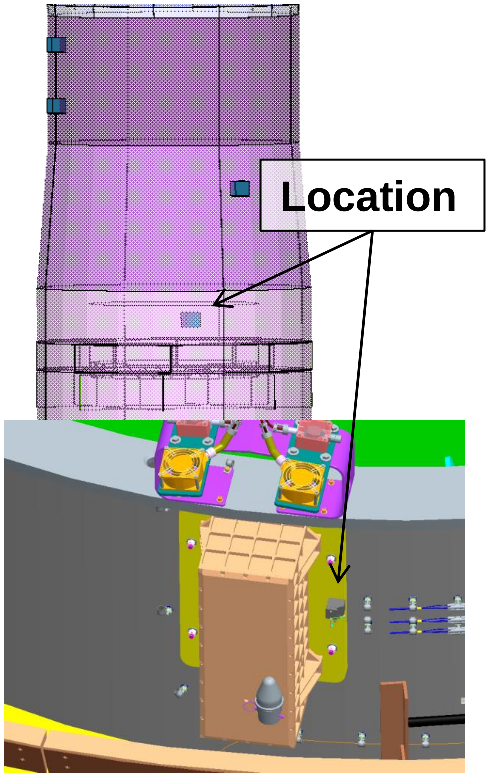
Liftoff Response Comparison

Model vs. Flight Data





The instrument is mounted directly next to flight avionics but SEA bare panel response slightly under predicts, most likely due to model fidelity

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