



Boeing Space Exploration

# Ares 1X Hybrid Modeling with Comparisons to Flight Data

**Dan Niedermaier**  
Boeing Space Exploration, Texas, US

**Mo Kaouk**  
NASA – Johnson Space Center, Texas, US

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# Spacecraft and Launch Vehicle Dynamic Environments Workshop

- 3 Day Workshop with about 40 presentations
- Good mix of high and low frequency dynamics
- Attendance include about 200 engineers from NASA, ESA, CSA, CNES, academia, and industry
- Proceedings:

<http://www.aero.org/conferences/sclv/2010proceedings.html>

# Outline

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

# Ares 1X Test Flight

October 28<sup>th</sup>, 2009



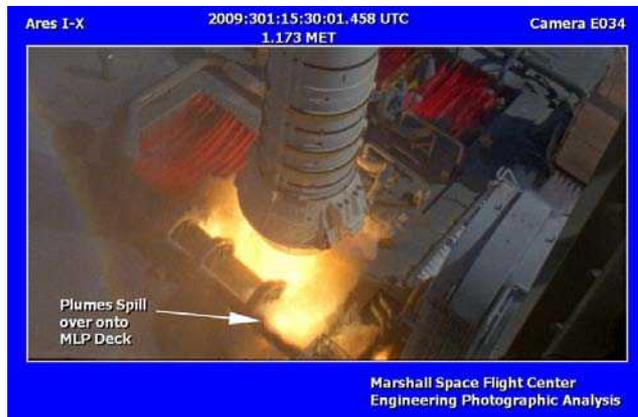
- Flight objectives included characterization of acoustic and random vibration environments
- Assessment of the vibroacoustic modeling methods possible

# 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

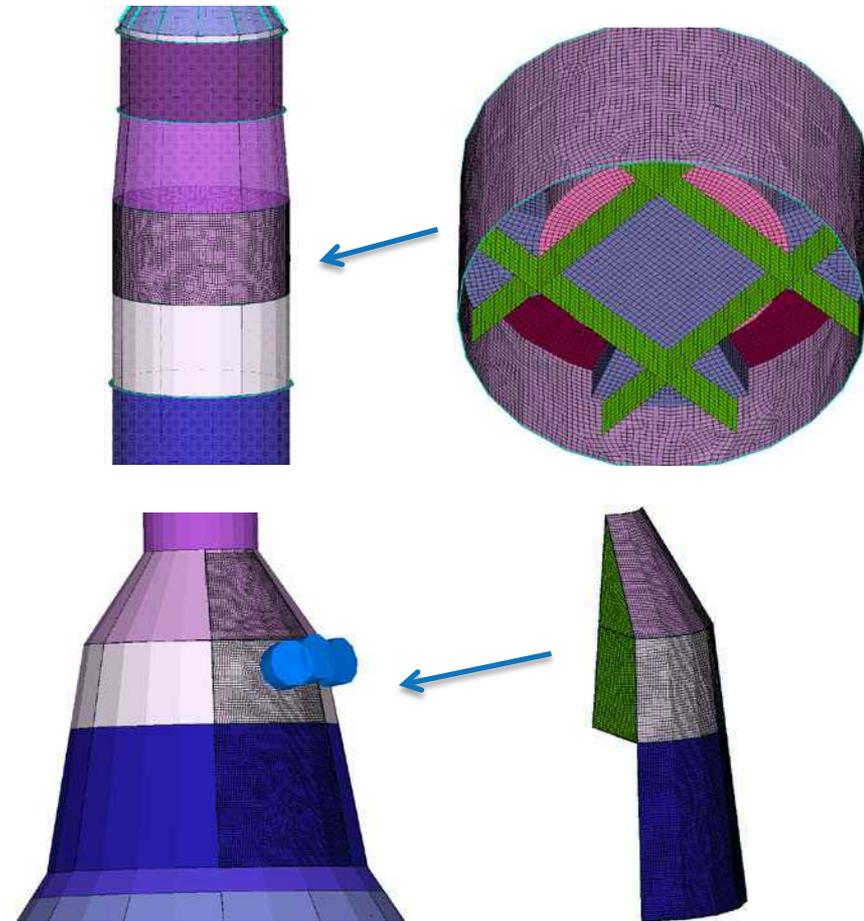
# Ares 1X Flight Data Summary

- 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*

# 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*

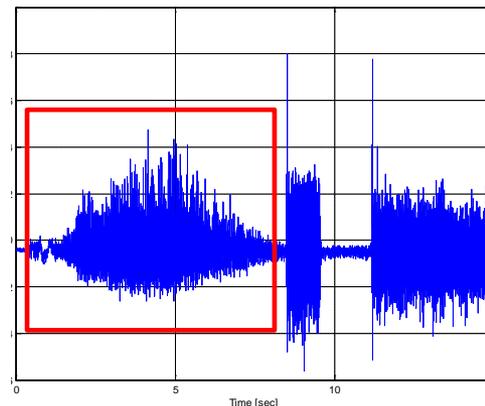


# Liftoff Reconstruction Analysis

*Flight time 4 to 4.5 seconds*

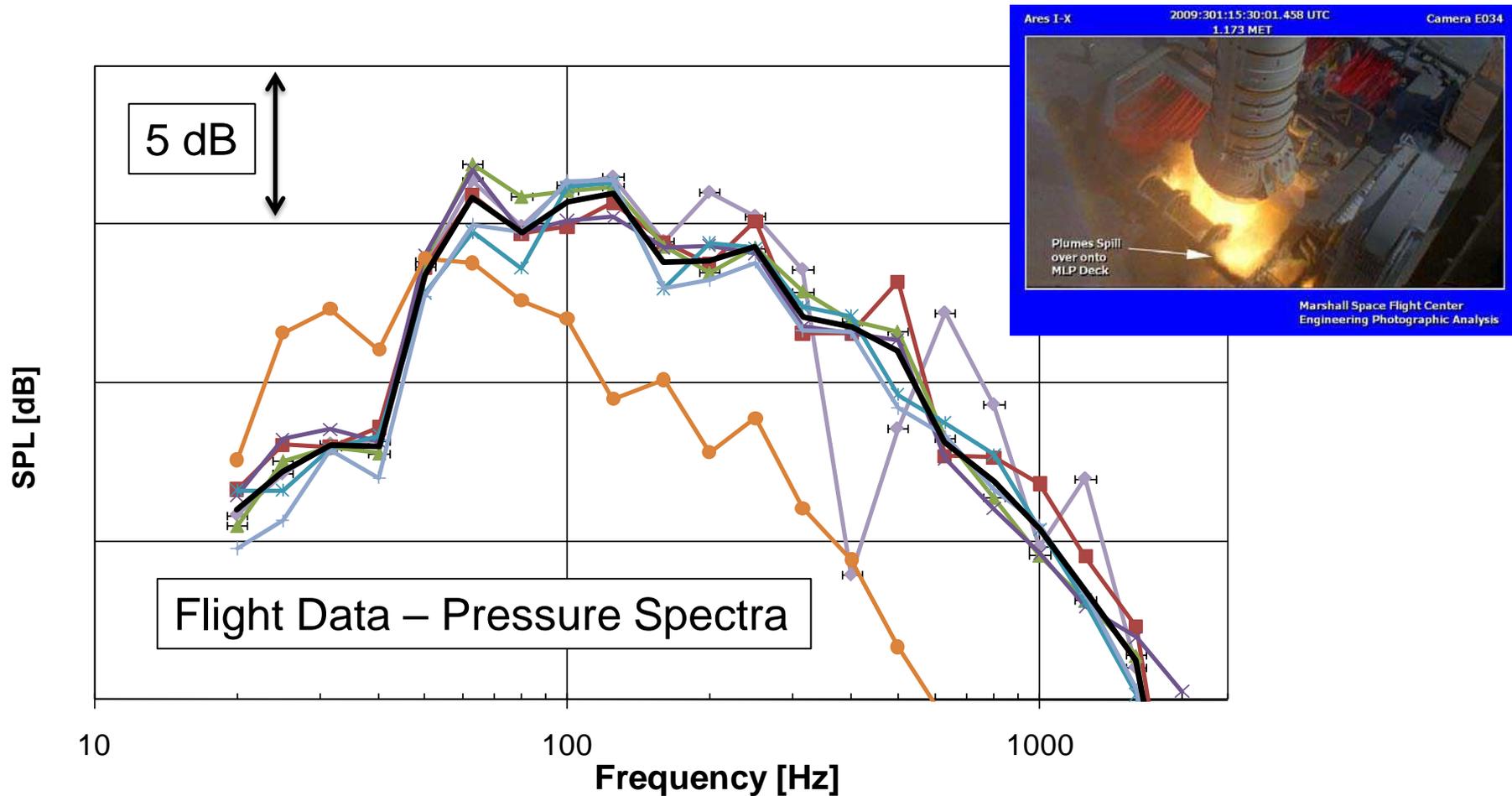
- SEA and SEA/FE hybrid model results compared to processed flight data (20-1000 Hz for 5200 sample rate, 20-2000Hz for 10400 sample rate)
- Processed flight data for pressures and accelerations at the 4 – 4.5 second interval
- Applied flight pressures to the model and recovered accelerations at the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

*Pressure Time History*



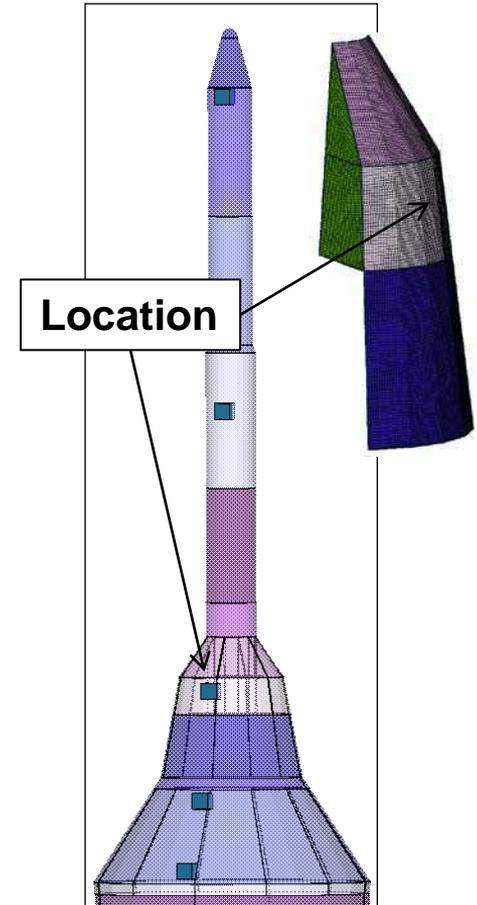
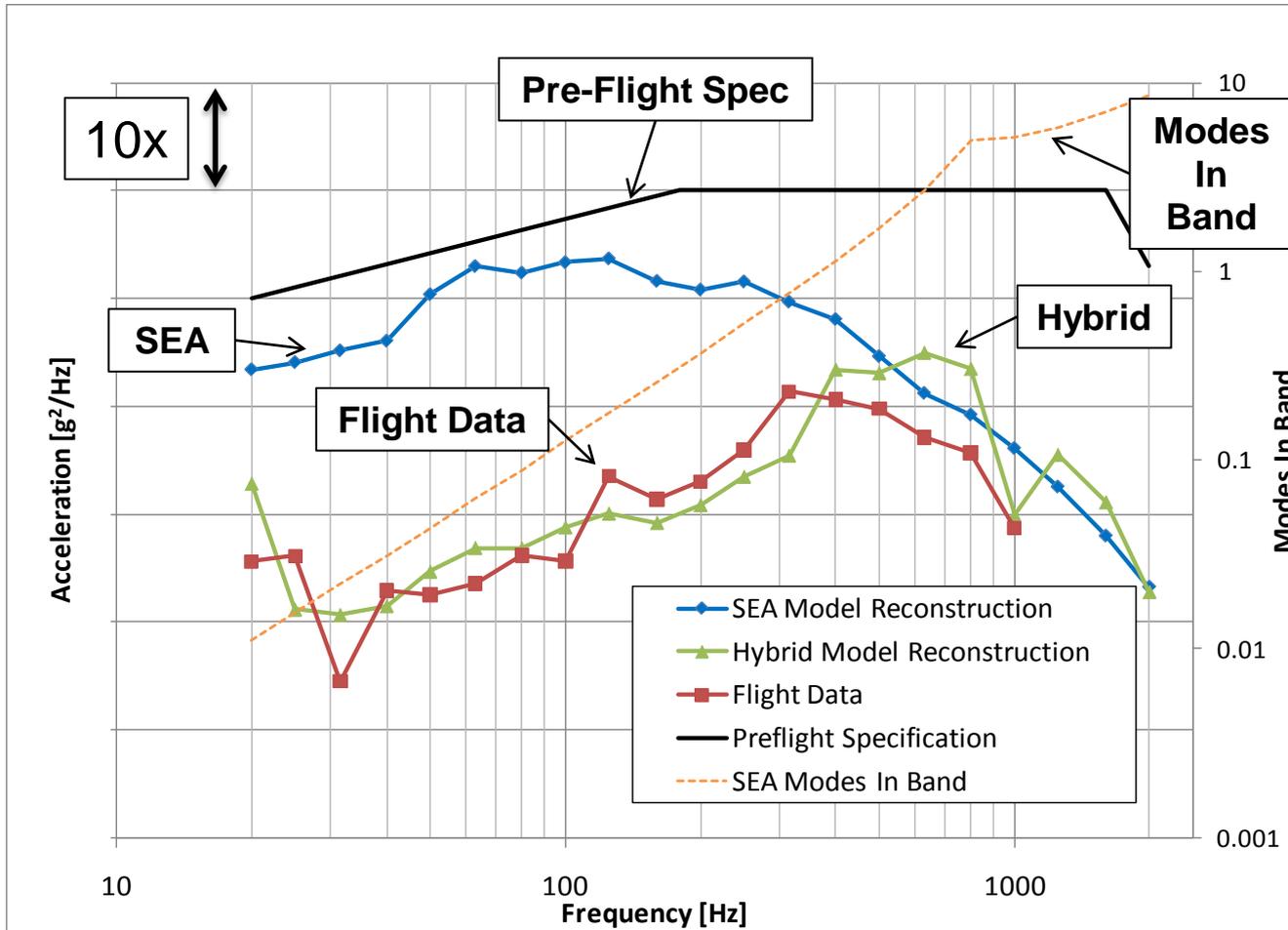
# Liftoff PSDs (T = 4-4.5s)

## Forward Vehicle Section



# Liftoff Response Comparison

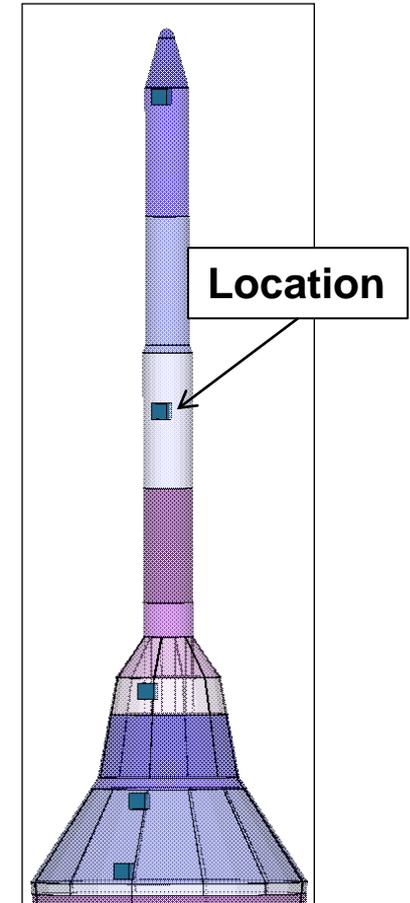
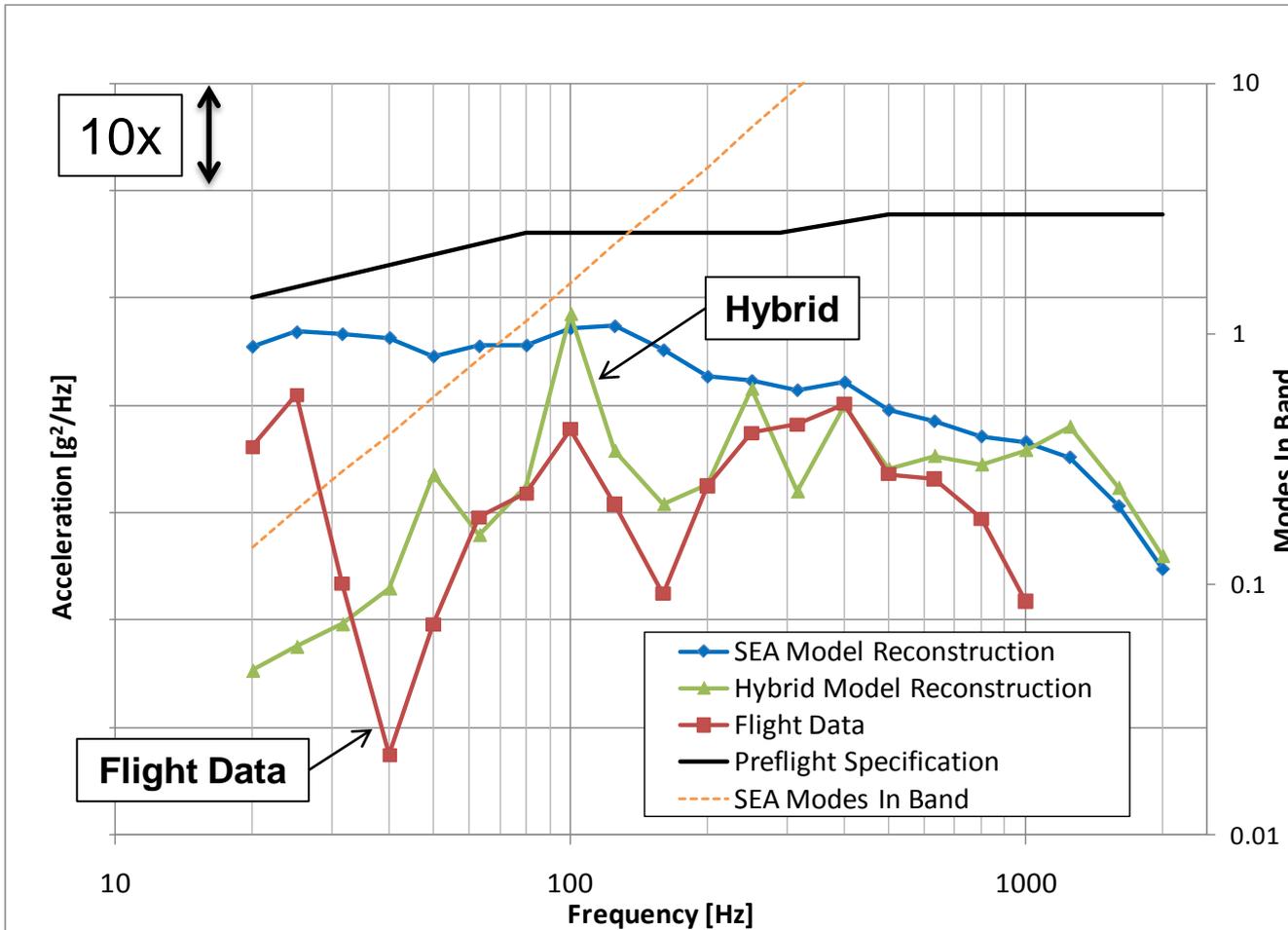
*Model vs. Flight Data*



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

# Liftoff Response Comparison

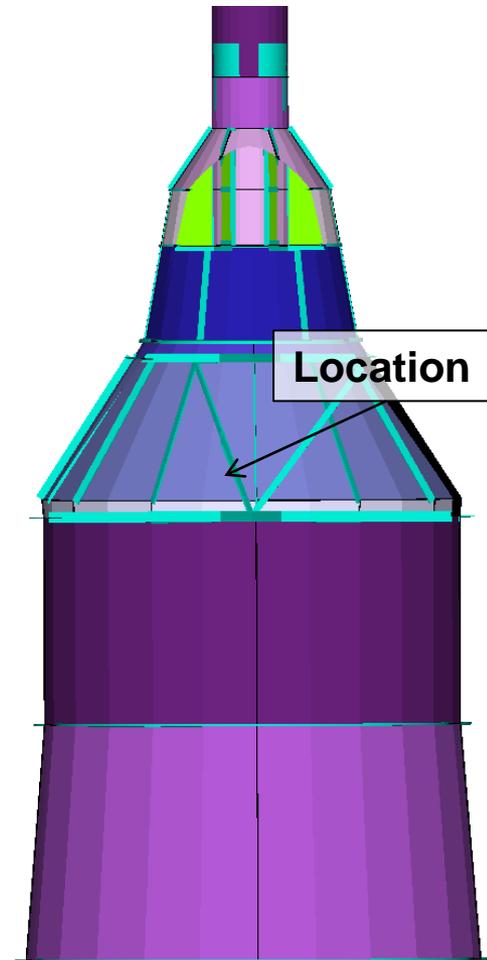
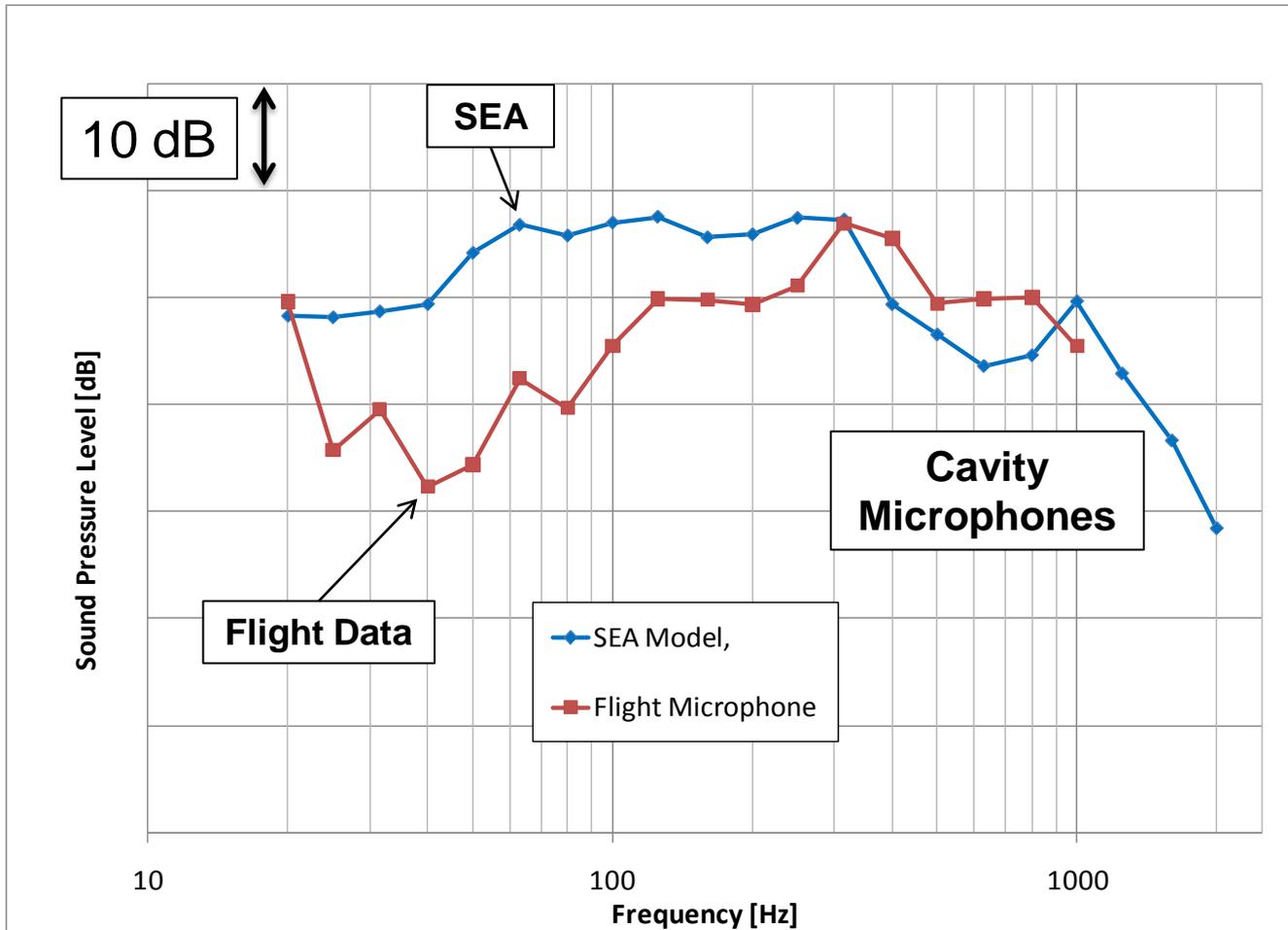
*Model vs. Flight Data*



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

# Liftoff Response Comparison

*Model vs. Flight Data*



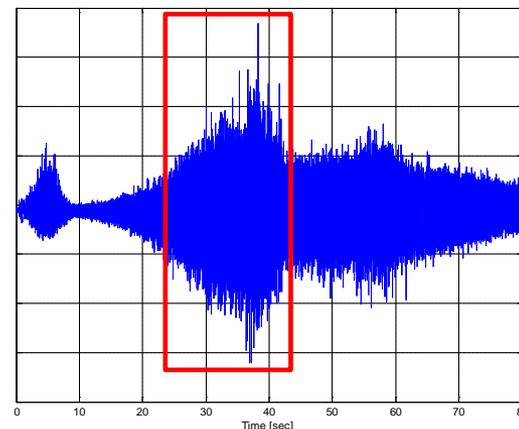
Poor correlation most likely from the inability to capture correct CM Panel response

# Transonic Reconstruction Analysis

*Flight time 35.5 to 36.0 seconds*

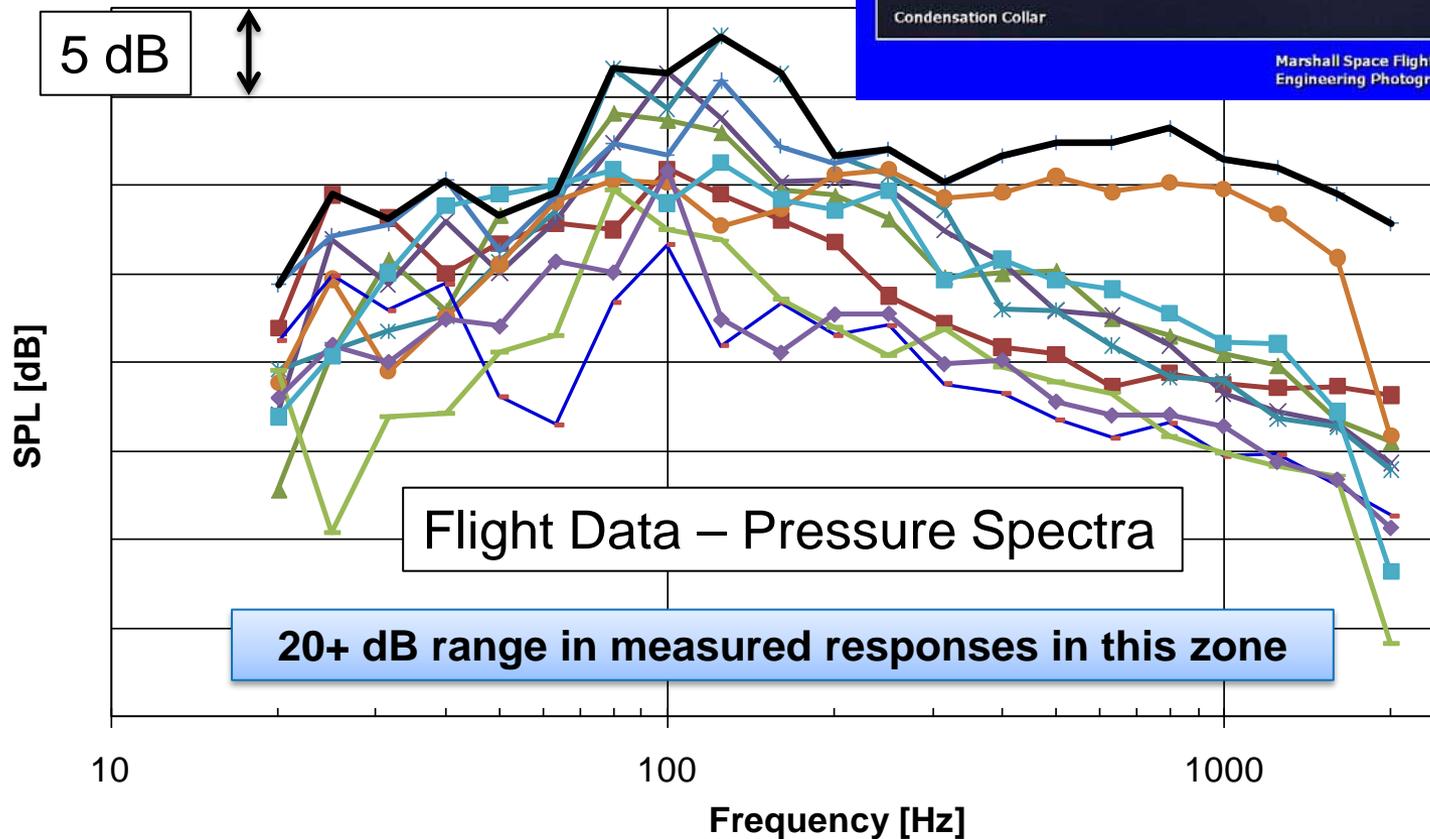
- SEA and SEA/FE hybrid model results compared to processed flight data (20-1000 Hz for 5200 sample rate, 20-2000Hz for 10400 sample rate)
- Due to the widely varying pressures and minimum and maximum pressure level were used
- Applied TBL loading for  $M=0.85$  with default parameters
  - *Distance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

*Pressure Time History*



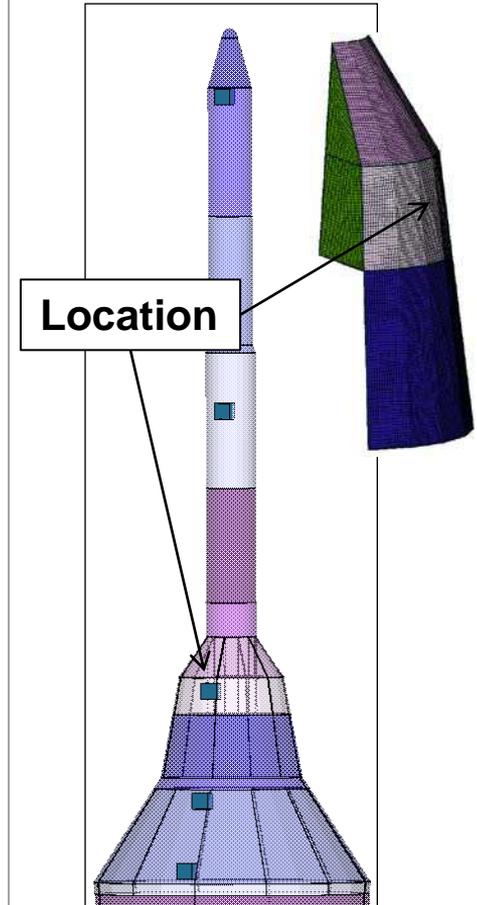
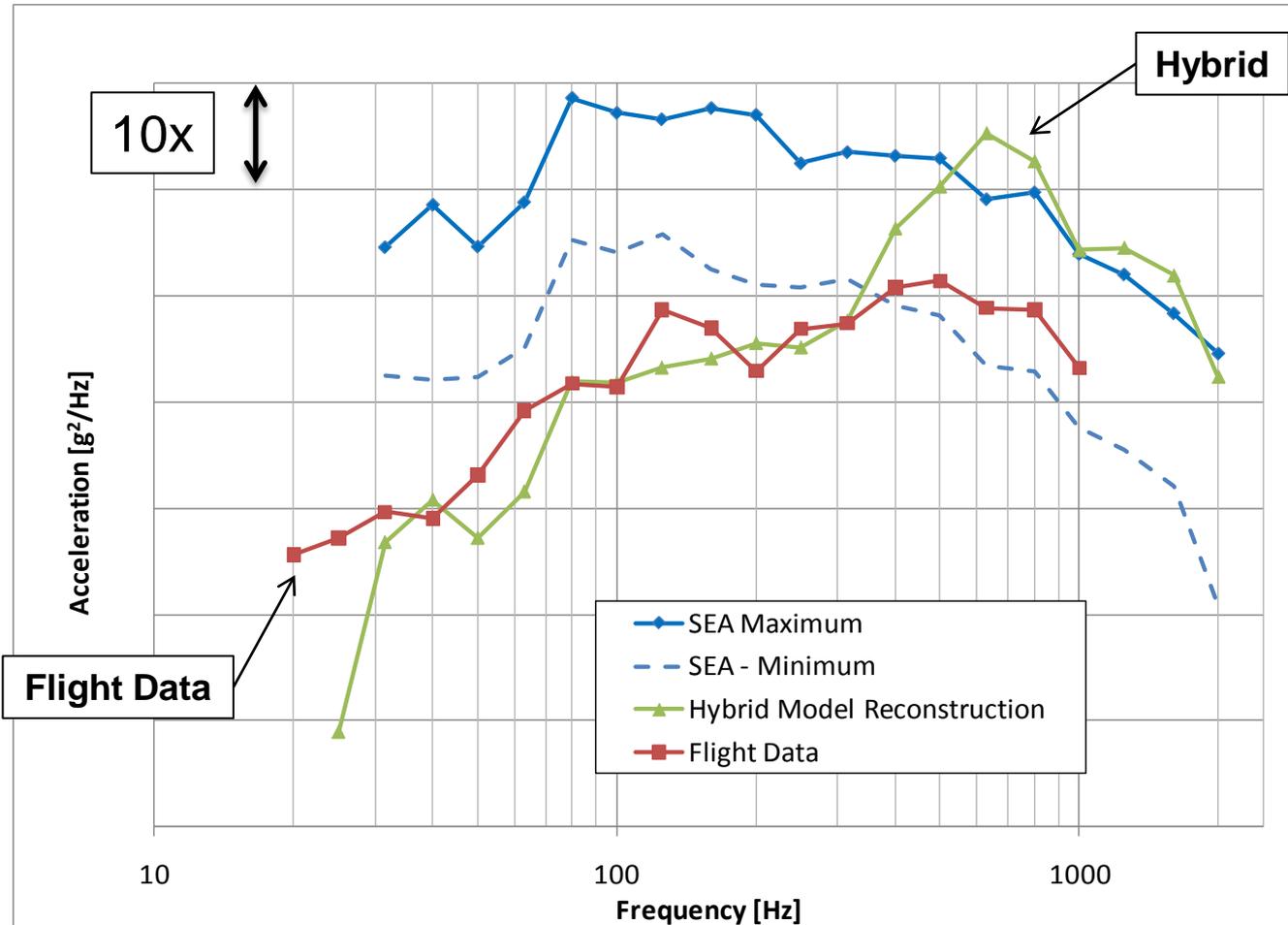
# Transonic PSDs (T = 35.5-36.0s)

Forward Vehicle Section



# Transonic Response Comparison

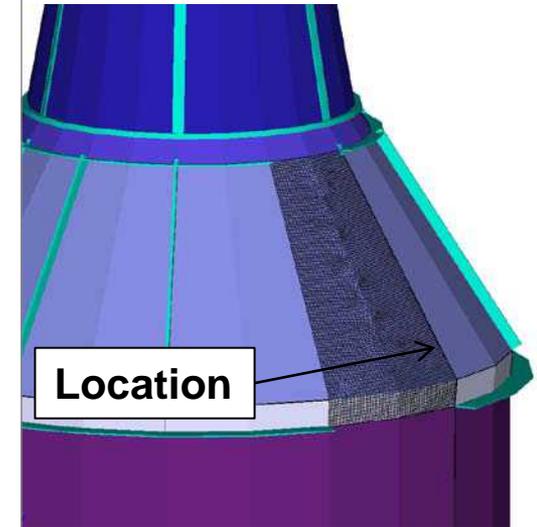
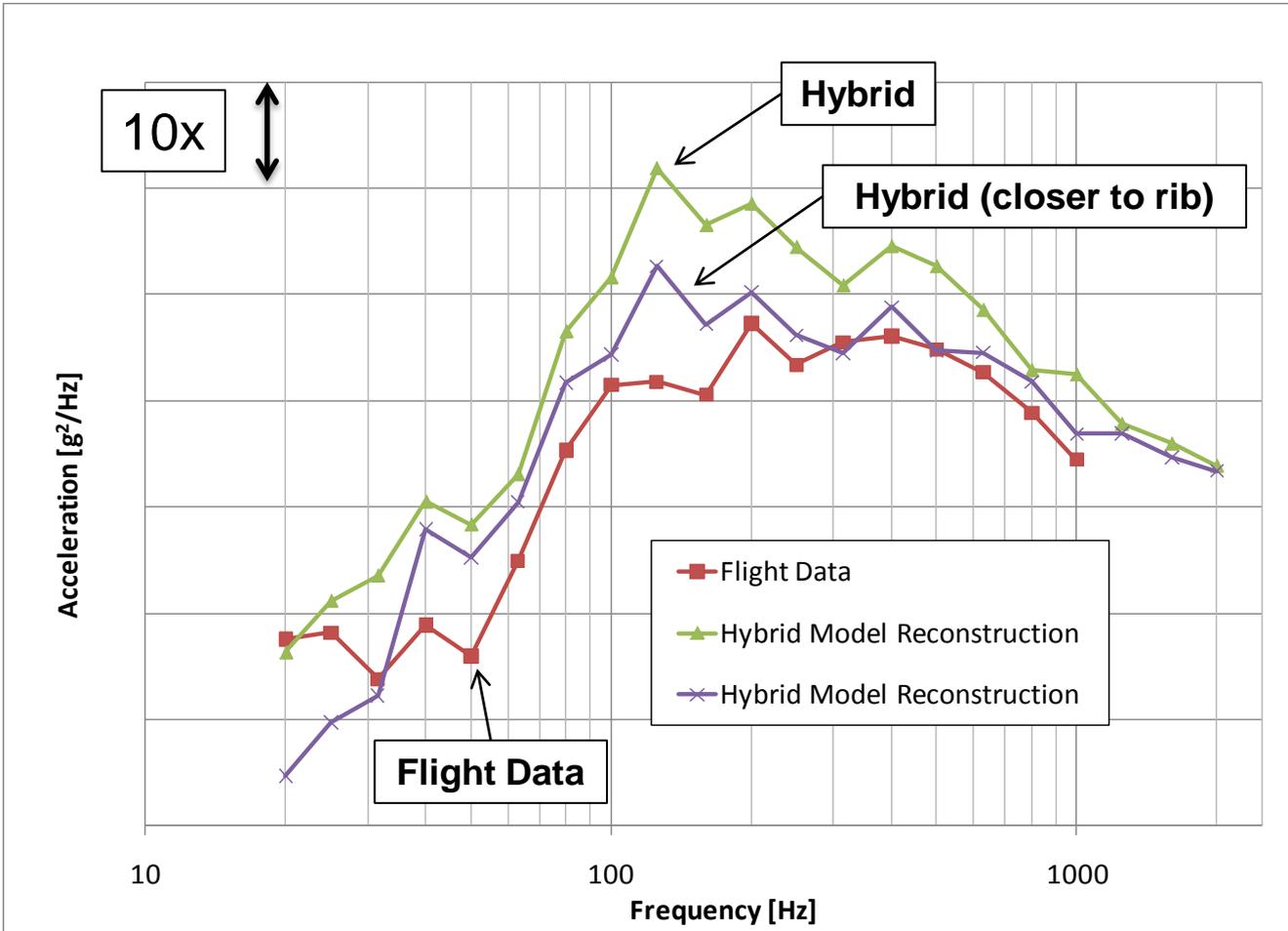
*Model vs. Flight Data*



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

# Transonic Response Comparison

*Model vs. Flight Data*

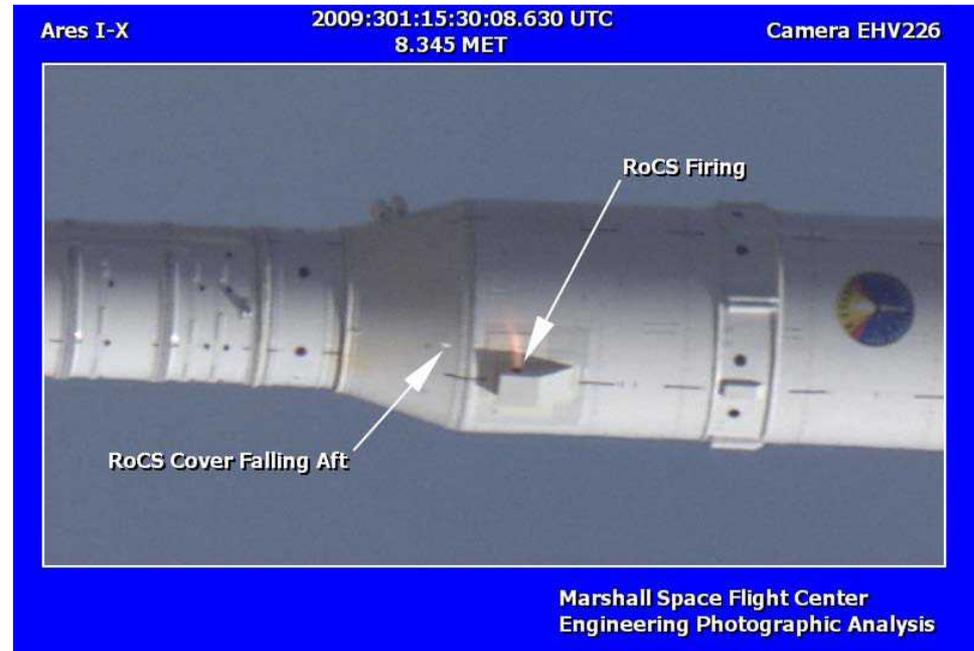
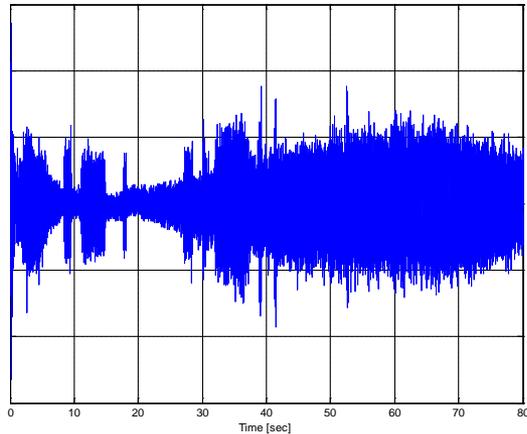


**Instrument location is a significant factor in assessing the accuracy of the model predictions**

# Roll Control Thruster Firings

*Flight time 8.5 seconds*

## Acceleration Time History



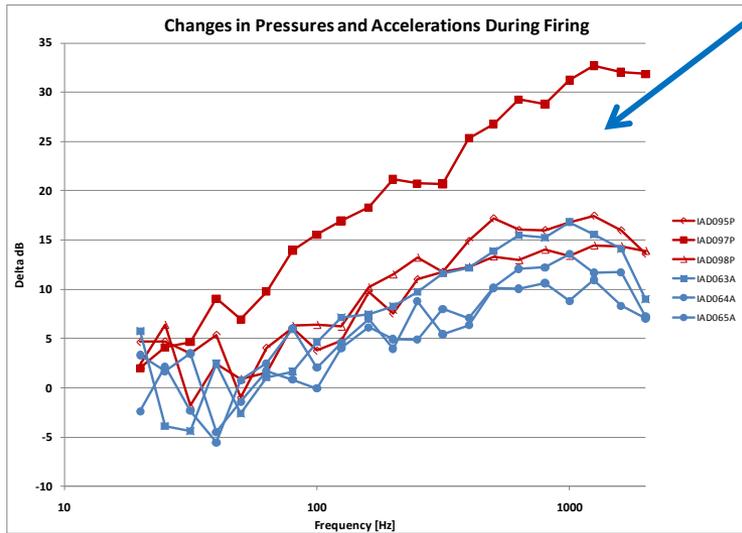
- Thruster firings induced significant vibrations in the first and upper stages
- Data and modeling assessment completed to determine the source of the vibration and the ability to simulate the event

# 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 thruster plume acoustic driven

### Delta dB increase when thrusters fire Upper Stage

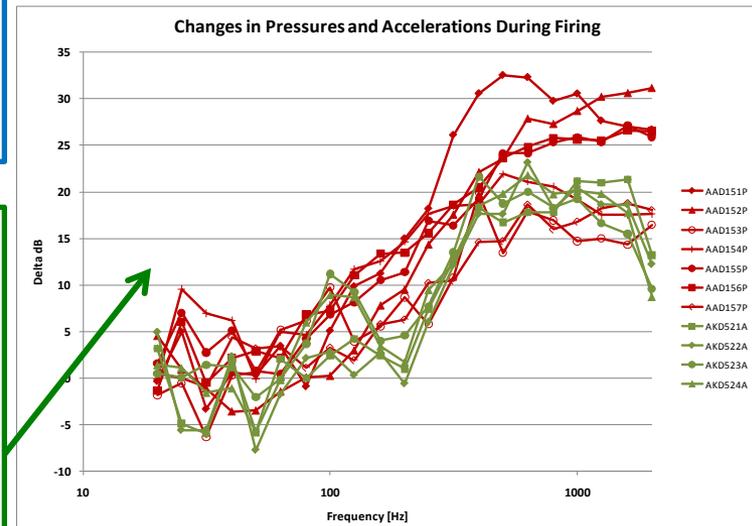


Red are pressure response deltas

Blue are acceleration response deltas

RoCS Thrusters (1980 in. @ 0, 180)

### Delta dB increase when thrusters fire First Stage



Red are pressure response deltas

Green are acceleration response deltas

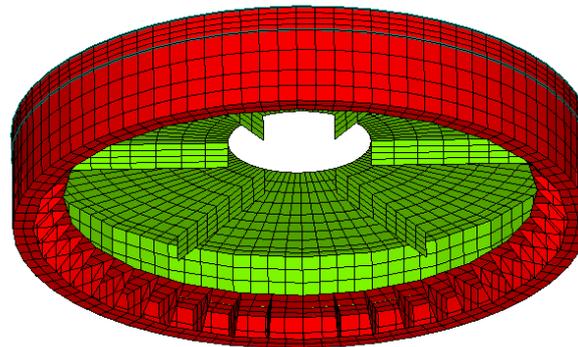
# RCS Firing SEA/Hybrid Modeling

## *Multi-model approach*

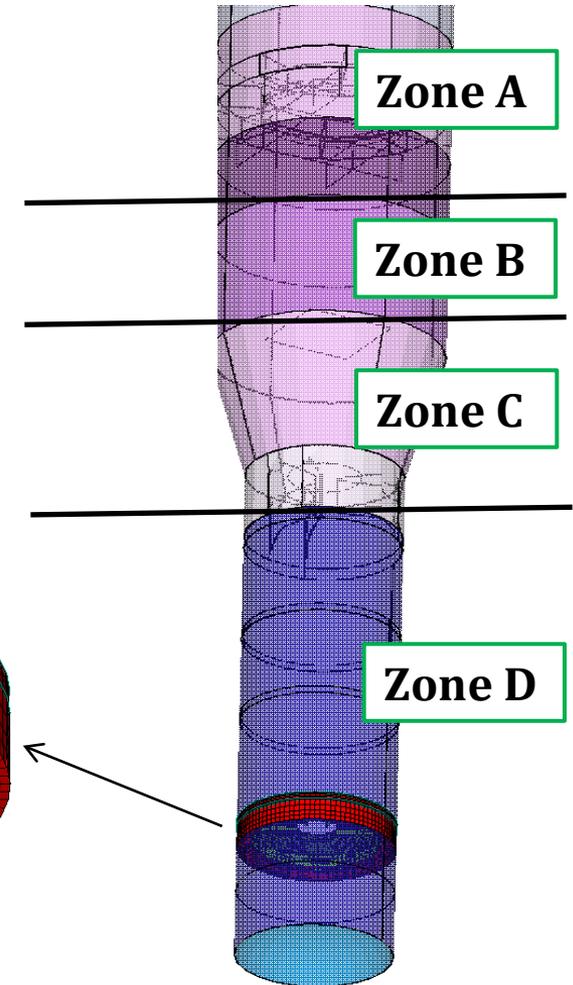
- Model First Stage Avionics Module (FSAM) location during a time while RCS is firing and a time without
- Apply the time consistent pressures and compare the change in predicted response to the flight response
- Partially integrated model broken into 4 loading zones



**FSAM CAD**



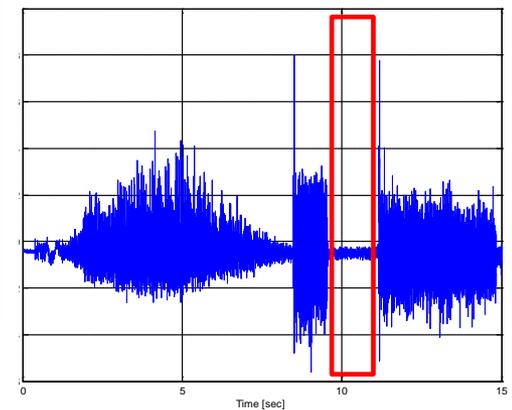
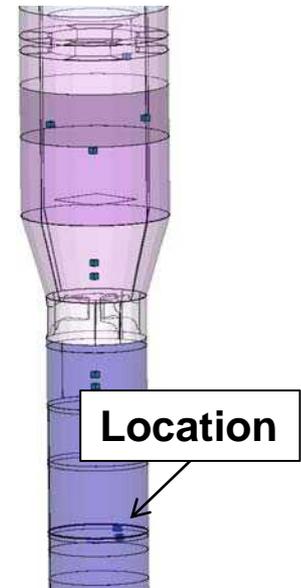
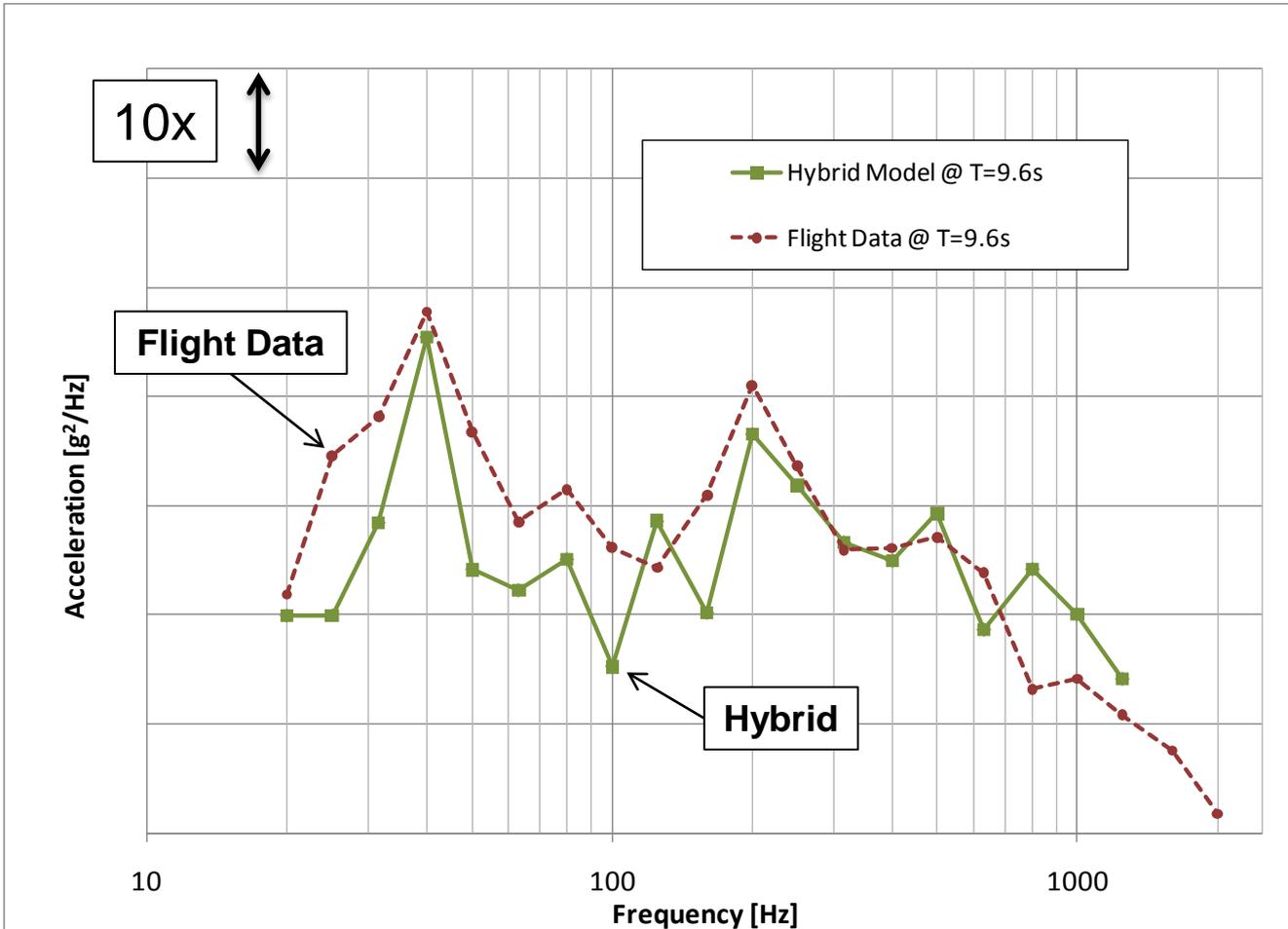
**FSAM FE Section**



**Hybrid Model**

# Nominal Flight Response Comparison

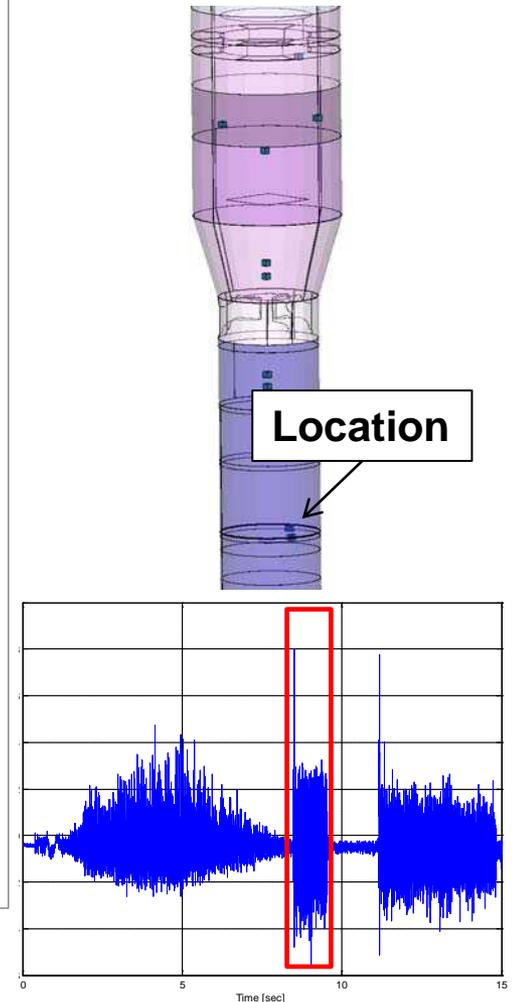
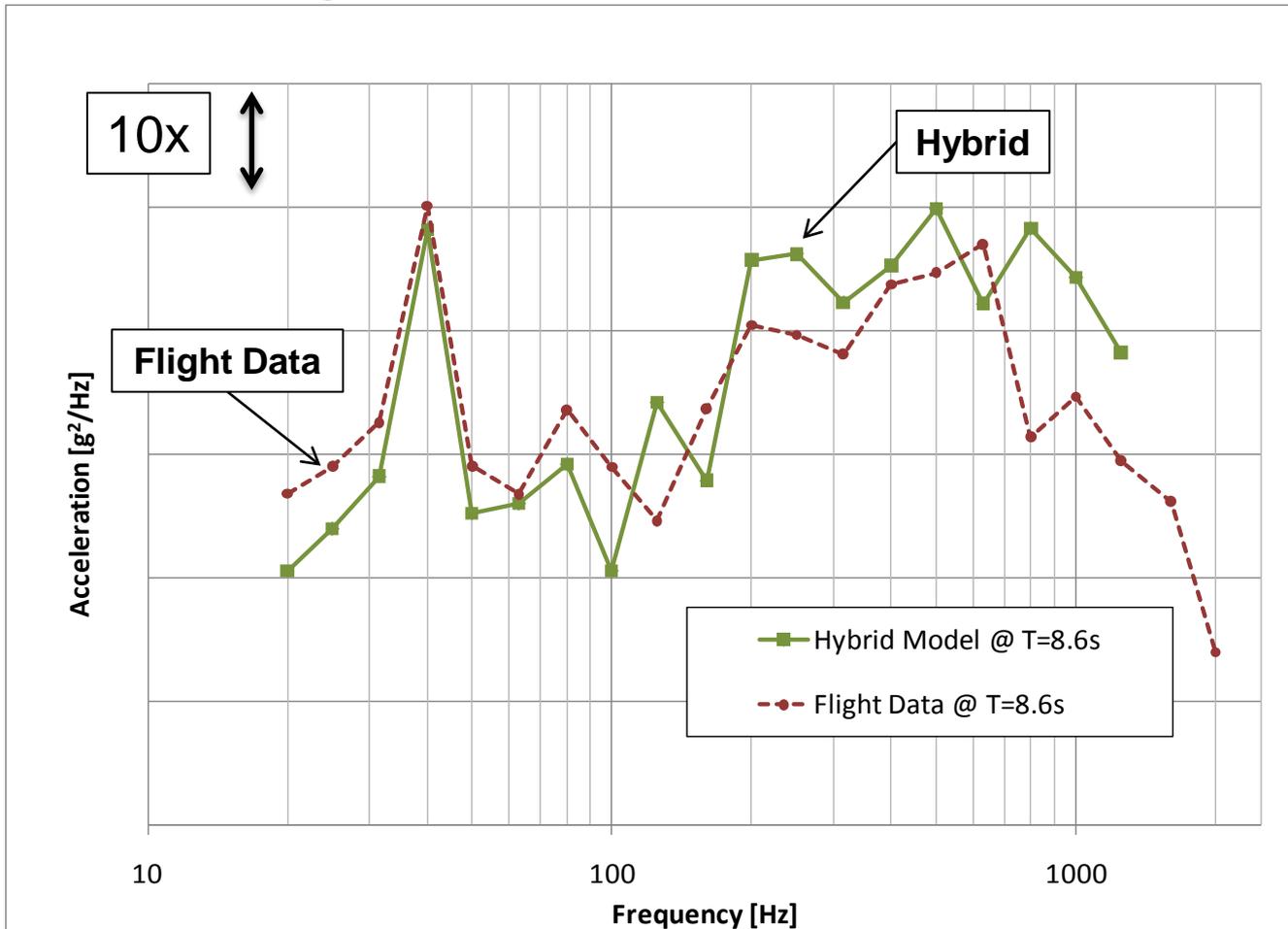
*Model vs. Flight Data*



**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 through modeling*

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

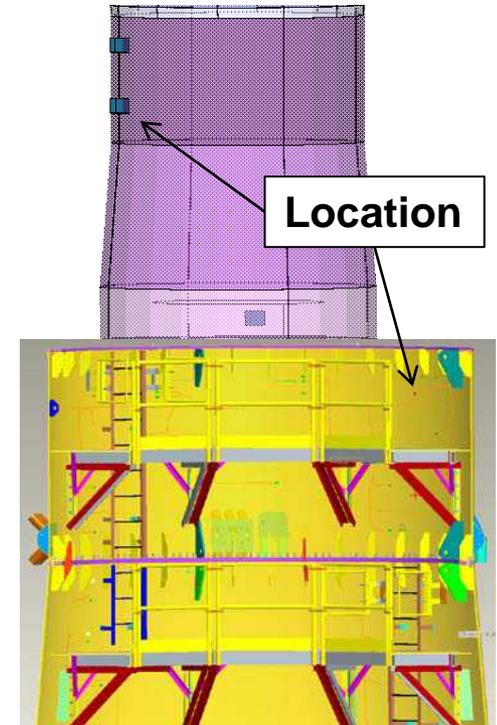
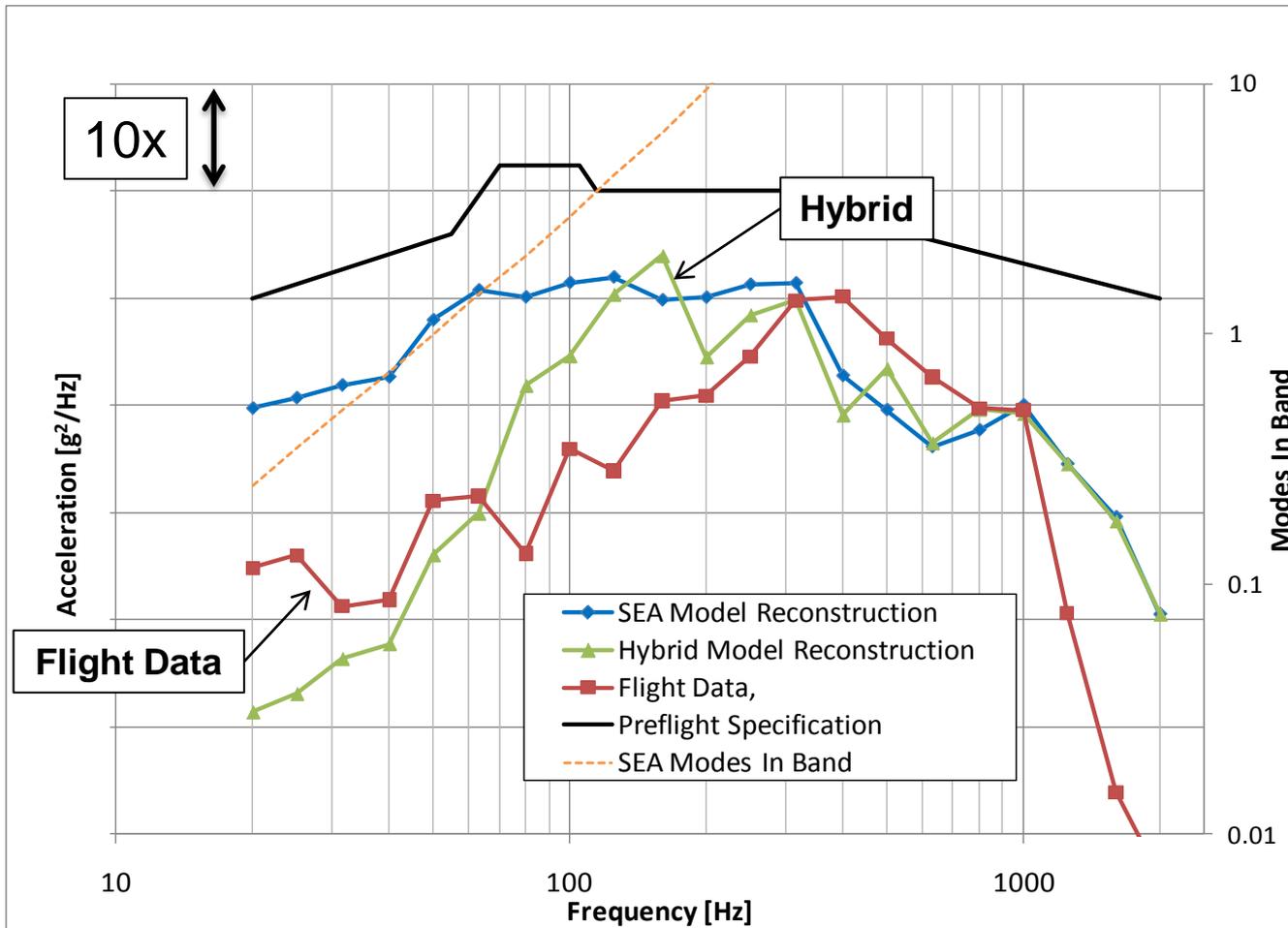


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# Thank you

# Liftoff Response Comparison

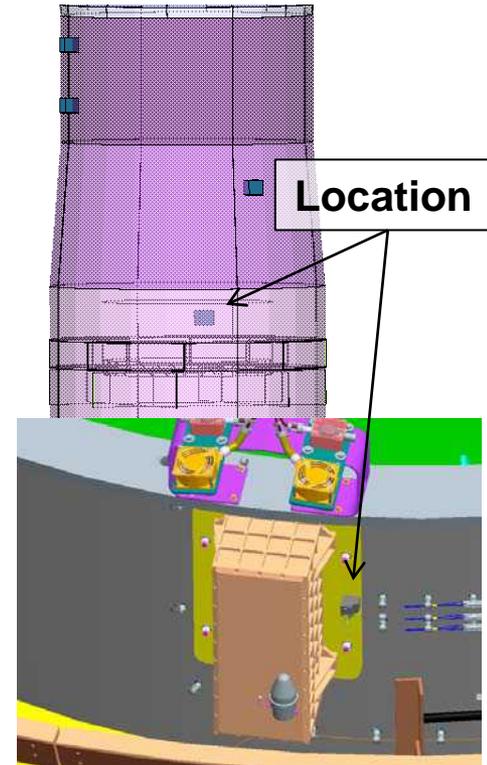
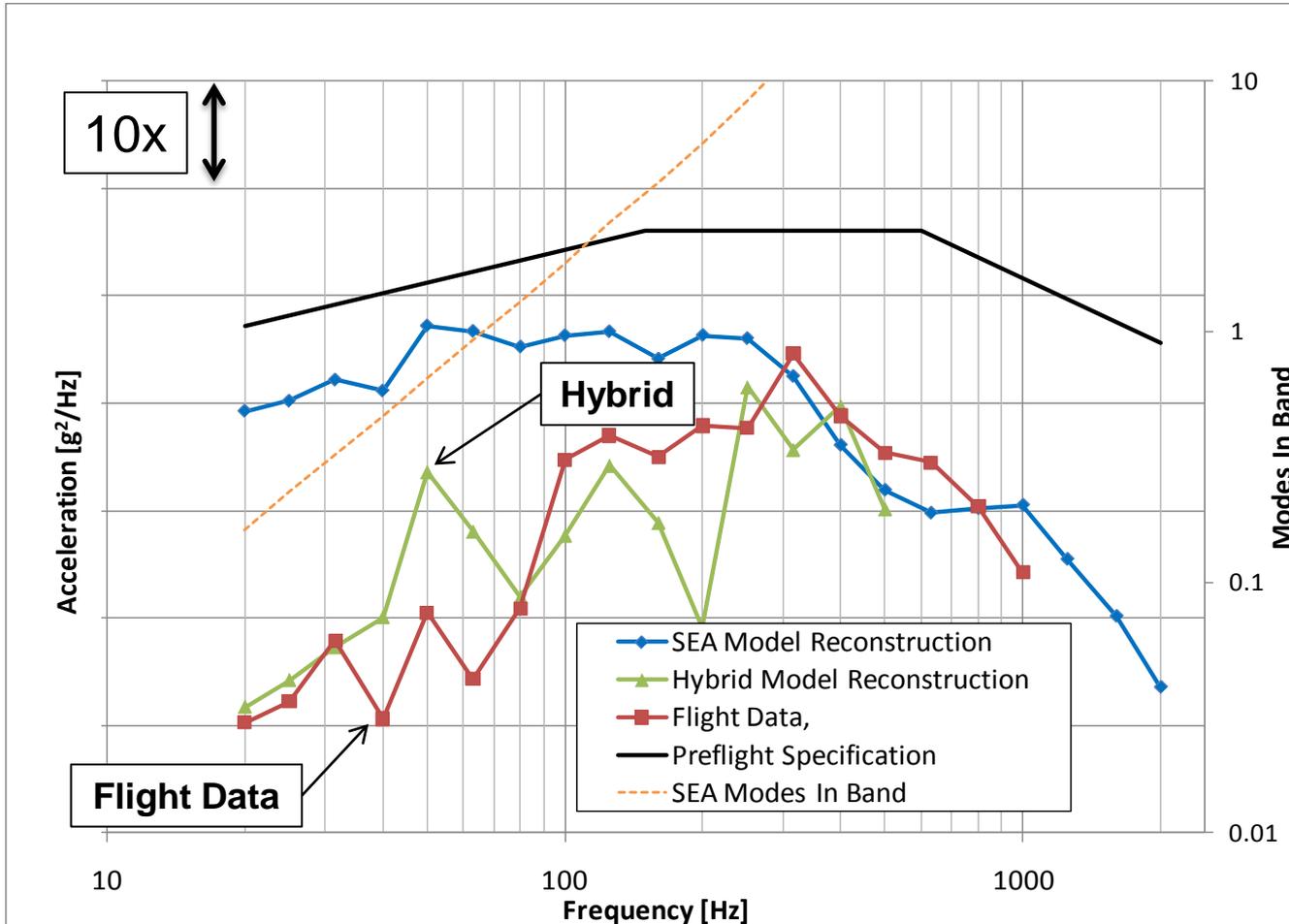
*Model vs. Flight Data*



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

# 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