National Aeronautics and Space Administration

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# SPACE LAUNCH SYSTEM

## SLS Aeroacoustic Wind Tunnel Test Results

AIAA Aviation Forum 2019

# Outline

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- **Testing Overview**
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  - Configurations
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  - Downstream effects of protuberances
  - Effects of interstage flanges
  - Multibody effects
  - Fairing configuration comparison

# Background

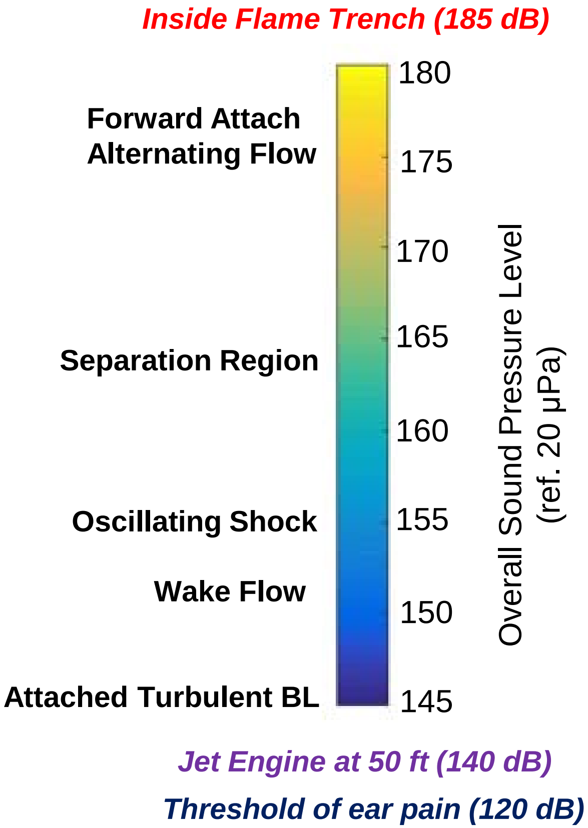
- **Aeroacoustics is the energy transferred into the vehicle structure from pressure fluctuations (sound) on the surface**
- **Common unsteady flow features include:**
  - Turbulent boundary layers
  - Regions of separated flow at compression and expansion corners
  - Shock waves
    - Particularly terminal shocks generated by localized supersonic flow
  - Alternating flows
    - Shifting between attached and separated boundary layer
  - Wake flows
- **Unsteady phenomena are most prevalent in the transonic regime (~0.7<M<1.2)**
- **Typically derived for fluctuations above 20 Hz**
  - Localized to panels/compartments in immediate vicinity
  - Below 20 Hz is considered buffet (full vehicle mode excitation)

Ares 1-X passing through transonic regime

# Background

- **Aeroacoustics is an input to vibroacoustics, which determines the structural response caused by the surface pressure fluctuations**
  - vibration of primary structure (panels) and secondary structure (equipment shelves, pressure bottles, pressure lines, etc.) is a critical component of vehicle design

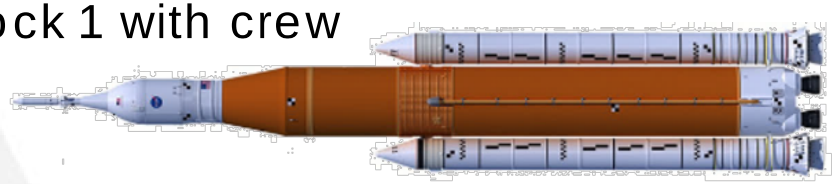
**Reverberant Acoustic Test Facility – NASA Plum Brook Station**



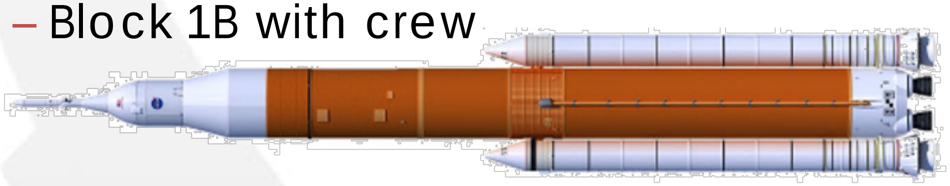
# Testing Overview

- **Two facilities have been used for SLS aeroacoustic environment development**
  - NASA Ames Unitary Plan Wind Tunnel
    - Continuous flow
    - 11’ x 11’ Transonic Test Section (Mach 0.7 to Mach 1.4)
    - 9’ x 7’ Supersonic Test Section (Mach 1.55 to Mach 2.5)
  - NASA Marshall Trisonic Wind Tunnel
    - Intermittent blow-down
    - 14” x 14” Test Section with multiple nozzles (Mach 0.2 to Mach 5)

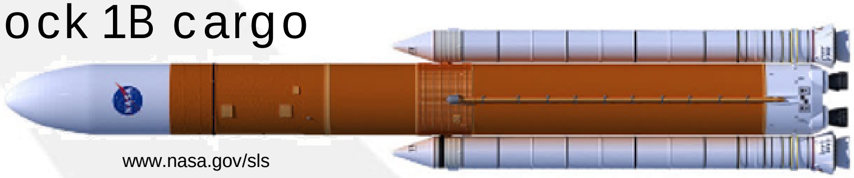
- **Evolvable approach has led to testing of multiple configurations**
  - Block 1 with crew



  - Block 1B with crew



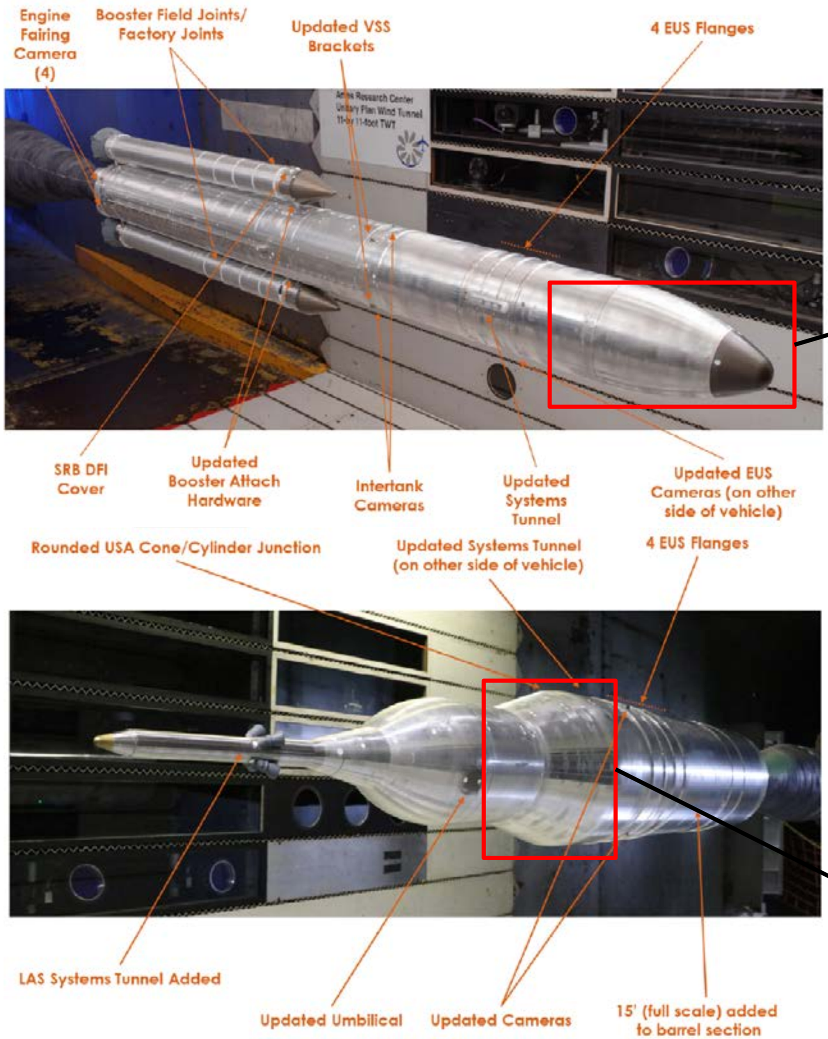
  - Block 1B cargo



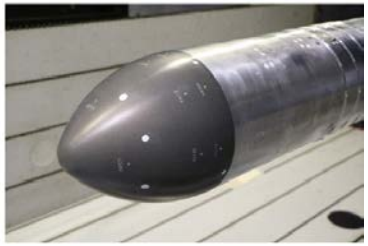
Ames UPWT 11’x11’

# Configuration Changes

- **Variations in the configurations tested allows for isolation of the effects of certain outer mold line features**
  - Applicable to many launch vehicle designs

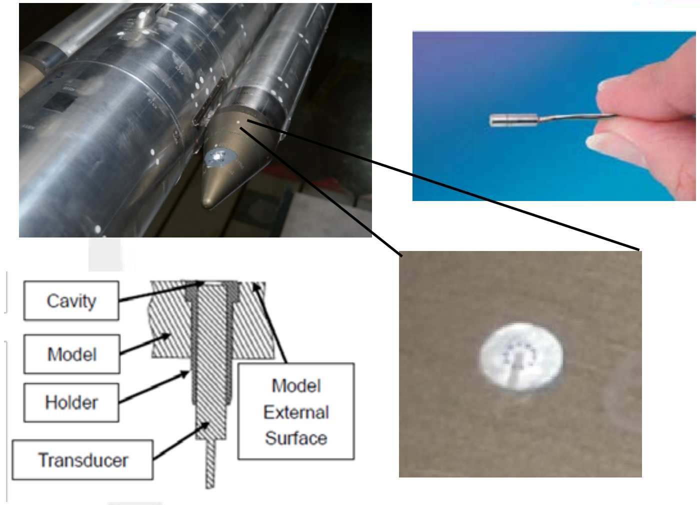



**Payload fairing variants**




**Stage adapter variants**

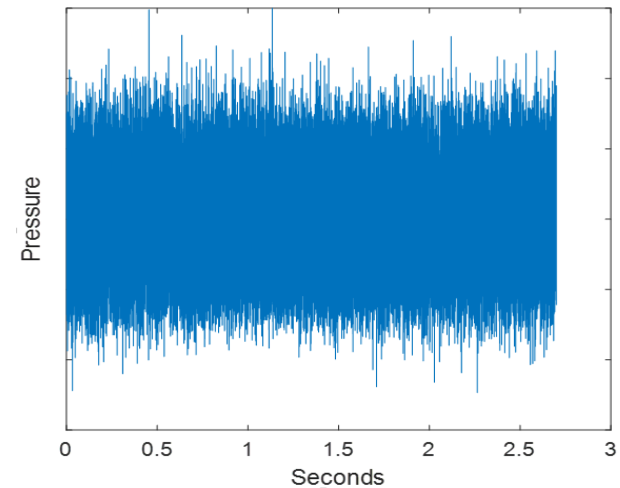
# Data Acquisition and Analysis




**High frequency pressure transducers**

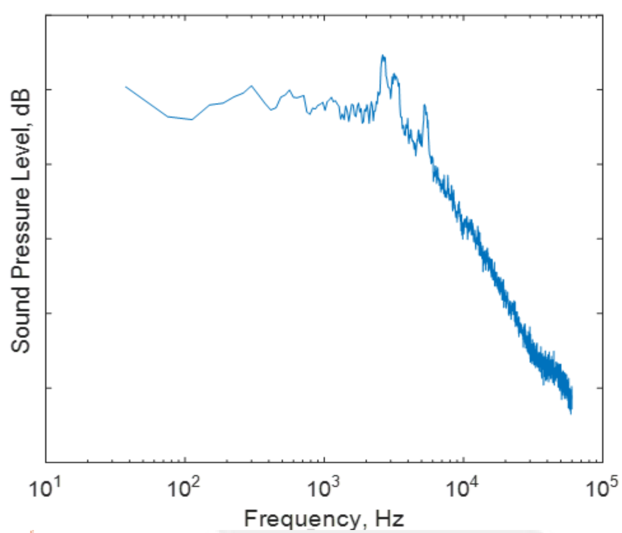
~100 – 200 per model

~200,000 samples/second




$$X(k) = \sum_{n=1}^{N} x(n) * e^{-2j\pi*(k-1)*(n-1)*\frac{1}{N}}$$

**Fourier Transform**




**Scale from Tunnel to Flight**

- **Amplitude**
  - Fluctuating pressure coefficient

$$|\Delta C_{p,rms}|_{flight} = |\Delta C_{p,rms}|_{tunnel}$$

$$\Delta C_{p,rms} = {p'_{rms}}/{q_\infty}$$

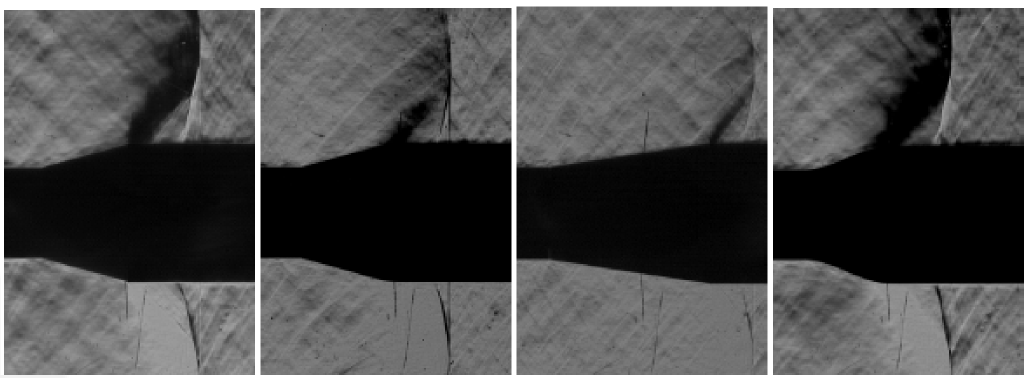
- **Frequency**
  - Strouhal number

$$|St|_{flight} = |St|_{tunnel}$$

$$St = {fl}/{U_\infty}$$

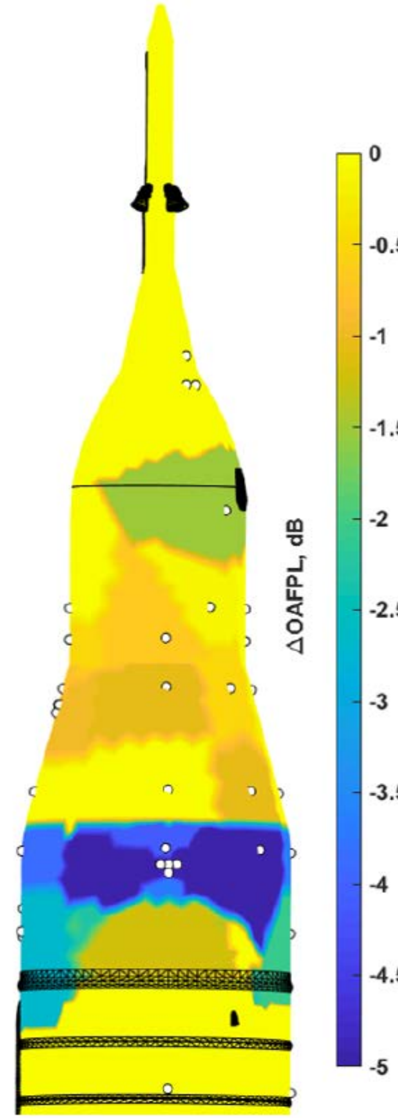
# Results – Stage Adapter Contour

- **Schlieren imagery used to perform low cost trade study**
  - Dark regions represent high density gradients
  - Supposition that larger regions correspond to higher fluctuating pressure levels
  - Comparisons below @ M=0.9, $\alpha/\beta = 0$



**Sharp Corner** | **Rounded Corner** | **Conic** | **3rd Order Polynomial**

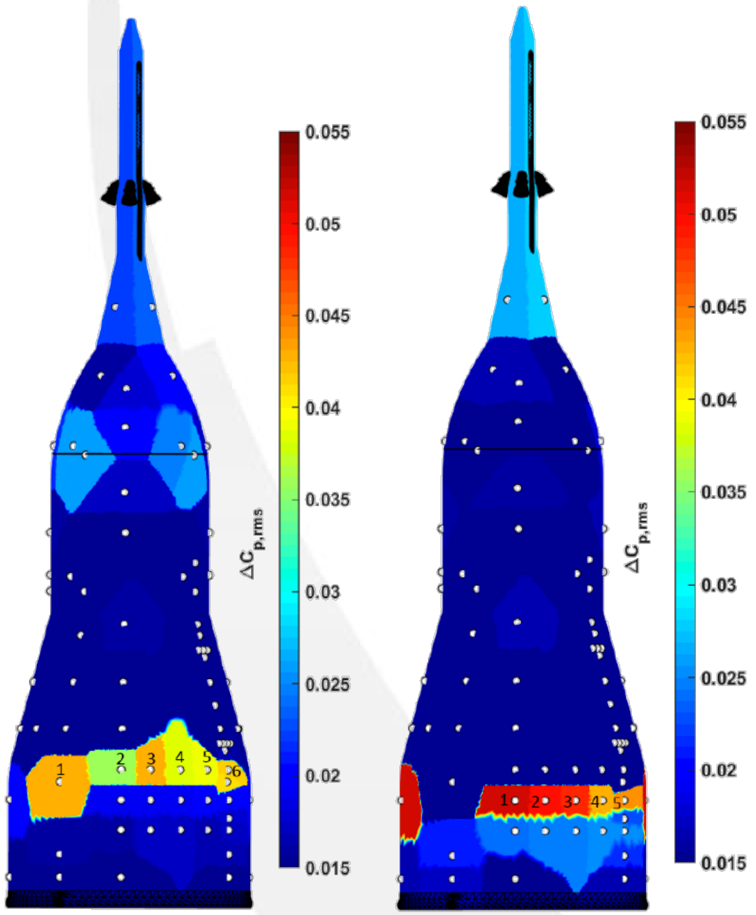
- **High frequency pressure measurements obtained for the sharp corner and rounded corner configurations**
  - The expansion is spread out over the rounded corner and the magnitude of the gradient reduced
  - Results in ~5 dB decrease immediately downstream of the shoulder



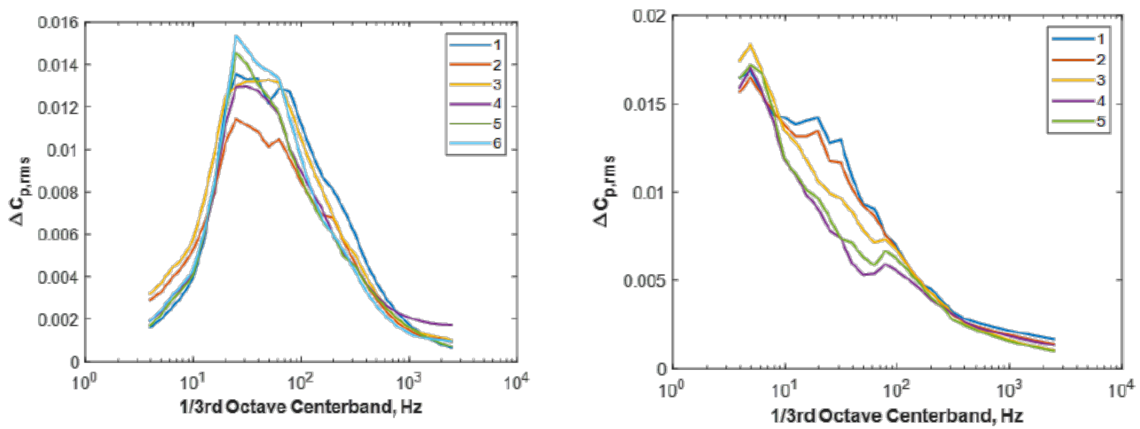

**Rounded corner enveloped measurements subtracted from sharp corner. Envelopes over all M,α,β**

# Results – Nozzle Wake Effects

- **Unsteady CFD results indicated interaction of the nozzle wake flow with the stage adapter expansion region**
  – Relatively dense grid of sensors placed here to measure effects




(a) Mach 0.73 (b) Mach 0.84

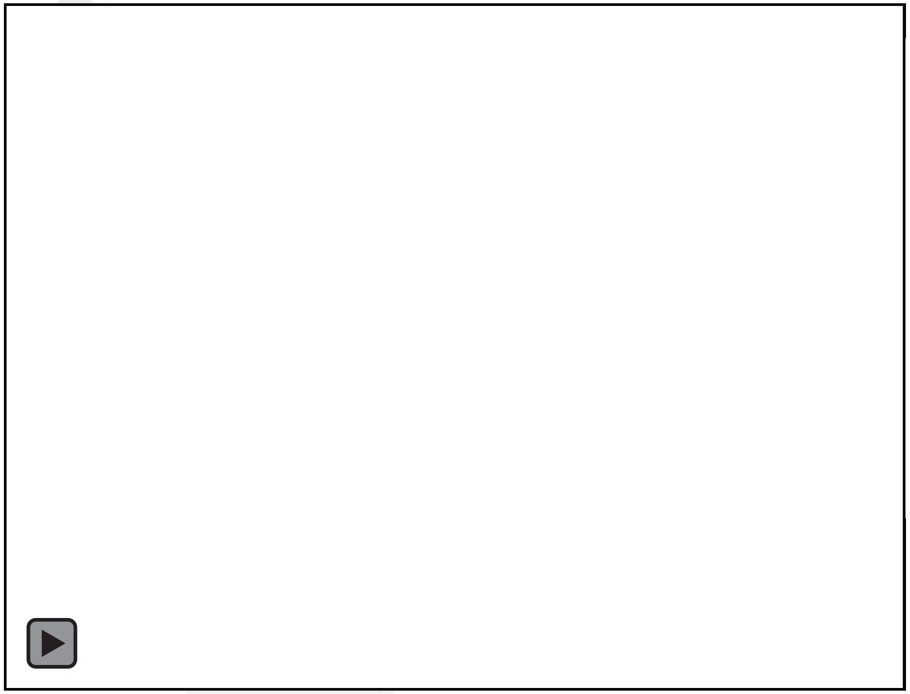



(a) Mach 0.73 (b) Mach 0.84

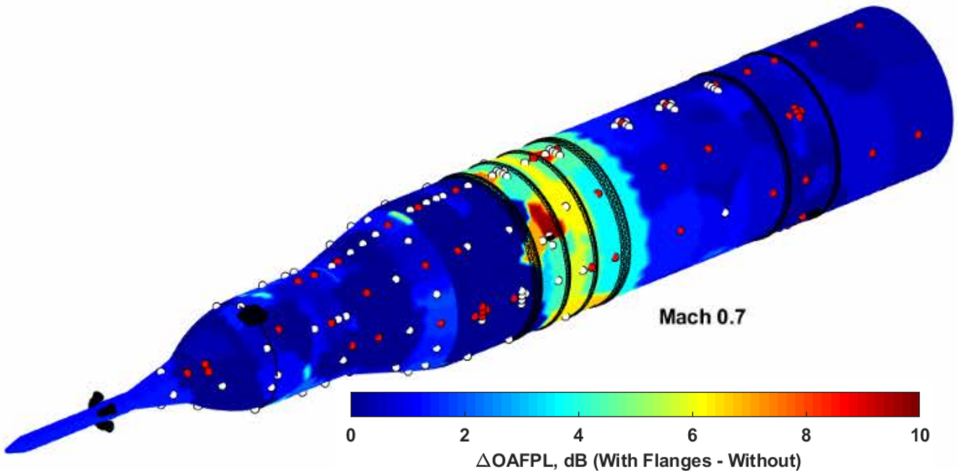
- **Up to ~50% variation in levels circumferentially across sensor patch in 10 to 100 Hz band**
  – Effect of alignment of nozzle on peaks not consistent
  – Flow evolving from simple expansion to terminal shock system
  – Possibility that there is some interaction between the nozzle wake and these flow features which interferes in certain locations constructively or destructively
- **Unsteady pressure sensitive paint (uPSP) measurements taken during test provide opportunity to inspect phenomena with higher spatial resolution and at more Mach numbers**

# Results - Flanges

- **Flanges in close proximity produce a significant effect**
  – Flange in isolation will produce 5 to 7 dB increase in OAFPL
  – Flanges in short succession produce ~10 dB increase in OAFPL



Pixel variance enhanced shadowgraph, courtesy of Ted Garbeff, NASA Ames

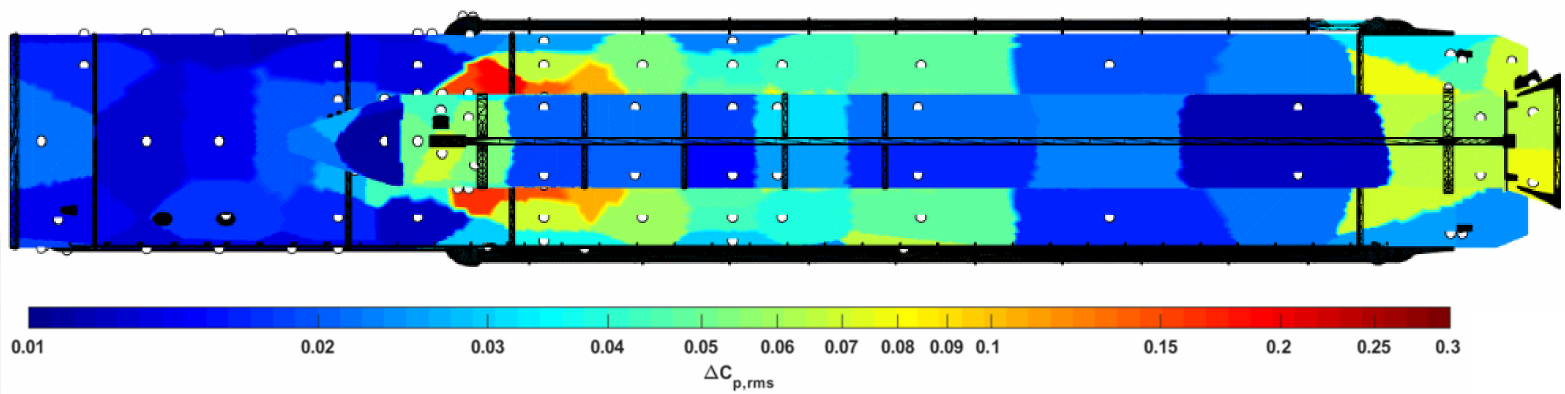


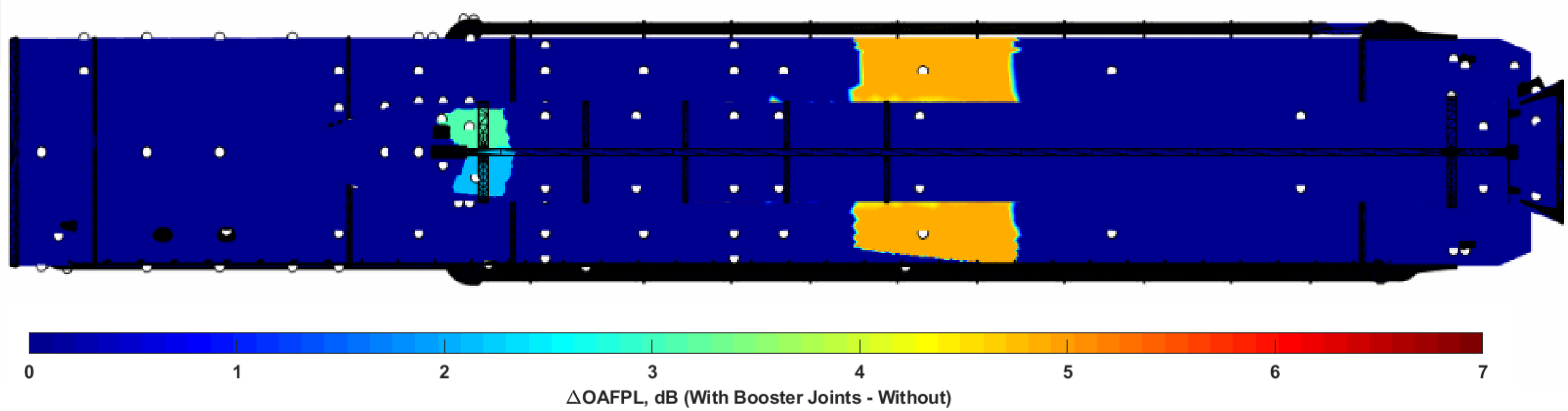

**Mach Sweep at α,β=0. White sensors from original test campaign, red sensors added for second**

- **Largest increases occur at supersonic Mach numbers once shocks form on flanges**
- **Altered interaction between flow separation and shock resulting in higher acoustic levels**

# Results – Multibody Interactions

- **Booster field/factory joints added to model effects on the flow in the immediate vicinity of the forward attach**
- **Unexpectedly the joints had the largest impact on the Core Stage Hydrogen Tank**
  - Joints are ~1 inch full scale and were expected to be buried in the boundary layer
  - Resulted in local flow separation and shocks which impinge on the Core

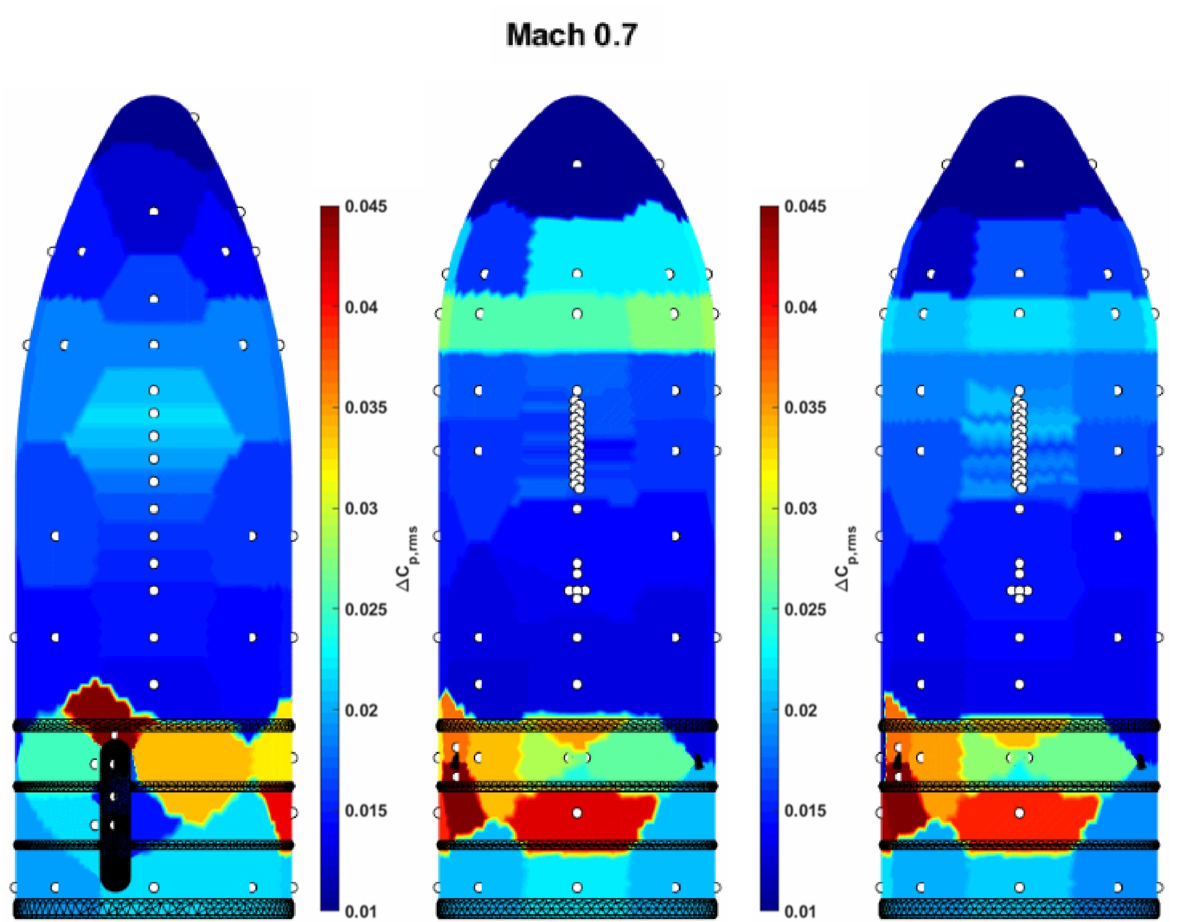


# Results – Payload Fairing

- **Three separate fairing configurations tested in transonic tunnel**
  – Alternate configurations enhance payload volume

- **Peak measured levels on the cylindrical section occur at ~Mach 0.85 for each configuration**
  – Possibility that absolute peak for alternate tangent-ogive is missed due to lack of sensors at upstream most portion of the shoulder
  – The peak for the biconic after the second expansion may occur farther downstream from the shoulder than the tangent-ogive configurations
- **The biconic experiences largest measured levels after the first expansion**
  – Potential buffet issue




Baseline tangent-ogive

Alternate tangent-ogive

Alternate biconic

# Conclusions

- **Configuration changes can be utilized to isolate the effects of specific features which are applicable to a broad range launch vehicles**
- **Observations:**
  - Rounded corners on fairings can reduce maximum loads by ~5dB
  - Flow features, such as those produced by abort nozzle wakes, are not localized and can propagate far downstream, interfering with other flow phenomena
  - Flanges in isolation can produce up to a 7 dB increase locally, while flanges in quick succession can produce up to a 10 dB increase
  - Multibody fluctuating pressure environments are difficult to predict or anticipate. It is therefore critical to model vehicle features at the highest fidelity practical