SLS

Space Launch System

Overview of the Space Launch System Transonic Buffet Environment Test Program

David J. Piatak Martin K. Sekula   Russ D. Rausch   James R. Florance

Thomas G. Ivanco

NASA Langley Research Center

Presented at

53rd AIAA Aerospace Sciences Meeting

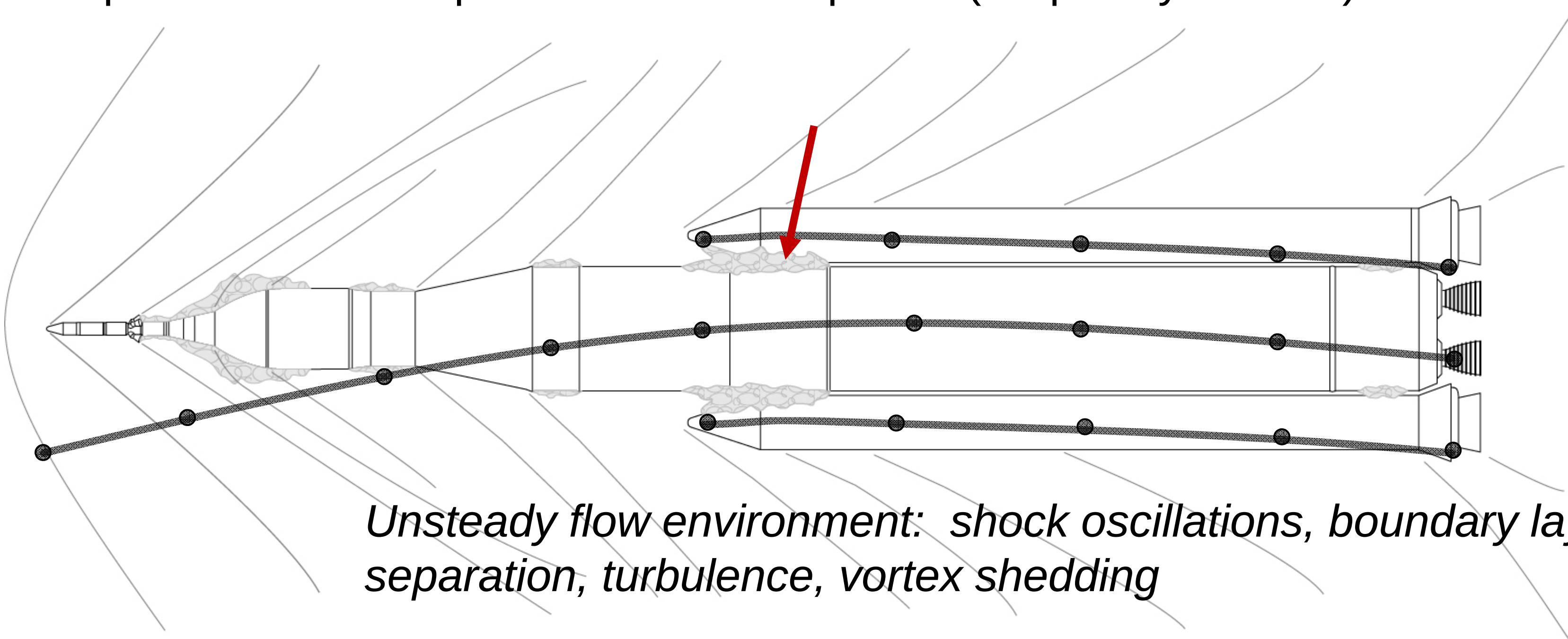
Kissimmee, FL, January 5-9, 2015

Outline

- Motivation for Buffet Testing
- Buffet Test Program Objectives
- Overview of Past SLS Buffet Environment Efforts
- Space Launch System Model Design
  - Test Configurations
  - Instrumentation
- Test Facility
- Results
- Conclusions

Rigid Buffet Model Motivation

- **Buffet loads due to unsteady aerodynamic phenomena can excite vehicle bending modes and local shell/panel modes**
- **Transonic regime is typically most critical (max-Q next runner-up)**
- **Buffet forcing functions are required for coupled loads analysis (CLA)**
- **Pure analytical solution is not feasible**
  - Experimental forcing functions (time domain)
  - Experimental auto-spectra and cross-spectra (frequency domain)



Unsteady flow environment: shock oscillations, boundary layer separation, turbulence, vortex shedding

SLS Space Launch System

Buffet Test Program Objectives

Test Objective:

- Acquire time-correlated unsteady pressures on rigid model at transonic conditions
  - Up ... Hz model scale)
  - ... odel scale)

Key D...

- Key ... sensor stat...

Cost o...

- Lac...
  - ...
  - ... re)

Mercury-Atlas Test Flight (MA-1) August 1960

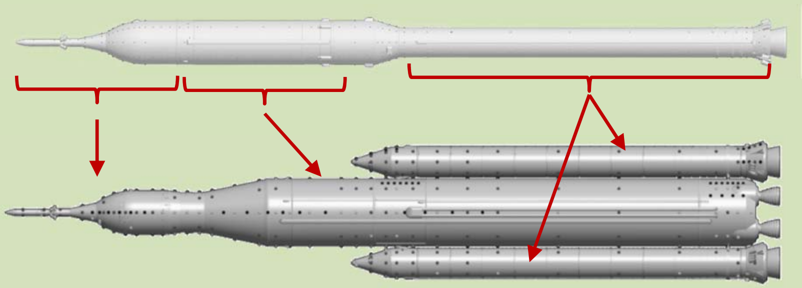
Panel buckling due to wake buffet of LAS tower and cone/cylinder junction

5% to 6% of launch vehicle failures can be attributed to structural failure

Launch Vehicle Failure Mode Database, Nickolas Demidovich, FAA, May 17, 2007

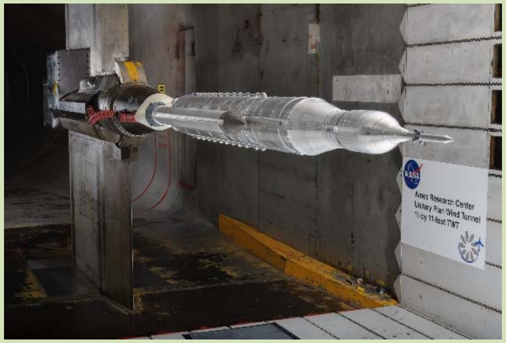
Overview of SLS Buffet Environment Efforts

Initial BFF Estimate (Feb 2012)
- Ares launch vehicle BFFs used as basis
- Scaled and mapped to SLS-10002
- Mach 0.95 provided for initial loads cycle



Buffet Test at TDT (Oct 2012)
- Three SLS configurations tested
- High buffet environments identified
- Buffet Loads Mitigation Task Team created

Ascent Aeroacoustic Test (Aug 2013)
- Ames Unitary Plan Wind Tunnel (UPWT)
- Primary goal: fluctuating pressure environments
- Buffet mitigation options (BMOs) tested



Buffet Test at TDT (May 2014)
- SLS-10005 configuration (Orion MPCV)
- Updated protuberances / Increased sensor ports
- Buffet mitigation options (BMOs) tested

SLS Space Launch System

Model Design: 2012 Test Configurations

3%-scale with 360 Unsteady pressure ports

SLS-10003 Vehicle Configuration
- 70-metric-ton payload (Orion)
- RS-25 engines (4)
- Enhanced 5-segment boosters (2)

SLS-11000 Vehicle Configuration
- 93-metric-ton payload (8.4m shroud)

SLS-13000/28000 Vehicle Configuration
- 93-metric-ton payload

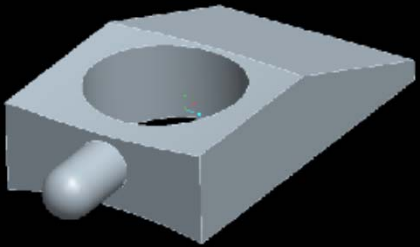
Model Design: 2014 Test Configurations

3%-scale with 472 Unsteady pressure ports

SLS-10005 Vehicle Configuration
- 89-metric-ton payload (Orion)
- RS-25 engines (4)
- Enhanced 5-segment boosters (2)

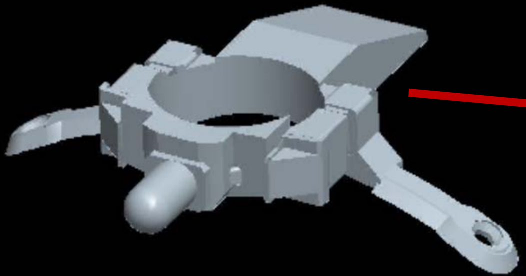
- Updated Protuberances
  * Booster forward attach, LOX feed lines,
    GO2/GH2 press lines, cameras.

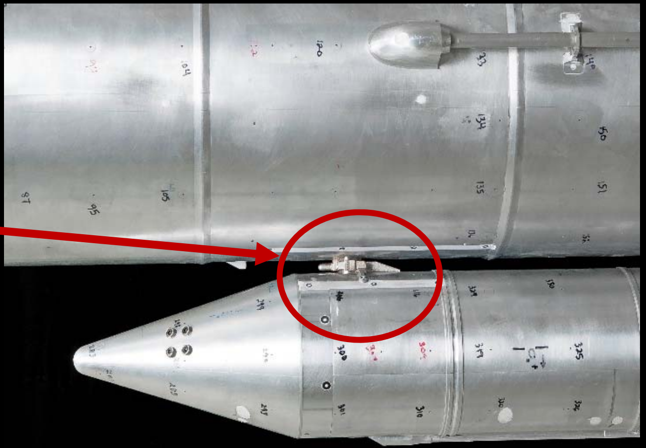
Refined versus Simplified Booster Forward Attachment Protuberance



2012 Test: Simplified

2014 Test: Refined





Model Design: 2014 Test Configurations

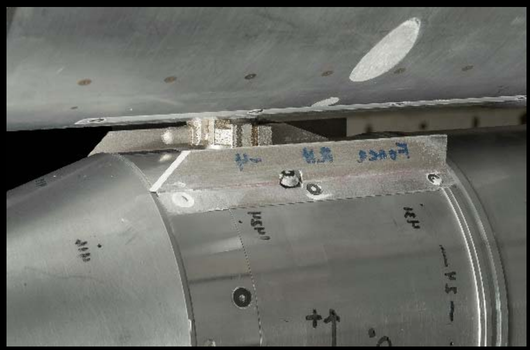
Booster Nose Cone Buffet Mitigation Options

Canted Ogive

Bent Bi-conic

Canted Straight

Fence Buffet Mitigation Options

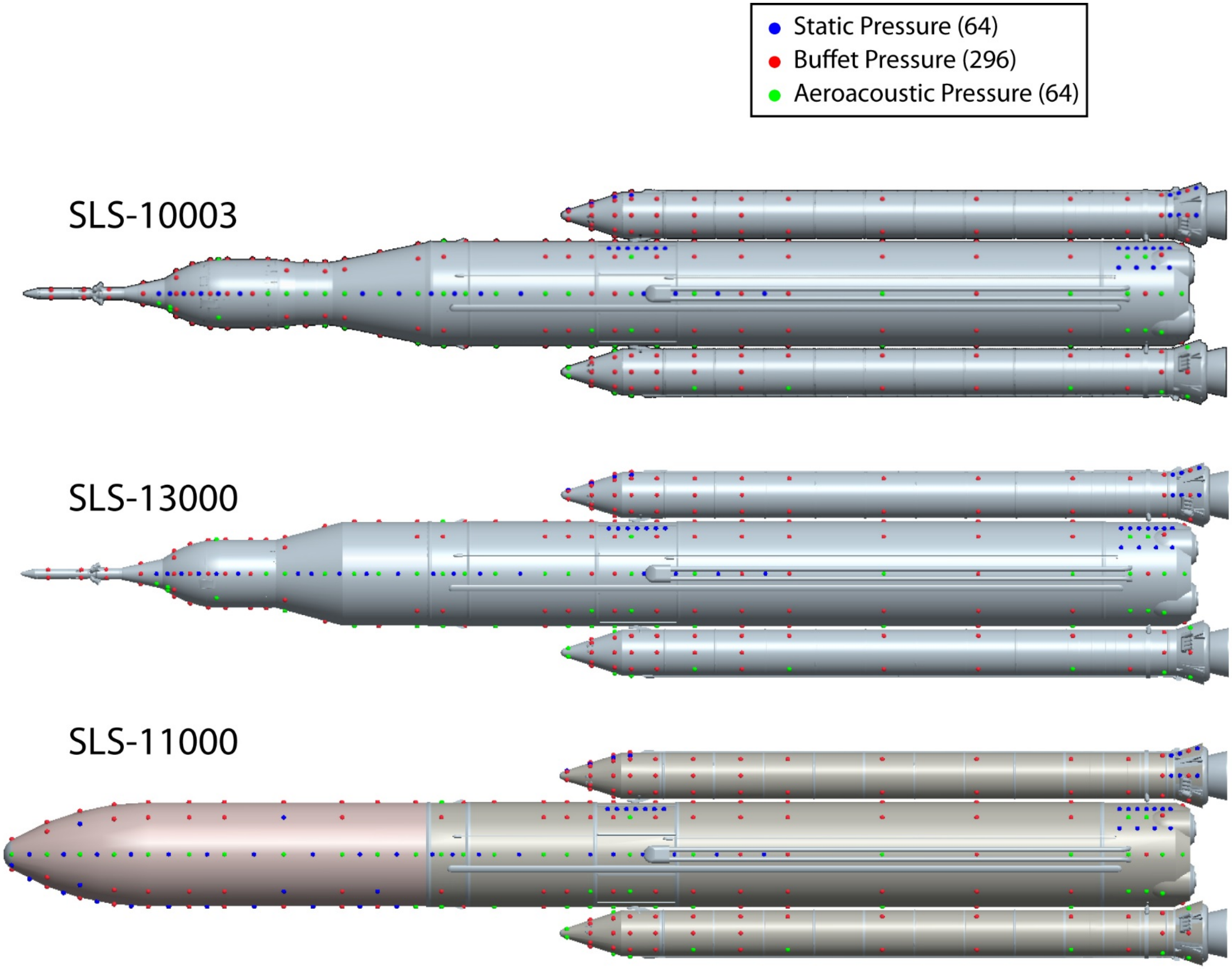


Sharp Booster Fence

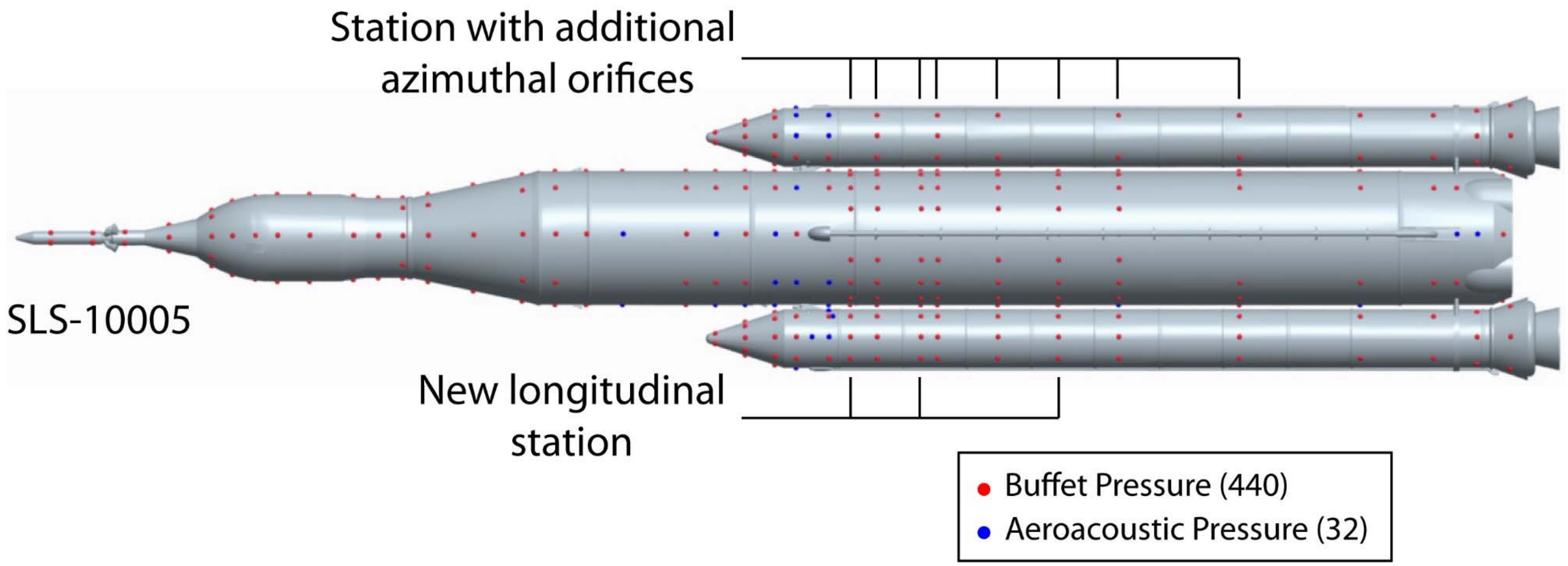
Blunt Booster Fence

Core Fence

Model Design: 2012 Test Pressure Measurement Locations



Model Design: 2014 Test
Pressure Measurement Locations



Model Design: Instrumentation

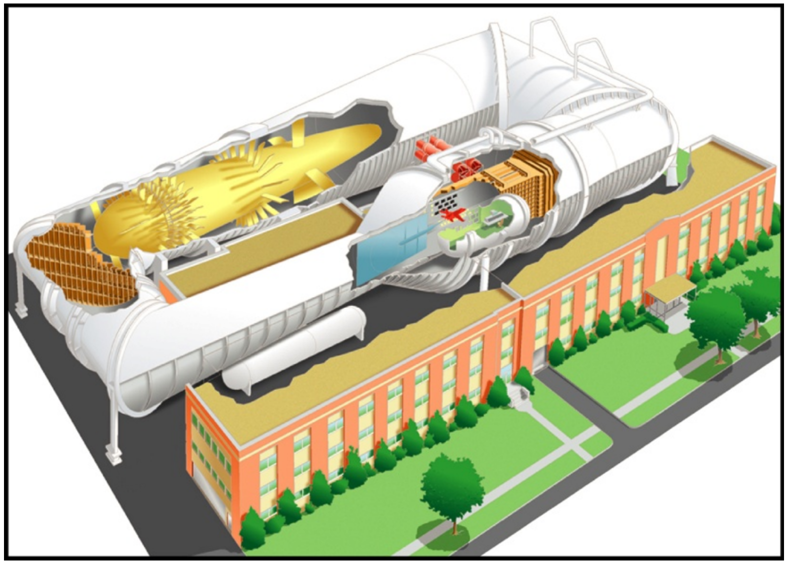
♦ Model Pressure Instrumentation

- Kulite Semiconductor XCL-100/072 unsteady pressure sensors
- Integrated amplifier to reduce signal attenuation at high frequencies
- Very high channel counts
  - 360 Kulites for 2012 test (64 aeroacoustic)
  - 472 Kulites for 2014 test (32 aeroacoustic)
- 64 steady pressures on core and RSRB (2012)

♦ Accelerometers and Q-flex Inclinometers

- Six accelerometers for model vibration response
- 3-axis Q-flex accels for model orientation (pitch/roll)

Transonic Dynamics Tunnel



Facility Characteristics

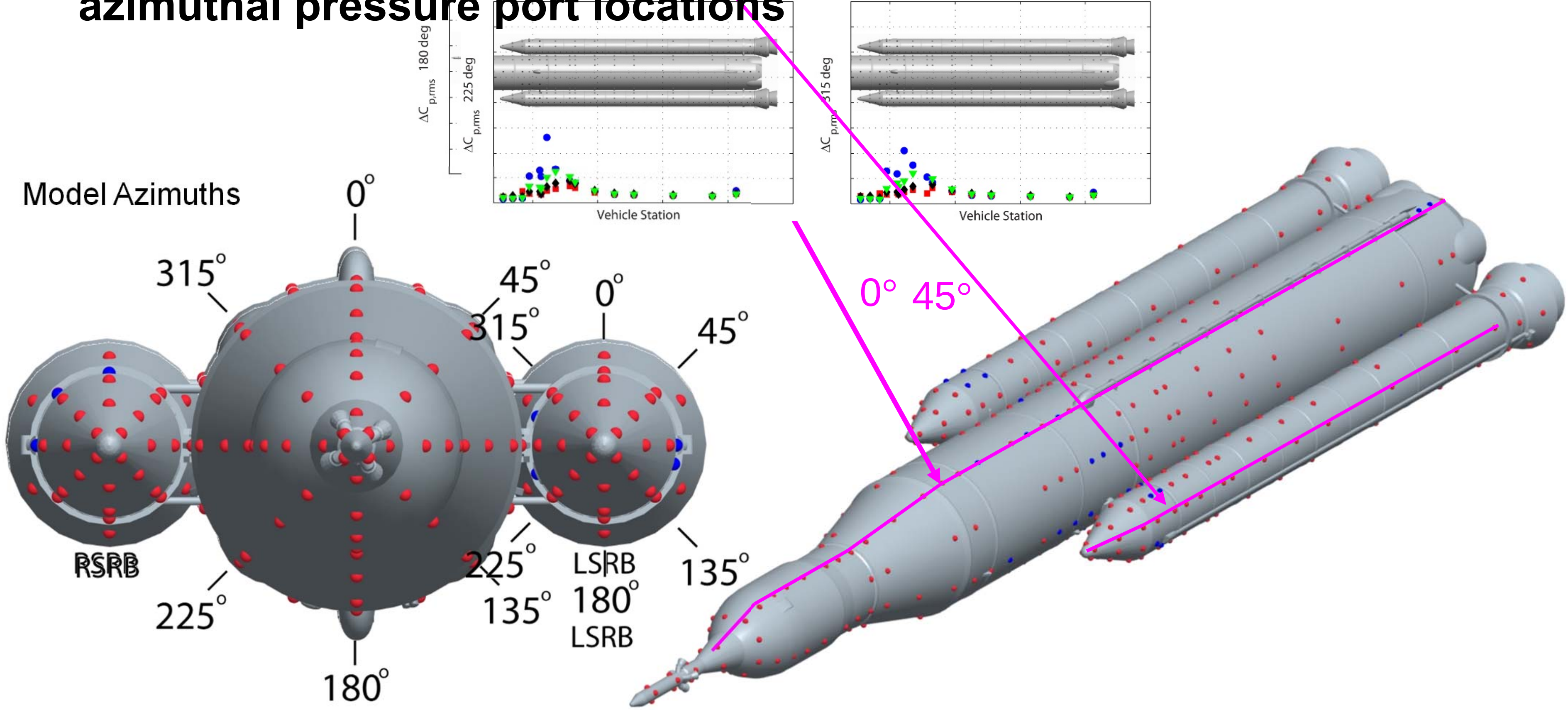
- Closed-circuit, continuous flow, transonic pressure tunnel
- Test section: 16 feet x 16 feet
- R134a or air test medium
- Mach numbers up to 1.2
- Dynamic pressures up to 550 psf

SLS Tests

- Mach 0.7 – 1.2
- R134a test medium
- Dynamic pressures up to 480 psf
- Reynolds numbers up to
- Model Pitch: ±8° Model Roll: ±180°
- Over 10 terabytes of data

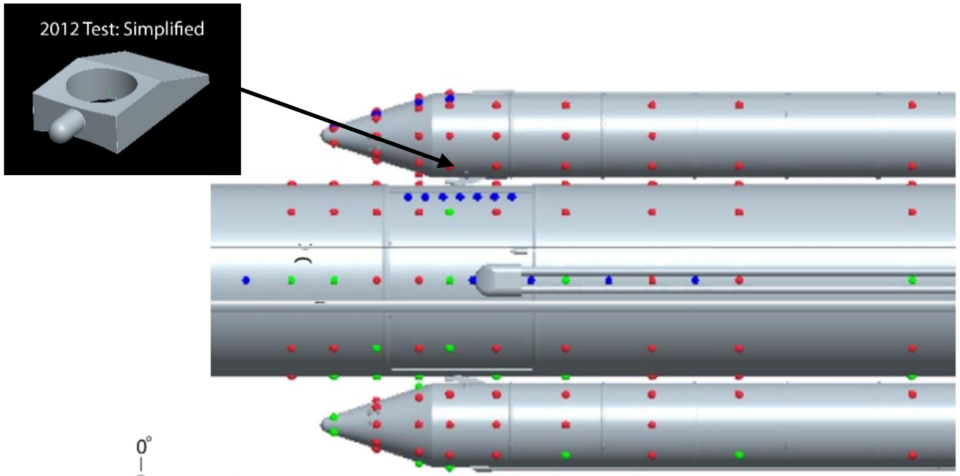
Presentation of Data

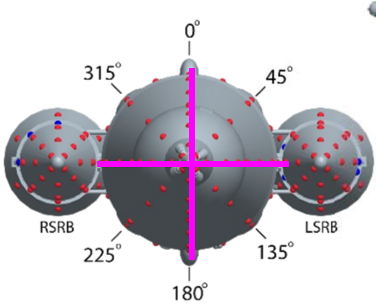
- Comparisons of buffet environments made using $\Delta C_{p,\,rms}$
- All results are presented without defined numerical scales
- All results have 0.5-60 Hz bandpass filter applied (full-scale freq)
- All results are presented for Mach 0.90 and pitch/roll of zero degrees
- Data is presented versus vehicle longitudinal station at common azimuthal pressure port locations

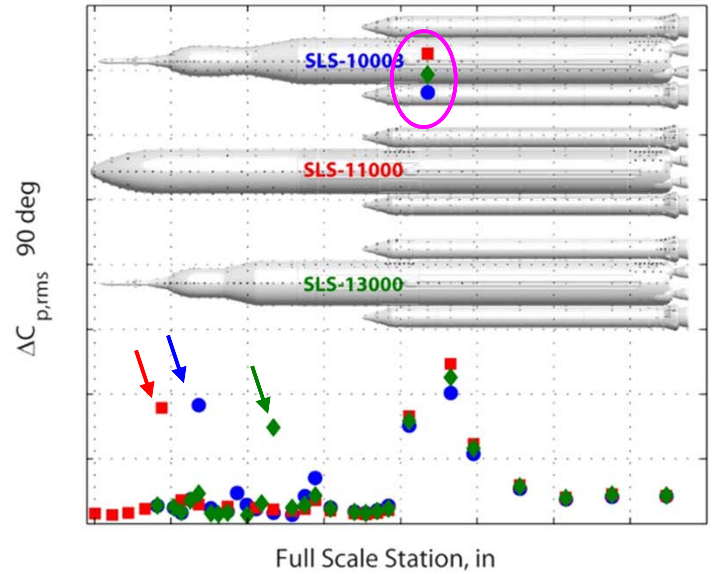


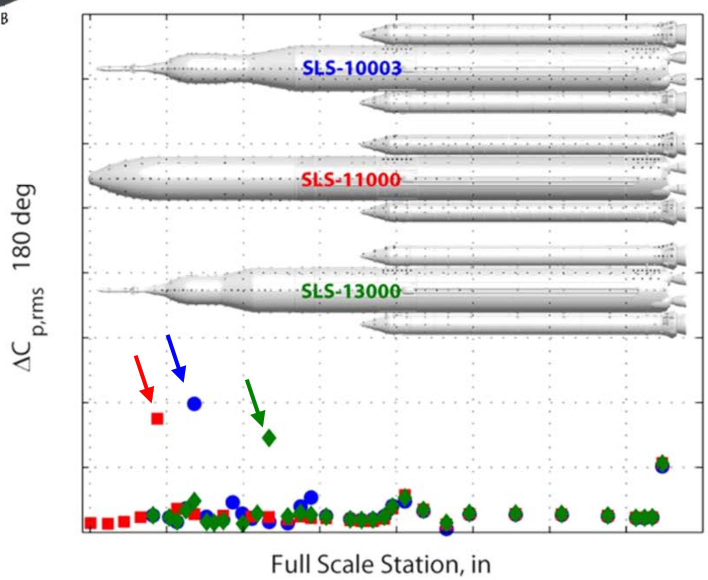
ΔC$_{p,rms}$ Trends on Core

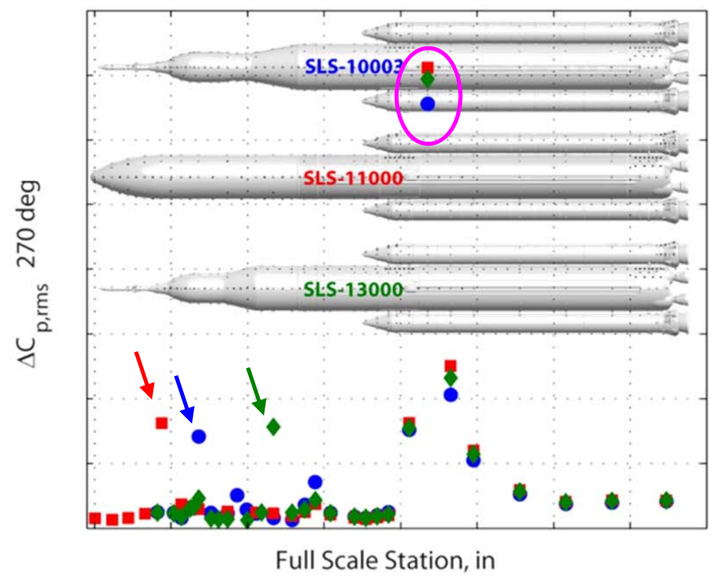
Mach 0.90; 0/90/180/270 deg azimuths





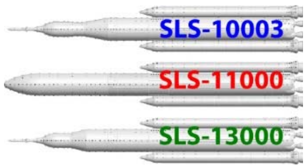


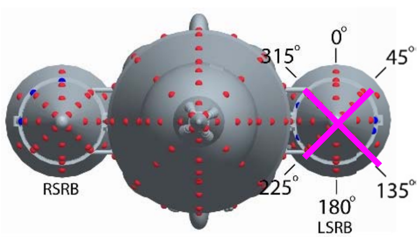


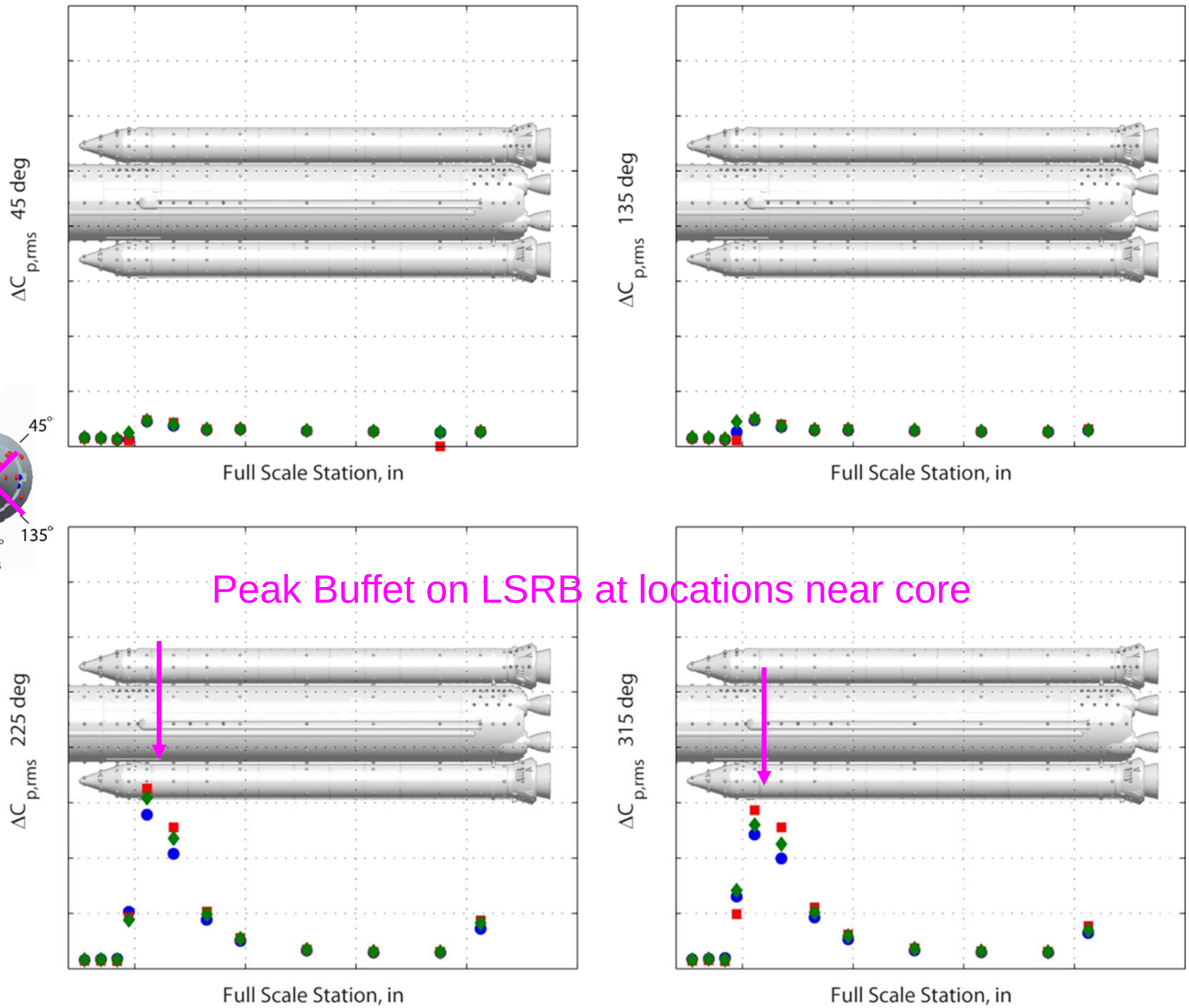


$\Delta C_{p,rms}$ Trends on LSRB

Mach 0.90; 45/135/225/315 deg azimuths

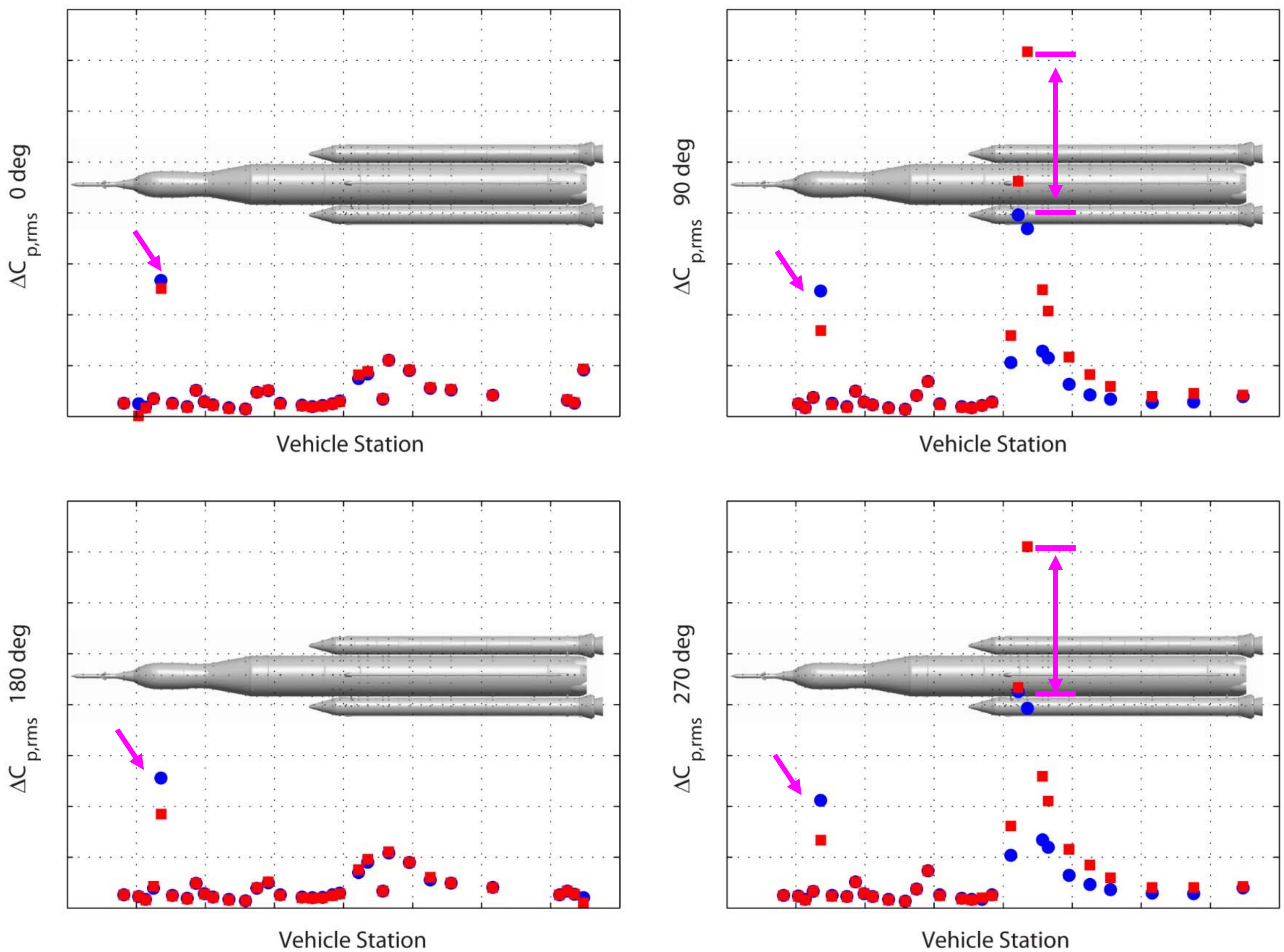


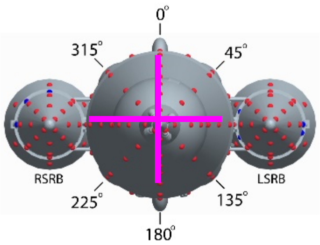




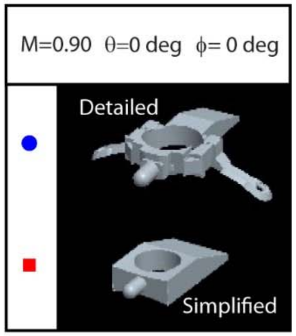
$\Delta C_{p,rms}$ Trends on Core

Mach 0.90; 0/90/180/270 deg azimuths



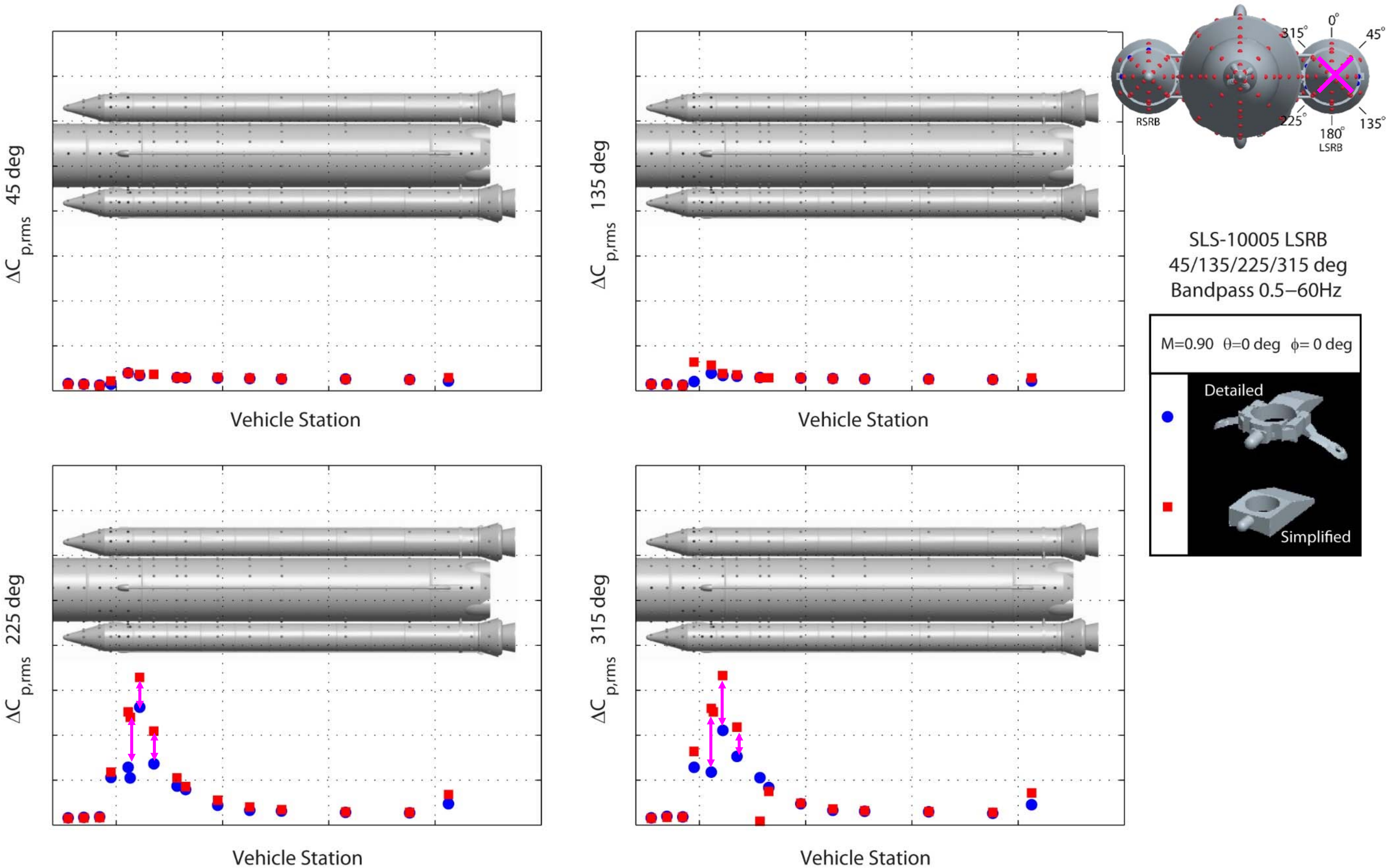


SLS-10005 Core
0/90/180/270 deg
Bandpass 0.5–60Hz



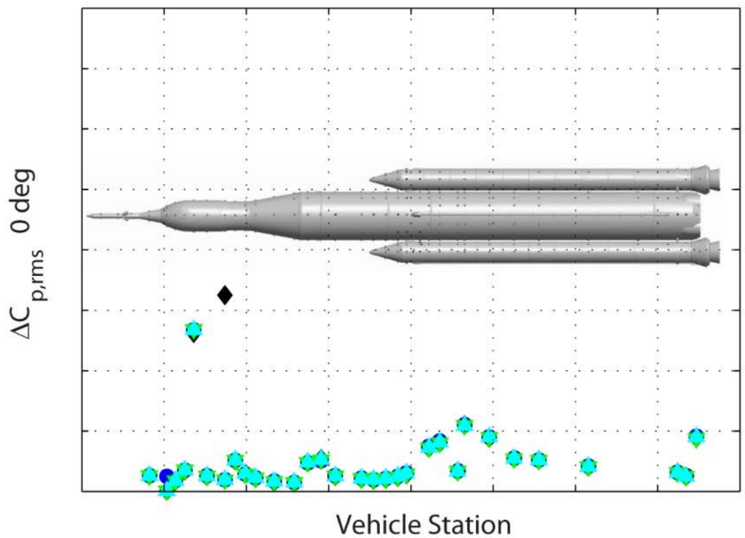
$\Delta C_{p,rms}$ Trends on LSRB

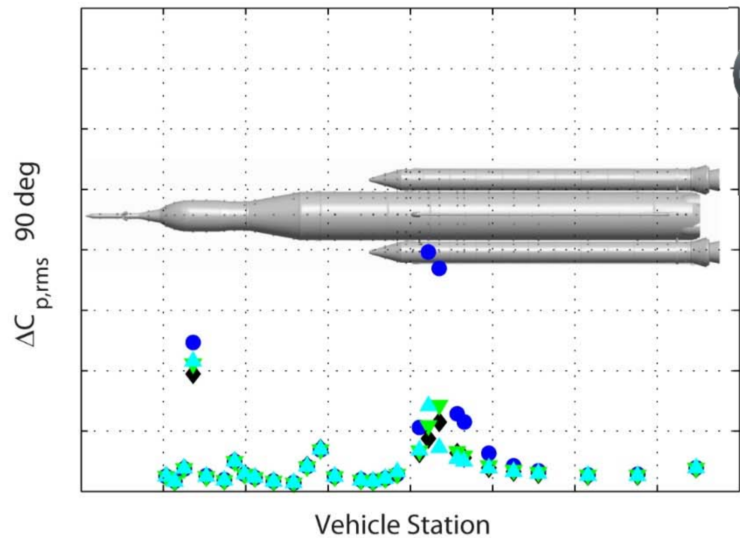
Mach 0.90; 45/135/225/315 deg azimuths

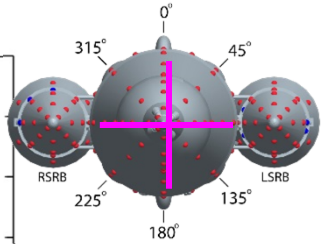


$\Delta C_{p,rms}$ Trends on Core

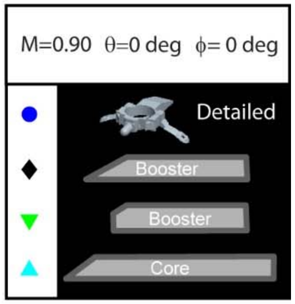
Mach 0.90; 0/90/180/270 deg azimuths

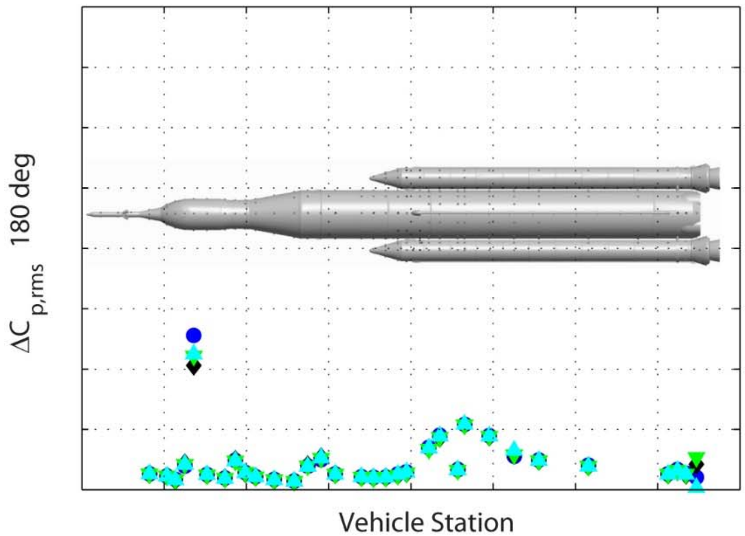


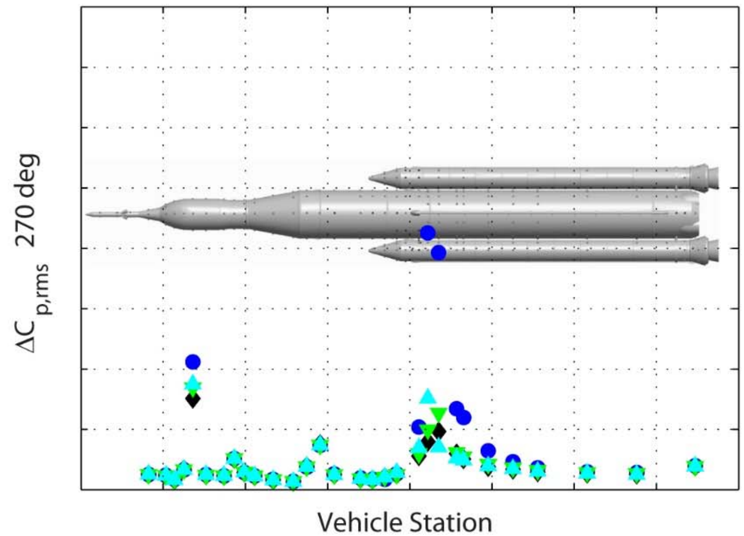




SLS-10005 Core
0/90/180/270 deg
Bandpass 0.5–60Hz



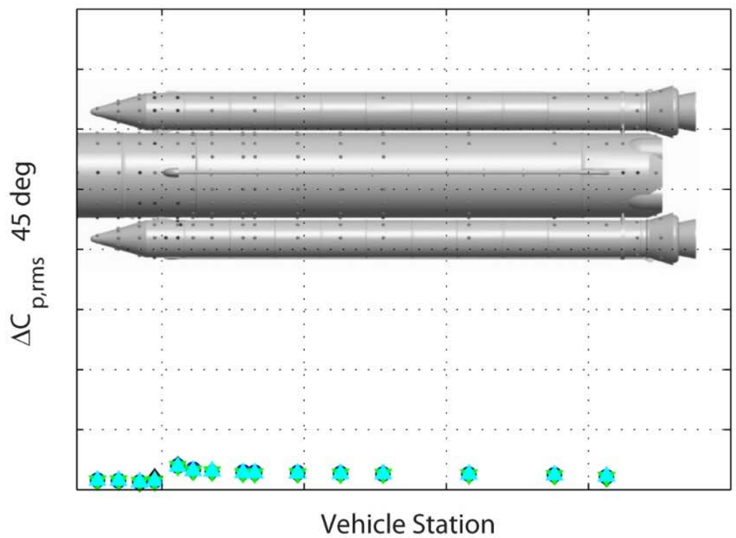


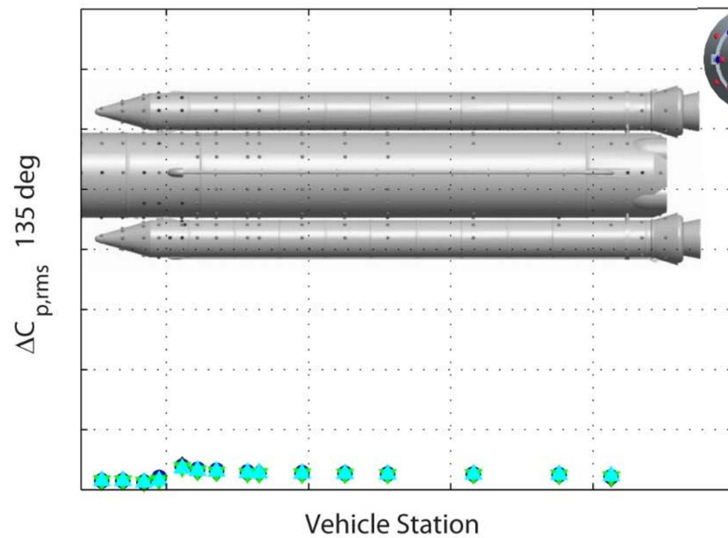


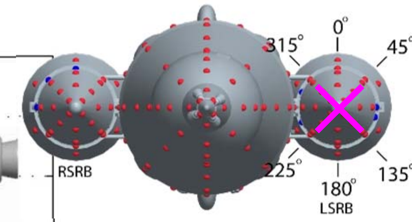
SLS Space Launch System

$\Delta C_{p,rms}$ Trends on LSRB

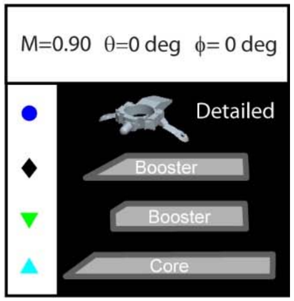
Mach 0.90; 45/135/225/315 deg azimuths

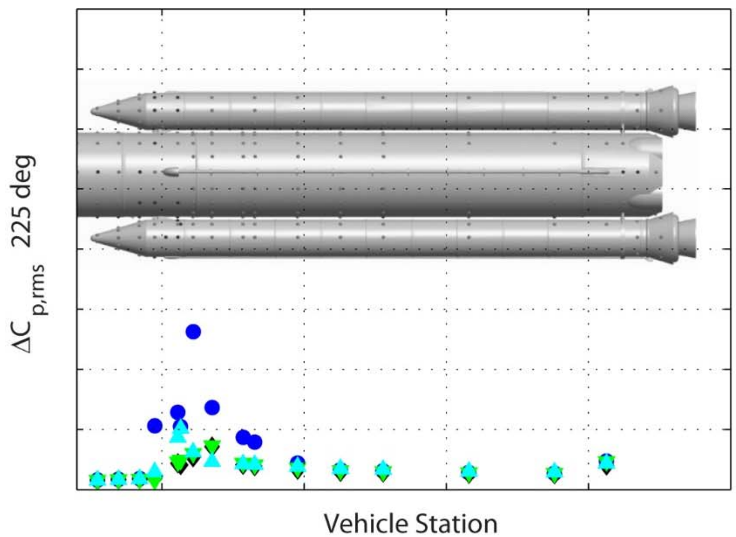


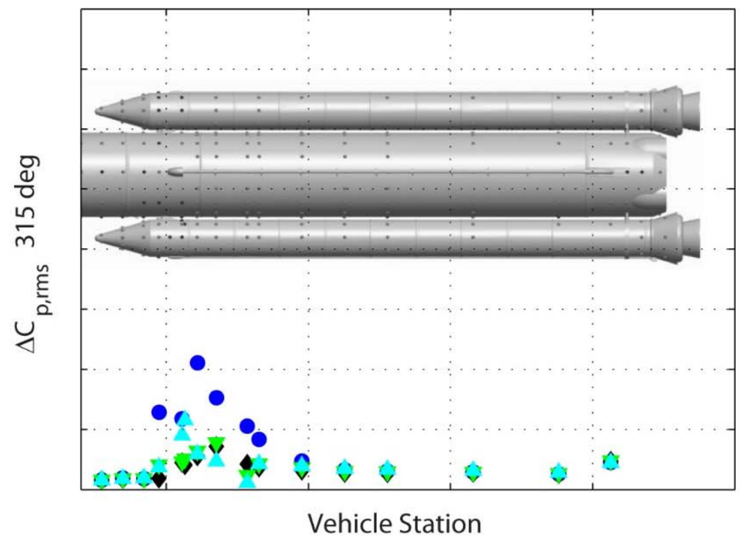




SLS-10005 LSRB
45/135/225/315 deg
Bandpass 0.5–60Hz

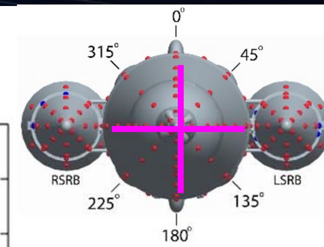




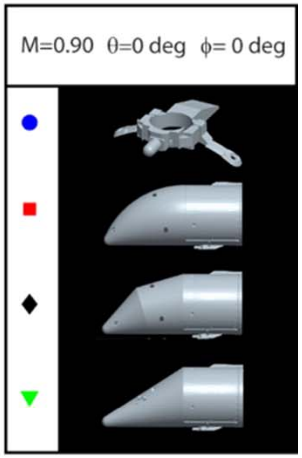


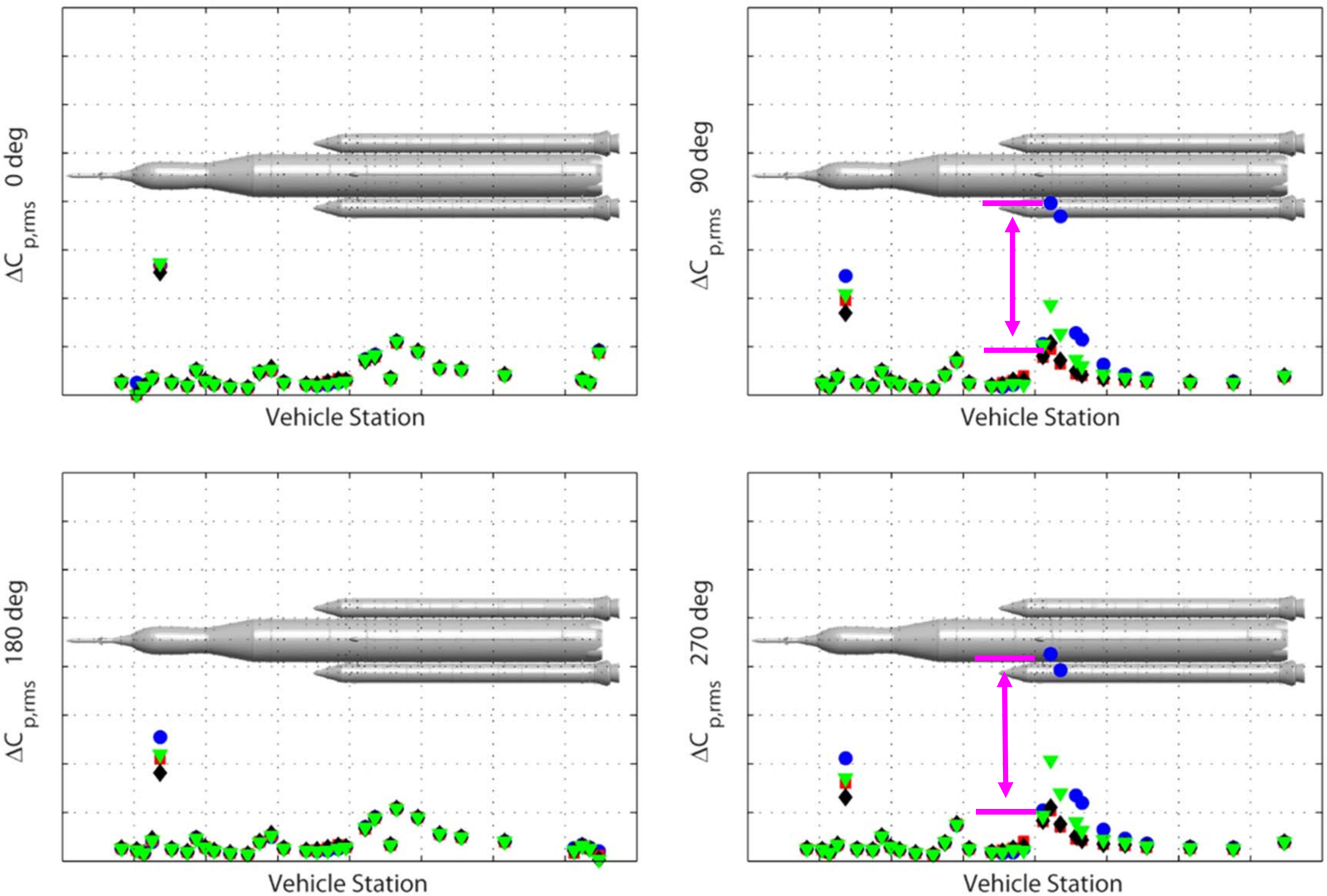
$\Delta C_{p,rms}$ Trends on Core

Mach 0.90; 0/90/180/270 deg azimuths

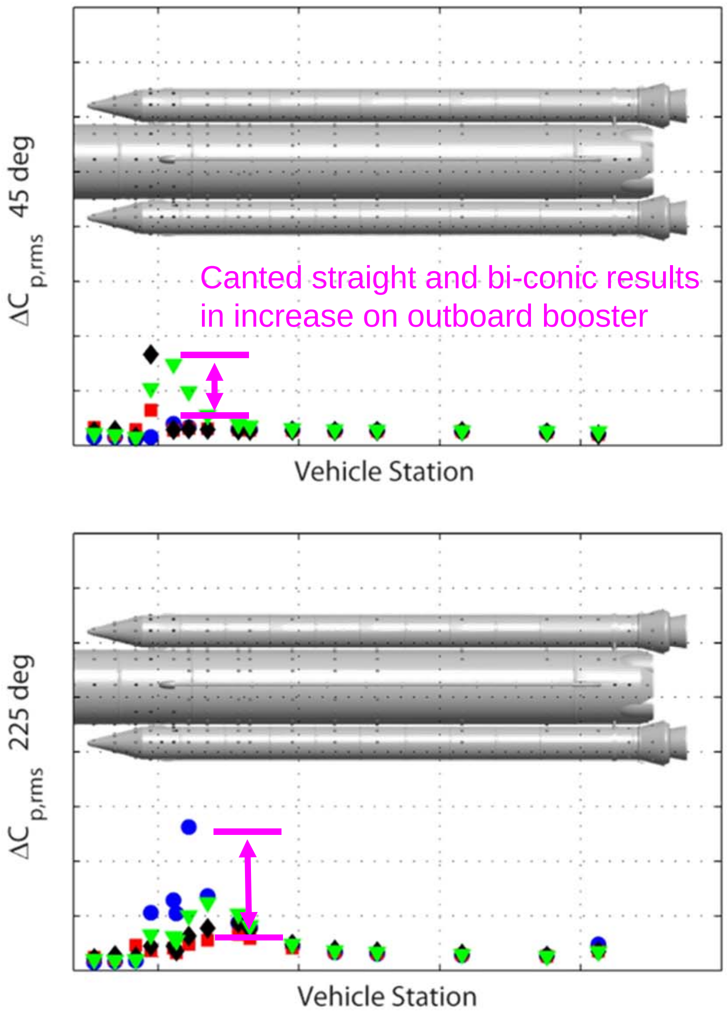


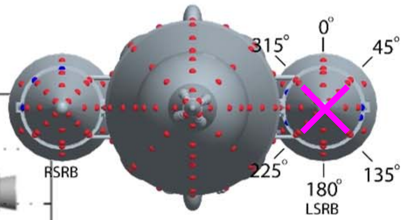
SLS-10005 Core
0/90/180/270 deg
Bandpass 0.5–60Hz



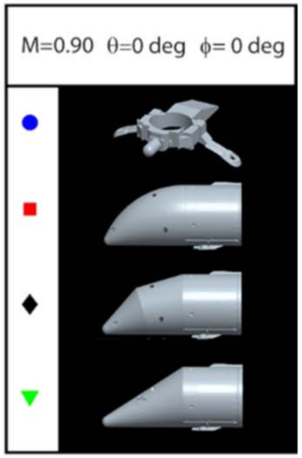


$\Delta C_{p,rms}$ Trends on LSRB
Mach 0.90; 45/135/225/315 deg azimuths





SLS-10005 LSRB
45/135/225/315 deg
Bandpass 0.5–60Hz

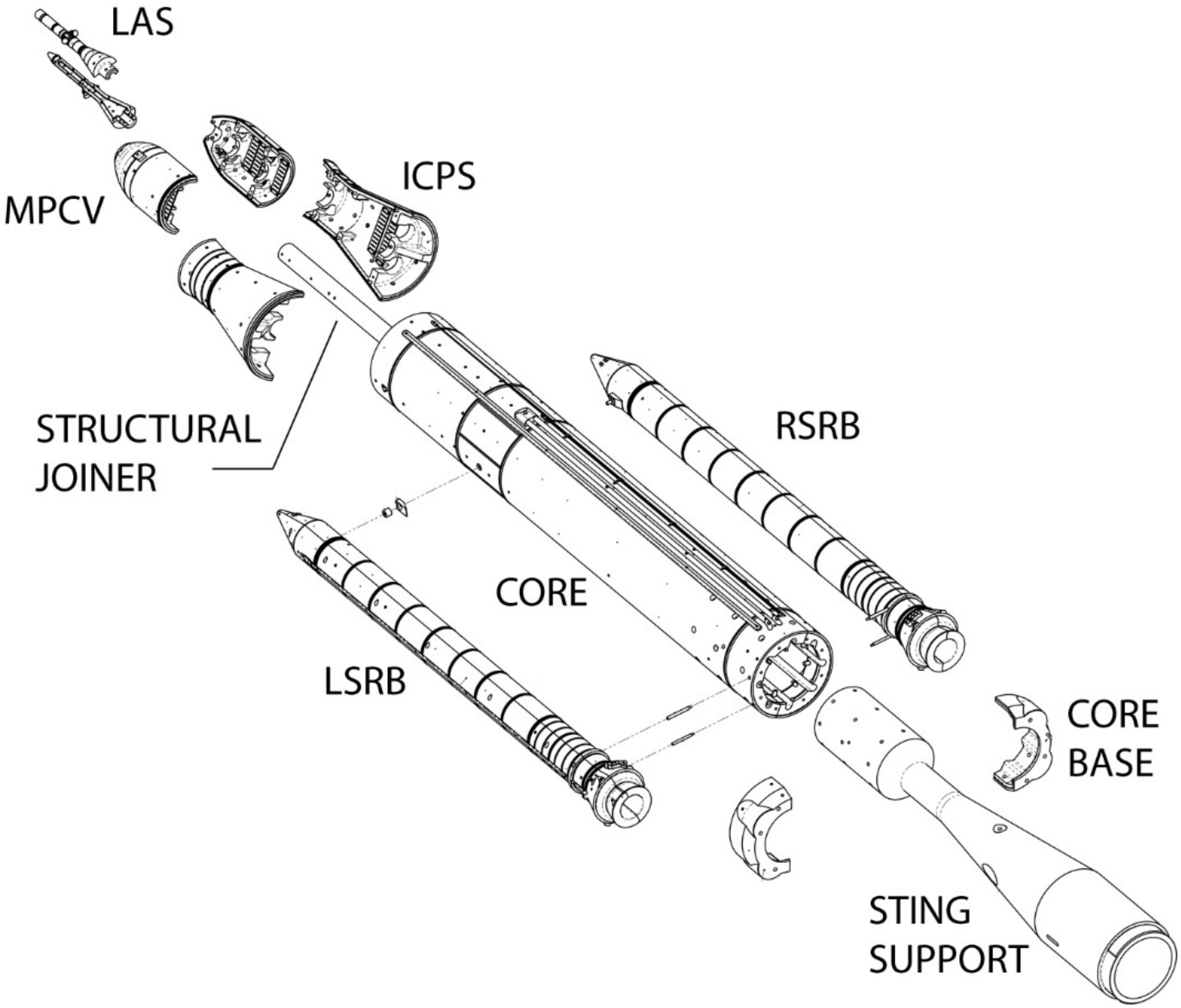


Conclusions

- **Space Launch System buffet test program development and project history has been presented**
- **Significant buffet model design characteristics which impact data quality have been discussed**
- **Comparisons of buffet environments made between various model configurations**
  - Buffet environments defined for the SLS-10003 Orion, SLS-11000 Cargo, and SLS-13000 Orion configurations
  - High buffet environments observed in vicinity downstream of booster forward attachment
  - Buffet environments shown to be reduced with detailed forward attachment protuberance
  - Fence buffet mitigation options (BMOs) shown to be effective at reducing buffet environments
    - Core fences slightly more effective
  - Nose cone BMOs shown to also be effective at reducing environments
    - Canted ogive is slightly more effective

Backup

Model Design: Components



Data Acquisition Systems

SLS Space Launch System

2012 SLS Buffet Test

- **Buffet Sensors (360 + 6 accels)**
  - NEFF 730 A/D
  - 12 KHz scan rate
  - 4.5 KHz anti-alias filter
- **Aeroacoustic Sensors (64)**
  - DSPCon Piranha III A/D
  - 100 KHz scan rate
  - Anti-alias filter at 50 KHz

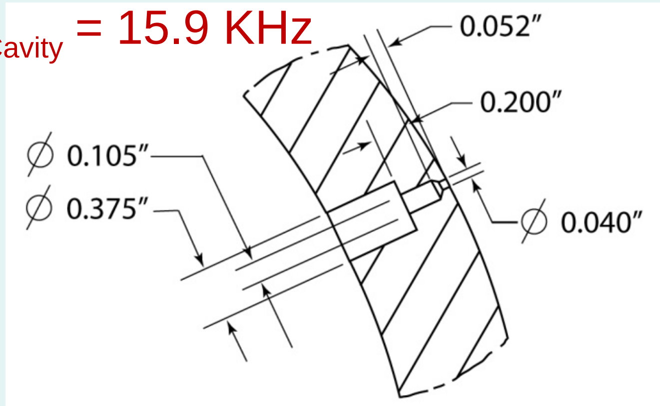
2014 SLS Buffet Test

- **Buffet Sensors (472 + 6 accels)**
  - Precision Filter 28000 + National Instruments PXI
  - 16 KHz scan rate
  - 6 KHz anti-alias filter
- **Aeroacoustic Sensors (32)**
  - Precision Filter 28000 + National Instruments PXI
  - 200 KHz scan rate
  - Anti-alias filter at 60 KHz

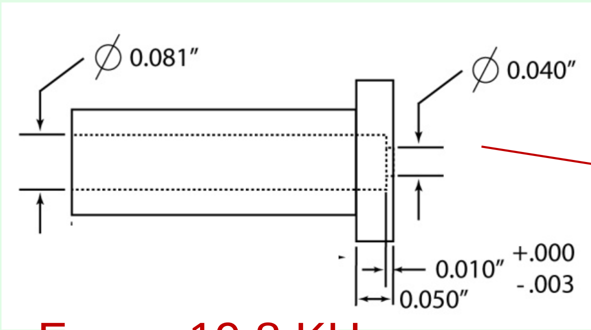
Model Design: Pressure Sensor Installation

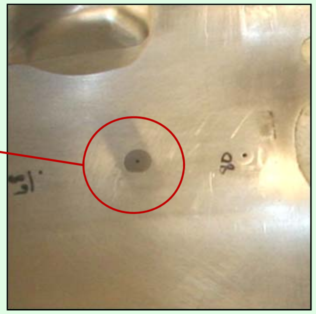
Buffet Kulite Installation: Sensor is sealed into hole with RTV

F_{Cavity} = 15.9 KHz



Aeroacoustic Kulite Installation: Precision insert and hand-worked to OML





F_{Cavity} = 19.8 KHz

Transducer Frequency Response In-Situ Testing