National Aeronautics and Space Administration



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Coherence analysis of the Space Launch System using Unsteady Pressure Sensitive Paint

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AIAA SciTech Forum, 11-15 & 19-21 January 2021

www.nasa.gov/sls

Acknowledgements

- The uPSP test team at the *NASA Ames Research Center*, to include **Nettie Roozeboom**, **Jennifer Baerny**, **Jie Li**, **David Murakami**, **Marc Shaw-Lecerf**, **Paul Stremel**, and **Lucy Tang** and also **Jessica Powell** at the *NASA Johnson Space Center* for their invaluable assistance in acquiring, processing, and discussing the uPSP data analyzed in this paper.

- **Derek Dalle**, *NASA Ames Research Center,* for providing the CFD data.

- **Craig Streett**, *NASA Langley Research Center,* for reviewing the paper and for his helpful comments.

Outline

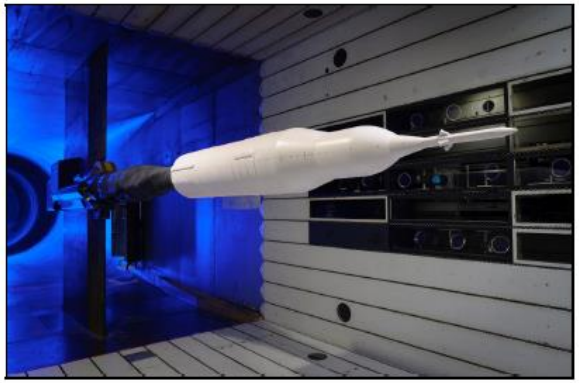
1. **Introduction**
2. **Description of the wind-tunnel tests and Unsteady Pressure Sensitive Paint (uPSP) data**
3. **Coherence analysis of the Space Launch System:**
   - Highlights of shock and forward attachment hardware environments
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   - Effects of longitudinal and azimuthal coherence factors
5. **Summary**

Introduction

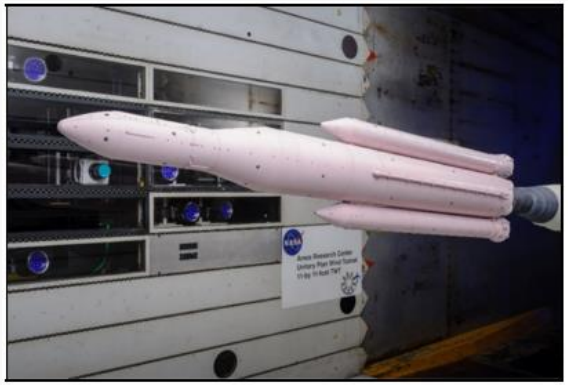
- ***Transonic buffet forces*** are a major source of unsteady loading on launch vehicles.
- Their estimation is based on wind-tunnel tests where the ***fluctuating pressures (p')*** are measured by pressure transducers (PTs) instrumented on a rigid buffet model.
- The ***p's*** are integrated over the surface of the vehicle to yield a series of centerline loads called BFFs.
- Typically, the PT layout aims at resolving the longitudinal pressure correlation. As a result, the distribution of ***azimuthal correlation*** and its impact on the BFFs are not well known.
- To fill these gaps, high-spatial-resolution uPSP data were collected for three different SLS configurations.
- The present work analyzes the spatio-temporal behavior of the pressure correlation on these vehicles and the impact of the azimuthal coherence on the BFFs.

Data description

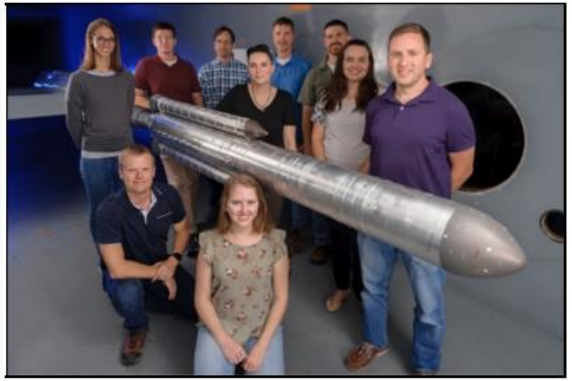
- Two transonic wind-tunnel tests (AUAT, ATAT) were conducted at the NASA Ames Research Center 11-Foot Transonic Unitary Plan Wind Tunnel
- AUAT: Ascent Unsteady Aerodynamics Test; ATAT: Ascent Transient Aerodynamics Test
- Photographs of the three SLS configurations for uPSP testing are shown below
- uPSP data: approaching 1M uPSP-nodes, sample rates up to 20 kHz
- Test conditions: $M_\infty = 0.70 - 1.40, \alpha, \beta = \pm 6$ deg
- A panel method, described in the paper, is utilized to average the uPSP pressures over defined panels



SLS Block 1B crew 4-percent scale model tested during AUAT (2017)



SLS Block 1 cargo 2.5-percent scale model tested during ATAT (2019)



SLS Block 1B cargo 2.5-percent scale model tested during ATAT (2019)

Shock environment: $\Delta C_{p,rms}$ and γ^2

$Mach = 0.80, \alpha = \beta = 0$ degrees

- For a pair of panels (j,k) the magnitude-squared coherence is computed as* :

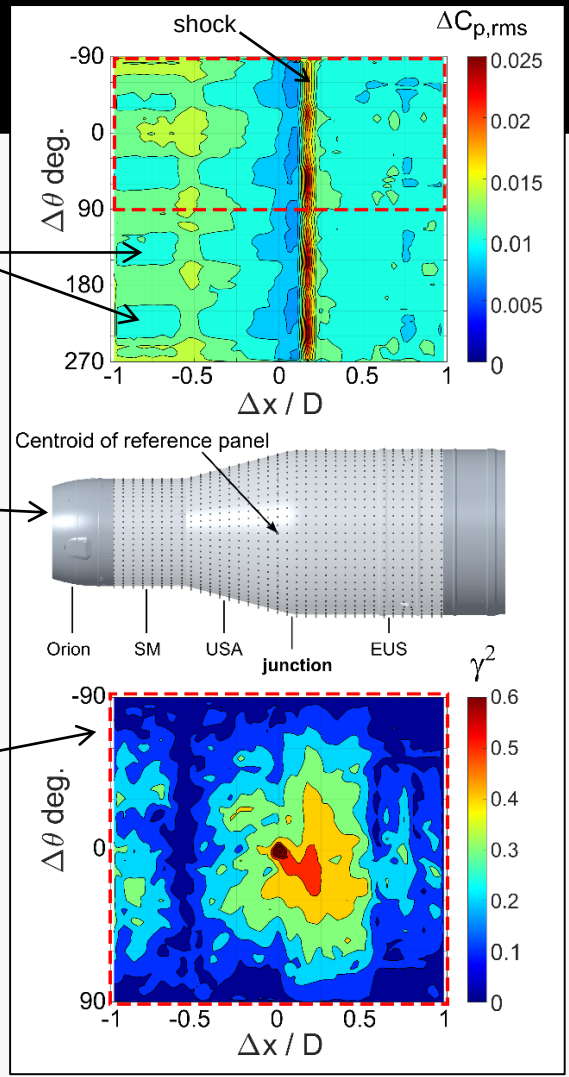
$$\gamma(\omega)^2 = \frac{\left|\Phi^p_{jk}(\omega)\right|^2}{\Phi^p_{jj}(\omega)\,\Phi^p_{kk}(\omega)},$$

- Shown on the right: unwrapped (Δx, Δθ) distributions of $\Delta C_{p,rms}$ and γ^2 for the Block 1B crew vehicle.

At the junction between the Universal Stage Adapter (USA) and the Exploration Upper Stage (EUS), the terminal shock interacting with turbulence is a source of unsteadiness ($\Delta C_{p,rms}$) and increased azimuthal coherence (γ^2).

*using a 2048-sample Hamming window with 50% overlap between windows

Regions where field of view of two uPSP cameras overlap

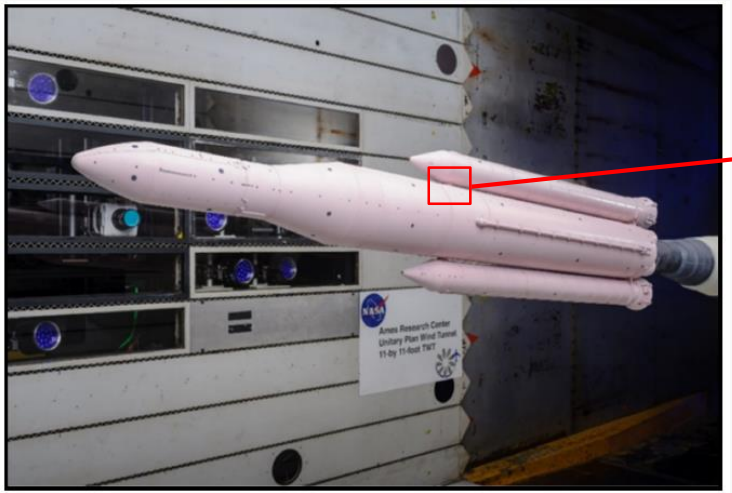


Block 1B crew vehicle. Junction between Universal Stage Adapter (USA) and Exploration Upper Stage (EUS)

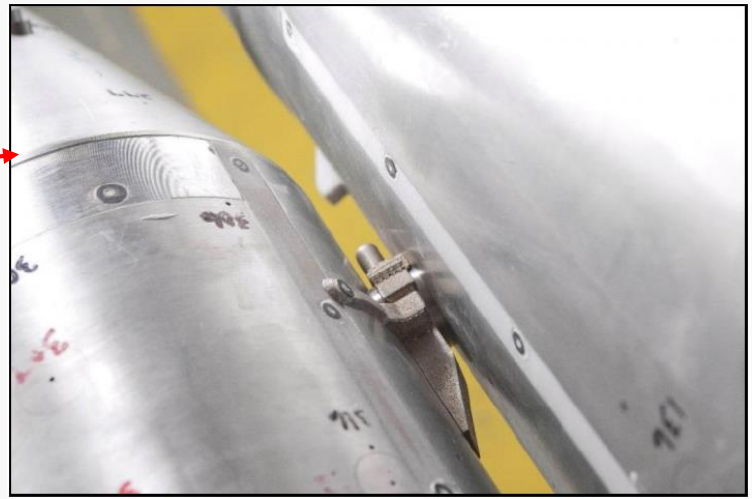
Magnitude-squared coherence shown at: $St = fD/U_\infty = 0.20$, where D = core stage diameter

FAH hardware environment

- The most severe buffet-environment on the SLS vehicle is located downstream of the Forward Attachment Hardware (FAH) that connects the solid rocket boosters (SRBs) to the core stage.
- Vortex shedding off the FAH results in propagation of highly coherent vortices down the length of the vehicle, causing high pressure fluctuations on the SRBs and on the core.



SLS Block 1 cargo 2.5-percent scale model tested during ATAT



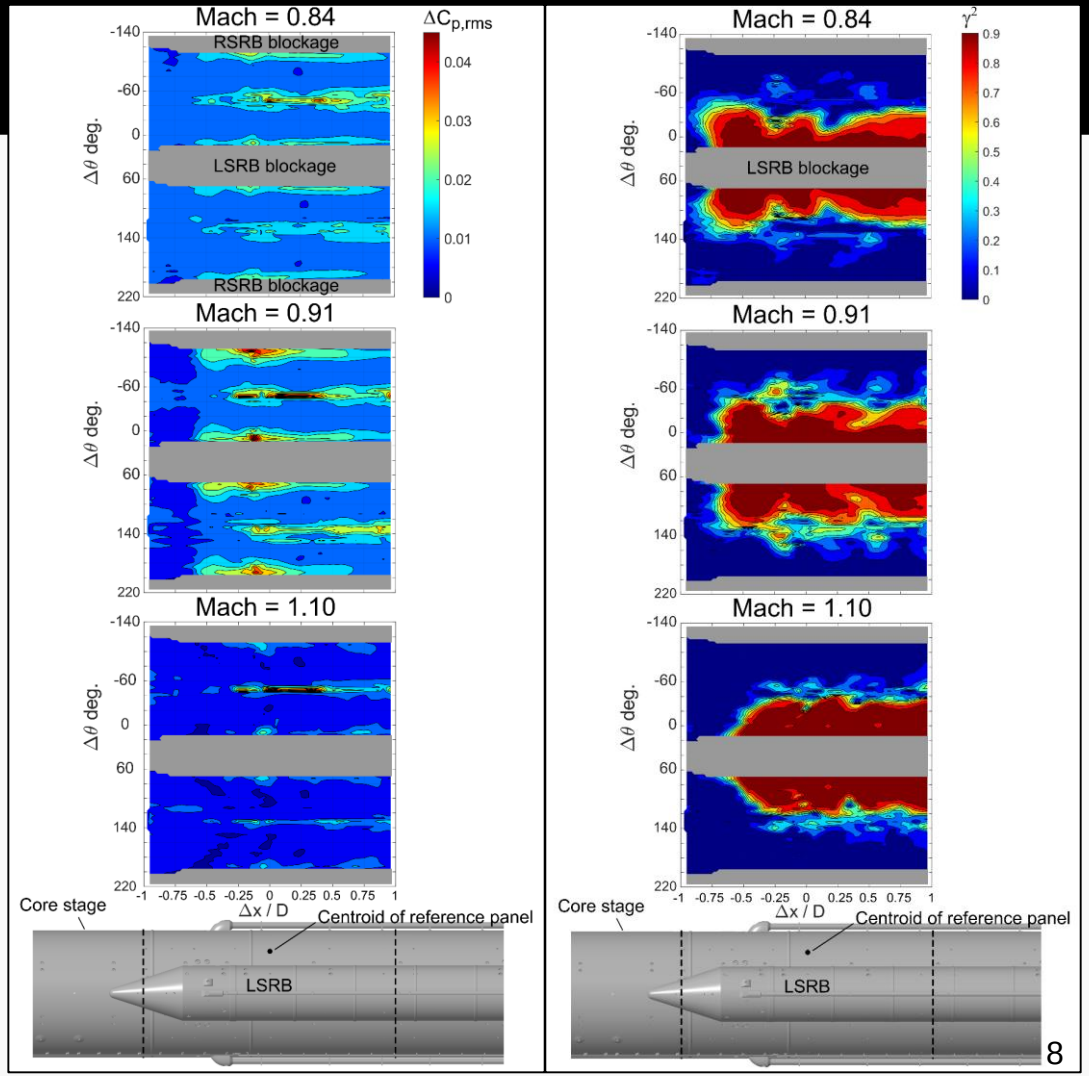
Booster forward attachment hardware detail

FAH environment

Distributions of $\Delta C_{p,rms}$ and γ^2 :

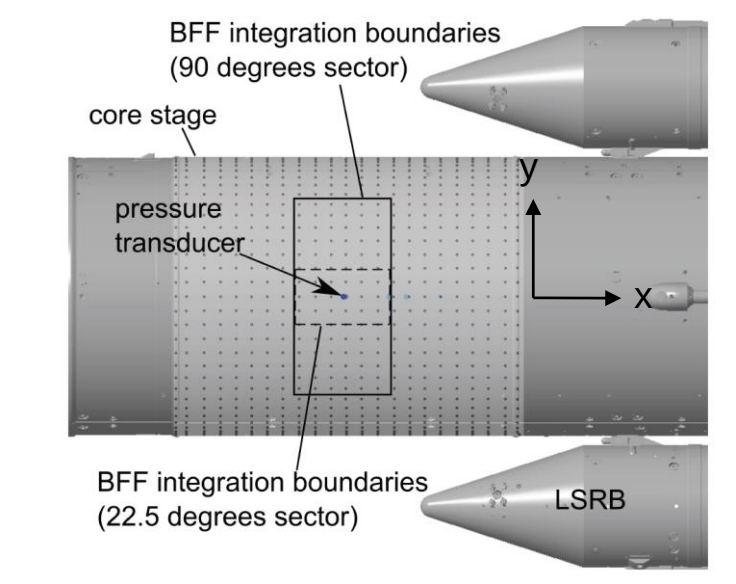
- At each Mach number, the magnitude squared coherence is plotted at the frequency of vortex shedding of the FAH.
- Data shown at zero degrees attitude.
- uPSP data reveals significant coherence levels both longitudinally and azimuthally.

SLS Block 1 cargo:

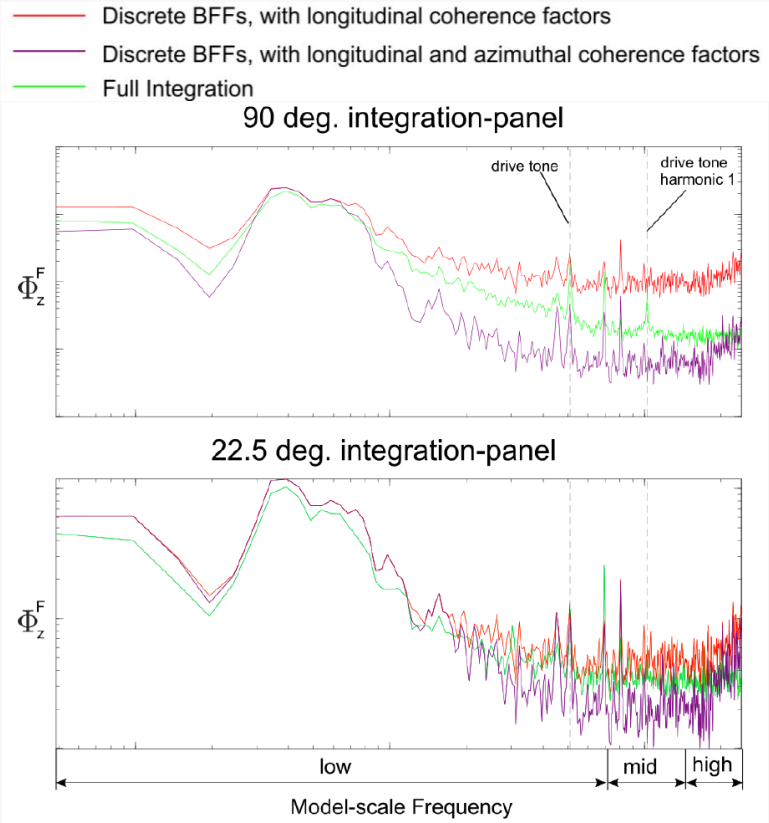


EXAMPLE OF $uPSP$-BASED BFF ACTING ON A PANEL

Block 1 cargo vehicle



Mach 0.91 $\alpha = 0.0°, \beta = 0.0°$



For these selected integration panels on the core stage, when both **longitudinal and azimuthal** coherence factors are applied, discrete BFFs underestimate those obtained from full integration of the uPSP data

Summary

- An analysis of the pressure correlation on the SLS is presented based on high-spatial-density uPSP data obtained for three SLS configurations.
- The spatio-temporal behavior of the pressure correlation on these vehicles is analyzed and flow features of interest are investigated.
- For instance, terminal shocks interacting with turbulence are a source of increased azimuthal coherence (spanning up to 180 degrees), especially when the shock develops at a vehicle junction.
- The *p*'s associated with vortex shedding off the forward attachment hardware are highly coherent aft of the attachment and up to 40 degrees away from the boosters.
- For selected areas of the vehicle, factoring the azimuthal coherence into the attenuation of discrete-measurement-based BFFs results in underprediction relative to the BFFs obtained from full integration of the uPSP data.