



SPACE LAUNCH SYSTEM

Development of Unsteady Aerodynamic Environments for the SLS Core Stage from High Spatial Resolution Wind Tunnel Data

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Outline



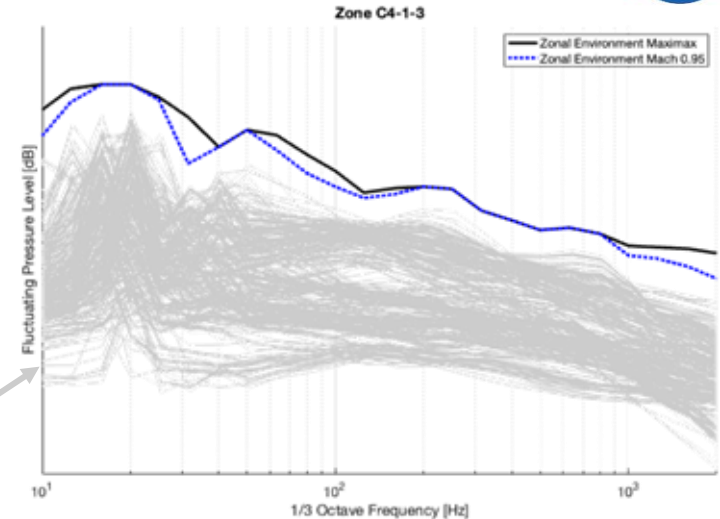
- **Zonal Aeroacoustic Environments**
- **Artemis I Observations**
 - Forward Attach Vortex Shedding Environment
- **VADIR Wind Tunnel Test**
 - Overview
 - Instrumentation Layout
 - Data Products
- **Forcing Function Development**
- **New Artemis II Environments**

Zonal Aeroacoustic Environments

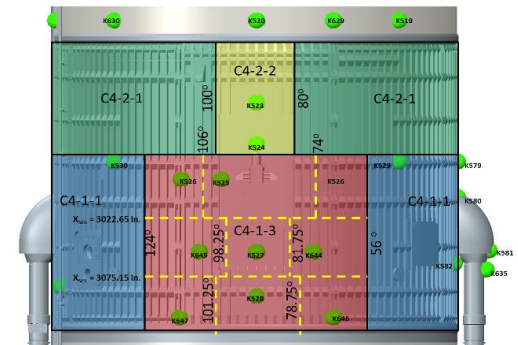


- Within the SLS program, wind tunnel-based aeroacoustic environments have typically been delivered as acoustic spectra on a per-Mach basis as a **maximax envelope**

- Maximum of:
 - All measurements within a defined zone
 - All alpha/beta conditions within a defined range



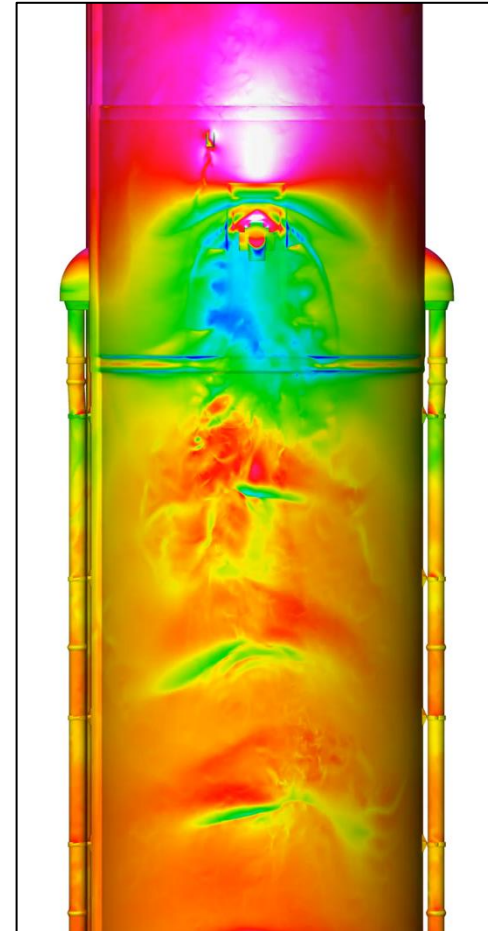
- Zonal environments typically used to predict vibration response using Corcos model.
 - Spatial decorrelation generally modeled as attached or separated boundary layer



SLS Intertank Zones

Artemis I

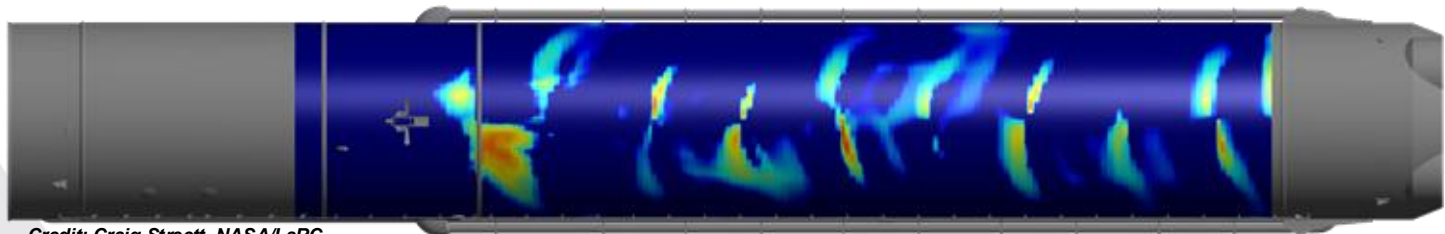
- **Artemis I postflight analysis revealed the excitation of a global vehicle mode at 25 Hz.**
- **Timing and frequency of the excitation aligned with vortex shedding off the Core Stage-Booster Forward Attach**
 - Vortex shedding manifests as a strong tone with a frequency that generally increases as a function of Mach (i.e., Strouhal shedding).
 - Alternating shed vortices are 180° out of phase on opposing sides of the attach hardware.



Vortex Shedding Environment



- **The vortex shedding environment is:**
 1. Periodic in nature (dominated by shedding tone)
 2. Spatially non-uniform
 3. 180° out of phase across *the centerline*
- **While the traditional zonal environments did envelope the magnitudes, these include no phase or mode shape information.**
- **The anti-symmetric nature of the vortex shedding and its mode shape's alignment with structural modes are required to appropriately model the environment.**
- **CFD solutions do contain all information needed for accurate modeling.**
 - CFD solutions were decimated and applied to a Finite Element Model (FEM) to determine the sensor resolution required from a wind tunnel test, which confirmed the usability of this model.

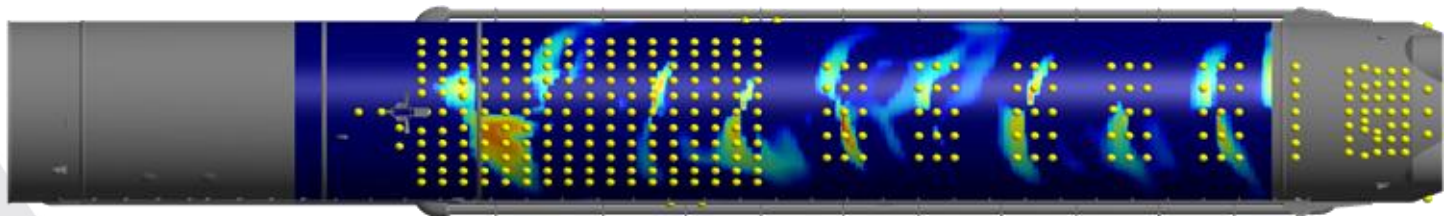


Credit: Craig Streett, NASA/LaRC

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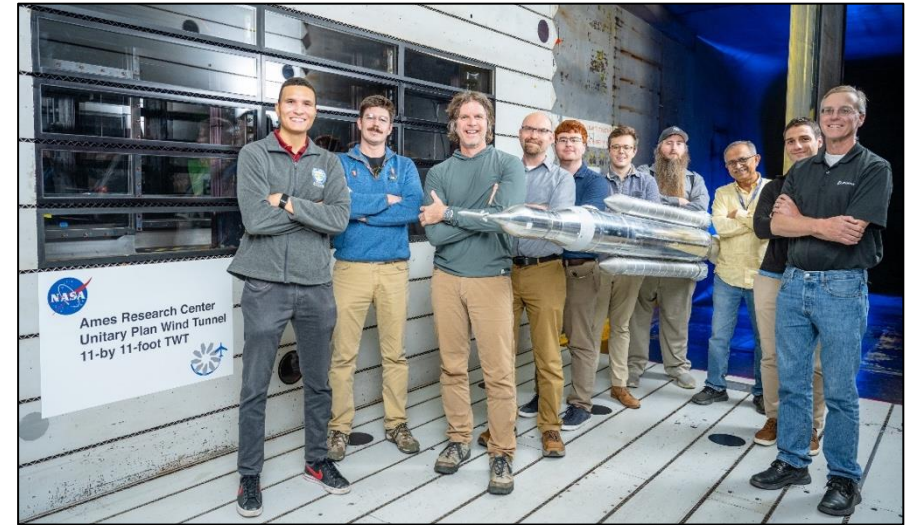


Credit: Craig Streett, NASA/LaRC

VADIR Wind Tunnel Test



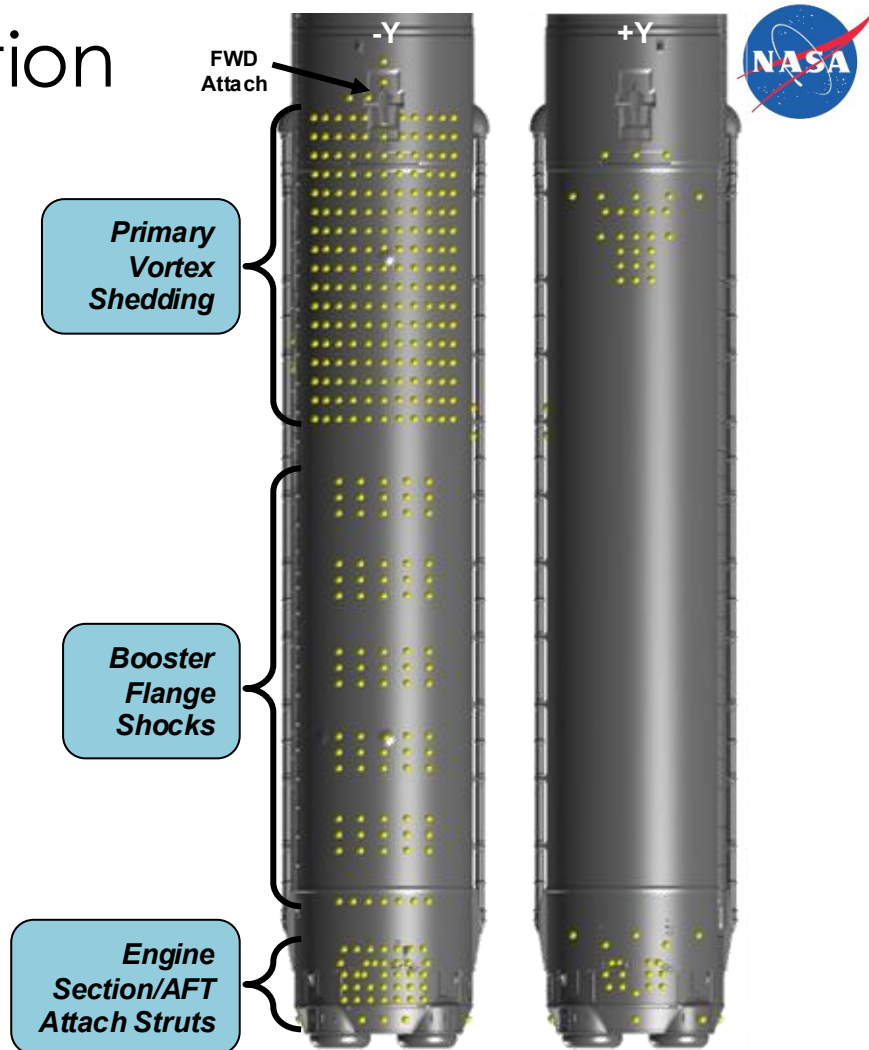
- **VADIR: Vortex Assessment with Dense Instrumented aRray**
- **Test conducted at the NASA Ames Unitary Plan Wind Tunnel (UPWT) in October-November 2024**
- **2.5%-scale SLS Block 1 Crew model**
 - Instrumented with 383 Kulite pressure transducers
 - 3 configurations tested:
 - As-flown
 - 91" strakes
 - 76" strakes
- **Data recorded at over 11,000 distinct test points consisting of:**
 - **Configurations:** 3
 - **Mach:** 0.75 – 2.5
 - **α/β :** -5° – $+5^\circ$



3D-printed Forward Attach Fitting

Wind Tunnel Instrumentation

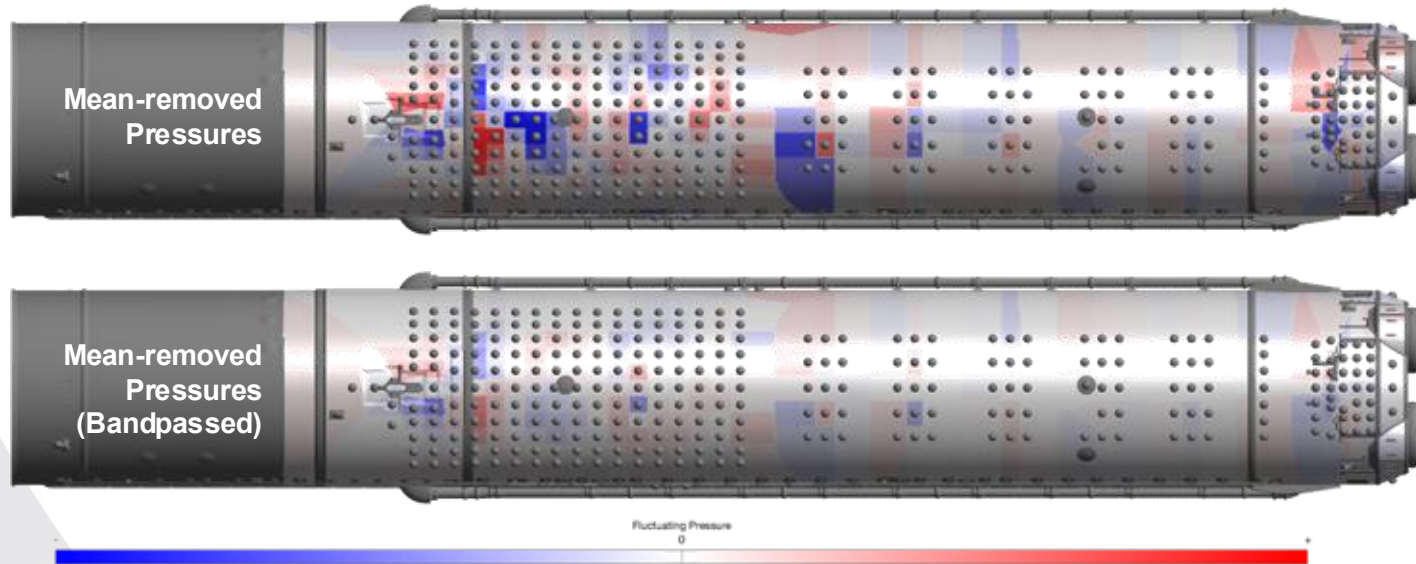
- **364 Kulite transducers located on the Core Stage**
- **Patches on -Y side are located to measure primary vortex shedding features, as informed by CFD**
- **+Y transducers are placed to:**
 - Understand differences between +/- Y due to asymmetries
 - Match instrumentation from flight and other WT tests



Wind Tunnel Data



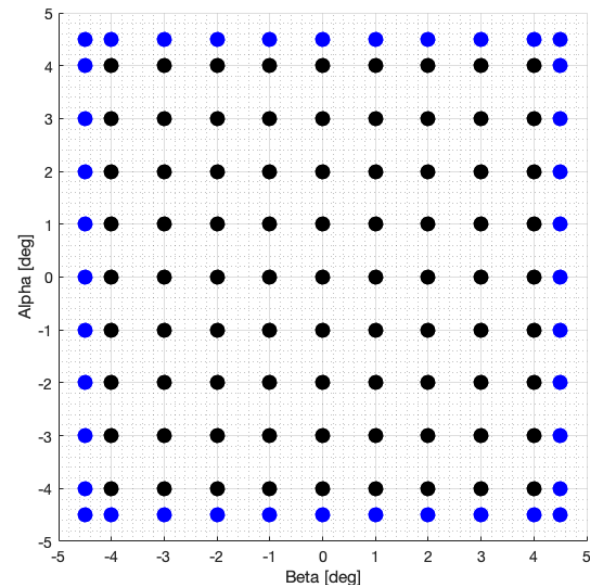
- Nearest neighbor interpolation of temporal wind tunnel data to an STL grid shows alternating high and low pressure of vortex shedding environment.



Forcing Functions



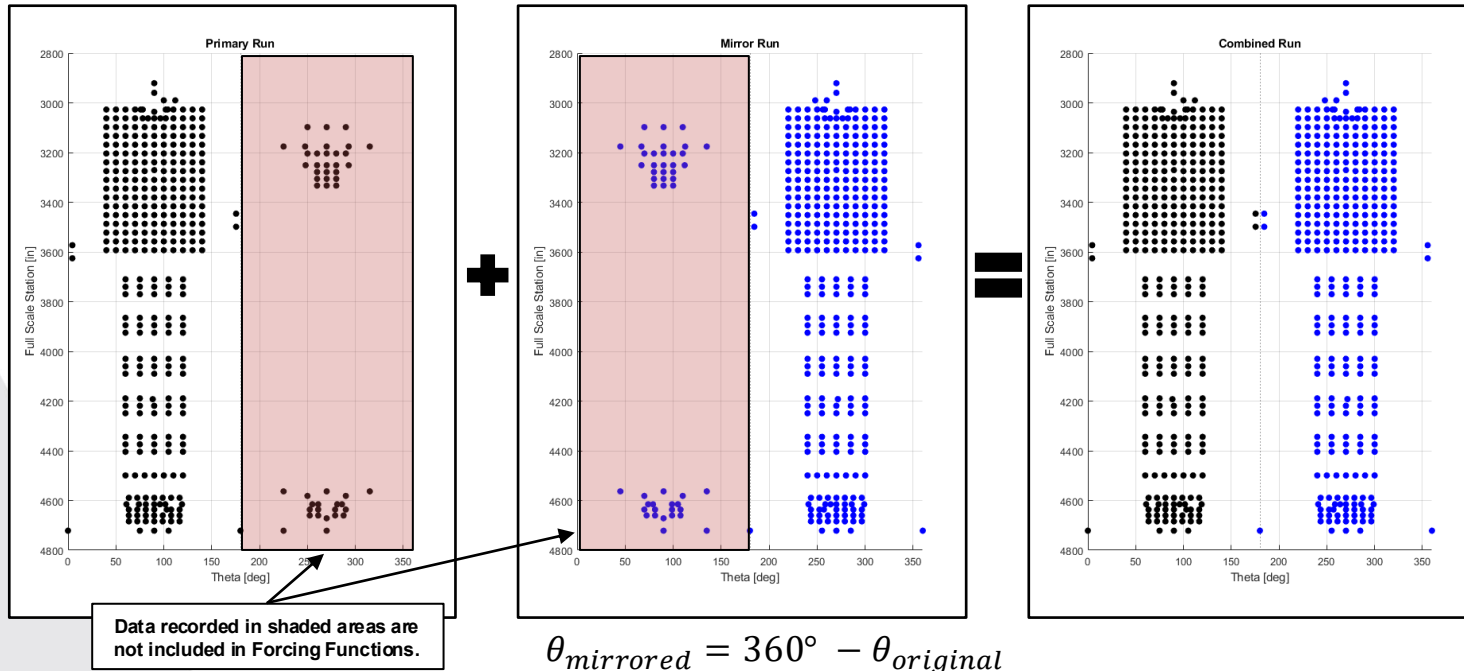
- **1,494 case specific forcing functions were created and delivered to the user.**
 - Mach 0.9, 0.95, 1.05, 1.1, 1.2, 1.3, 1.4, 1.55, 1.7
 - Mach 1.6, 1.8, 2.0, 2.25, 2.5
- **Each forcing function contains pressure time history data at 634 locations on the Core Stage.**
 - 250 Hz flight scale
 - 600 seconds of data
- **Like CFD, pressure time history data contains all amplitude and phase information required to model the vortex shedding.**



Forcing Functions



- **Because high spatial density data was only recorded on -Y side of the model, a symmetry assumption was made to mirror data to opposing side.**
 - Utilizes data from $-\beta$ mirrored run condition
 - Recorded frequency observed on +Y to apply correction for asymmetries



Conclusions



- **Application of as-flown configuration forcing functions along Artemis I BET to a FEM was able to accurately reconstruct vibration responses seen by components.**
- **High component vibration necessitated the addition of strakes to the Artemis II core stage**
 - Strakes reduce the area of peak energy caused by the vortex shedding, greatly reducing the component loads
 - Forcing functions developed using 91" strake configuration data were used to create bounding Artemis II environments

