Invited: uPSP Launch Vehicle Demonstration Test at NASA Ames Research Center

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Notice to Readers

Certain features and characteristics of the Space Launch System (SLS) vehicle are defined by the U.S. Government as Export-Controlled, Controlled Unclassified Information (CUI). To comply with CUI restrictions, values in some plots and figures have been either removed or normalized to arbitrary values. It is the opinion of the authors that these alternations do not detract from the relevant technical discussions.

I. Introduction

The unsteady pressure-sensitive paint (uPSP) development team at NASA Ames Research Center (ARC) has been working since October 2019 (FY 2020) to develop and innovate uPSP into a turnkey capability at NASA facilities. This effort is sponsored by the Aerosciences Evaluation Test Capability (AETC) Portfolio Office under the Aeronautics Research Mission Directorate (ARMD) within NASA as the uPSP Test Technology Capability Challenge. AETC oversees many of the wind tunnels across NASA. A previous paper outlining this development may be found in Ref. [1]. More technical aspects of the system development may be found in Refs. [2]-[8]. In April 2024, a Launch Vehicle Demonstration Test (LVDT) using a 4% scale Space Launch System (SLS) model was conducted at the NASA Ames Unitary Plan Wind Tunnel (UPWT) 11-by 11-ft Transonic Wind Tunnel (TWT). This was the same wind tunnel model tested as a demonstration of the uPSP technology as a part of SLS's Ascent Unsteady Aerodynamics Test (AUAT)[9]-[11] in 2017. AUAT was followed by SLS's Ascent Transient Aerodynamics Test (ATAT)[12],[13] in 2019, which also featured uPSP data.

LVDT represents a capstone experiment showcasing advancements in data acquisition, data transfer, and data processing for a production-level facility. For example, eight high-speed cameras were used to acquire the data whereas only four were used previously. In the 2019 SLS ATAT demonstration test, Project Red Rover[9],[14] was implemented as a connection between the UPWT and a high-performance computational facility, the NASA Advanced Supercomputing Division (NAS), also located at NASA Ames. This Red Rover pipeline has been improved and LVDT included the transfer, processing, and visualization of the data in near-real time. The uPSP processing software, which lives on the NAS, has been open source since January 2023.

This paper serves as a summary and overview of LVDT including the updated features of the system, objectives achieved, what was tested, and directs readers to additional publications pertaining to more explicit technical analysis from the results. This paper will also serve as a useful reference for future customers wishing to request uPSP as a part of their test entry. The data resulting from this test helps motivate the necessity of uPSP in the study of aerosciences, the challenges with leveraging the uPSP technology, and how the uPSP Development Team at NASA Ames produced a system to increase the functionality of uPSP at NASA wind tunnels. A brief outline is presented below.

II. The Model

The wind tunnel model used for this test was the 4% Block 1B crew and cargo configurations. This was the same model used as a part of the SLS AUAT piggyback demonstration in 2017.

A photo of the model installed in the NASA ARC UPWT is provided in Figure 1 with the crew configuration on the left and the cargo configuration on the right.

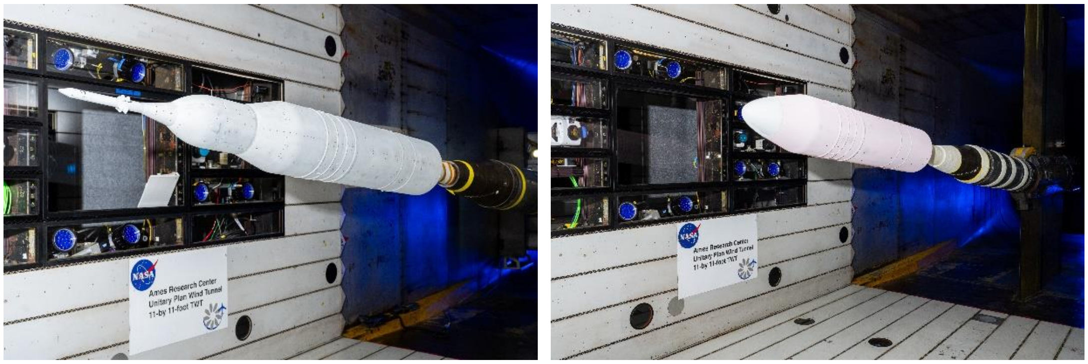

Figure 1. SLS 4% model with uPSP in the 11-by 11-ft TWT at the NASA ARC UPWT. Left: crew configuration. Right: cargo configuration.

III. Experimental Setup, Data Acquisition, Calibration

With the incorporation of eight high-speed cameras as a part of the uPSP data acquisition leg of the system, and with a new process to acquire uPSP lifetime data with high-speed cameras, significant upgrades have been made to the acquisition of pressure-sensitive paint data points. In addition, better camera and paint calibration procedures have been introduced that not only reduce the uncertainty of projecting the uPSP data onto a surface grid, but also allow for the calibration and incorporation of additional optical diagnostics into uPSP data products.

A. Test Objectives

There were a variety of test objectives to meet as a part of this test. Some include:

- Conduct a model change
- Increase magnification on one camera
- Demonstrate readiness of Red Rover 2.0
- Understand the best quality flow regimes for uPSP
- Integrate into existing Unitary acquisition systems
    - Including simultaneous Kulite and high-speed shadowgraph
- Improved paint calibrations
- Improved camera calibrations
    - Including flatfield calibrations
- Implement the high-speed lifetime methodology
- Demonstrate improved noise mitigation algorithms
- Produce data products same day as data was acquired as “hands-off” processing

IV. Project Red Rover

The initial application of Project Red Rover was during the SLS ATAT 2019 demonstration test. Since then, additional fiberoptic cabling and data transfer procedures have been implemented to ensure an even faster and more secure data transfer from the high-speed cameras in the UPWT test section to the NAS. This section will outline the improvements of Project Red Rover 2.0 that and how they performed as a part of LVDT.

V. Data Processing

In January of 2023, the uPSP Data Processing Software was officially made open source (https://github.com/nasa/upsp-processing). The software, in development since 2015[17], has been the major enabling factor for uPSP to be deployed in a production wind tunnel environment. Without a software that can take the raw high-speed images from multiple cameras with corresponding calibration and wind tunnel condition information, project on to a surface, convert from intensity to pressure, and subsequently produce useful data products on the order of minutes instead of months, then you can have the best paint and the best cameras and the best model, but the uPSP system would not be useful. This section will outline how the processing software performed once the data reached the NAS.

VI. Data Products and Visualization

The most basic output from the processing software is the pressure-time-history on the model surface grid. However, this data product is often not useful in and of itself. This section will outline the different data products that were produced during various timelines relative to the acquired datapoint and the visualization tools engineers and analysts have at their disposal to interact with the data. One example of this is our refined uPSP-Kulite (pressure transducer) comparison as outline in Ref. [4] and shown in Figure 2. An improved method to reduce the noise in the uPSP data to allow for better comparisons to Kulites was developed, although recognizing that uPSP is not well-suited for point-source measurements.

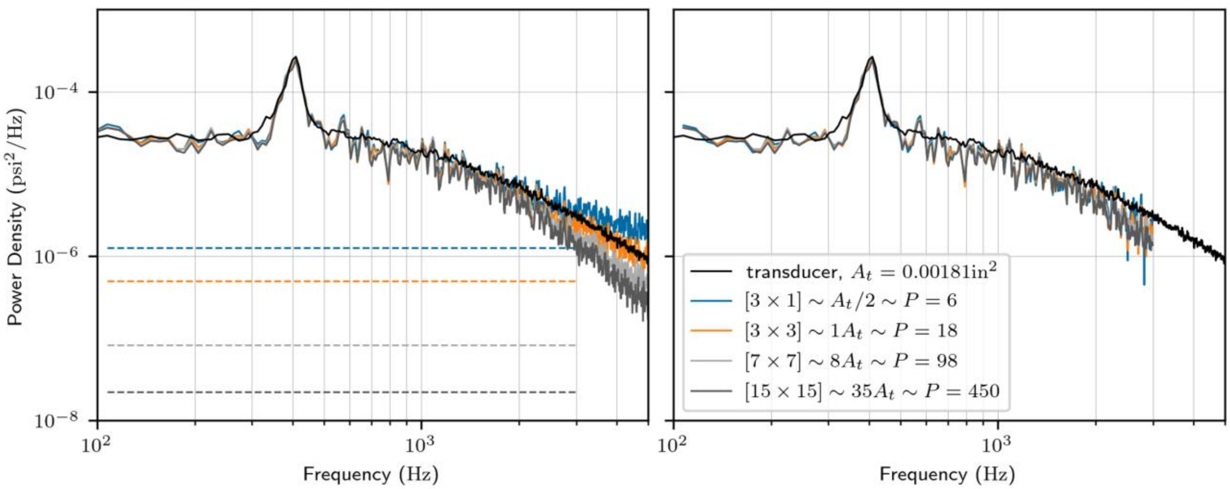

Figure 2. Power spectral density estimated from an area-averaged virtual transducer (uPSP data) signal before (left) and after (right) noise correction for comparisons to a pressure transducer [4].

VII. Conclusion & Future Work

This paper will outline the Launch Vehicle Demonstration Test (LVDT)) that was conducted at NASA Ames Research Center Unitary Plan Wind Tunnel 11-by 11-ft Transonic Wind Tunnel to make unsteady pressure-sensitive paint (uPSP) technology a turnkey system that is accessible to production-level wind tunnel facilities at NASA. This paper will also direct readers to additional resources about some of the more technical details related to the system.

There is the intention of continued development, which will focus on the greater integration of data products and visualization into the processing software, and transition to deployment at other NASA wind tunnels other than the ARC UPWT. Future use of the system will also leverage cloud computing and visualization tools in conjunction with parallel AETC efforts. Finally, future work will account for those added complexities of testing aircraft in wind tunnels that were of little concern when evaluating launch vehicles as well as moving models as a part of dynamic instability evaluations.

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