National Aeronautics and Space Administration

Verification and Validation of High-Fidelity Supersonic Parachute Deployment Modeling

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Program: FY22 SURP
Strategic Focus Area: Descent, Ascent

Objectives:

This project leverages JPL investments in the Stanford developed AERO computational suite that focused on creating the capability to model supersonic parachute inflations. Specifically, this SURP is focused on code validation using existing experimental data (MSL, ASPIRE, and M2020 flight-data), and on uncertainty quantification. This will allow JPL and Stanford to, for the first time, quantify modeling uncertainties for supersonic parachute inflations, and to understand parachute design and modeling sensitivities.

Background:

The structural failure of the supersonic parachutes on two flight tests during the Low-Density Supersonic Decelerator (LDSD) project was not predicted by traditional parachute design methods which were considered industry standard and had been used for nearly 40 years. The LDSD parachute failures motivated JPL to re-consider how parachutes should be qualified for future missions.

High-fidelity modeling of fluid-structure interactions (FSI) is a topic of great interest at JPL. Validating existing modeling tools is important due to the cost, difficulties, and test-as-you-fly exceptions associated with Mars-relevant parachute testing. The ASPIRE tests have provided a unique data set with high-resolution images and temporally resolved integrated loads of full-scale supersonic parachute inflations, yet no FSI simulations have been completed prior to this effort to model these experiments.

Approach and Results:

In year 2, the focus has been on simulating the ASPIRE flight tests to perform a sensitivity study and quantify the best practices for the modeling and simulation of supersonic parachute inflation dynamic problems. Simulations were run to quantify the uncertainty of several assumptions in the modeling; Fig. 1 summarizes the sets of parameters analyzed. Several results from these simulations are shown in Fig. 2. It can be observed that the LES (sim 3) seems crucial for capturing the 'breathing' phenomenon, which is an observed phenomena in supersonic flight data. Sims 5 and 6, which have a free payload, capture remarkably well the long-term drag history.

The team generated additional results which highlighted the discovery how the formation and persistence of a toroidal vortex inside the canopy (see Fig. 3) can play a large role in the drag oscillations seen during flight tests. Updated results were shown, and the detailed geometry and material properties used in the SURP team's simulations was published to provide a public dataset for others to use in validating their FSI simulations against the ASPIRE flight tests.

Finally, year 2 of this effort also resulted in advances such as a development of a new technique to run a "pre-inflate" simulation in order to smooth out discontinuities in the initial parachute shape and provide a more-realistic starting point for the FSI simulations. JPL re-assessed the ASPIRE geometry and material parameters being used in the simulations, and made many updates to fix inconsistencies.

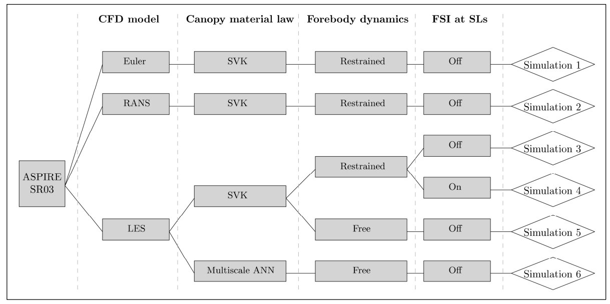

Figure 1. *Framework used to investigate parameter sensitivity for FSI simulations of supersonic parachute inflation*

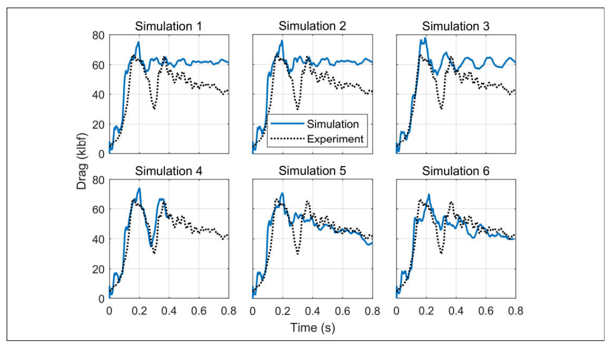

Figure 2. *Results of drag force vs. time for each of the parameter sensitivity simulations*

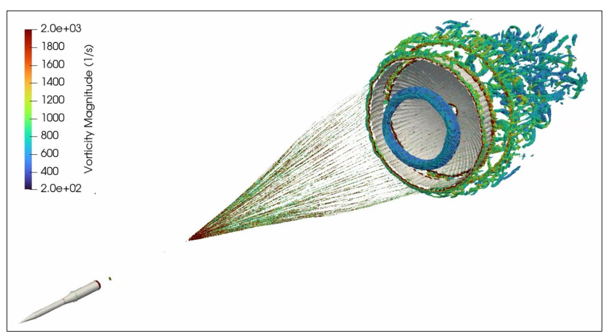

Figure 3. *Vorticity iso-surfaces showing formation of toroidal vortex (blue "donut") inside canopy*

Significance/Benefits to JPL and NASA:

A validated FSI computational framework will enable JPL to lead missions that use larger and more capable supersonic parachutes, improve our design for future parachutes and other deployable soft goods, and reduce the number of costly flight-like experiments required for future missions. However, it is critical that the validation effort be completed in a rigorous manner with published results, in order for future flight missions to have confidence in this simulation capability. A continuing interaction with Prof. Farhat (a world leader in FSI and computational mechanics) allows JPL to continue to increase its ability to accurately model complex physical problems directly related to spacecraft. This partnership will also continue to encourage talented Stanford students to seek careers at JPL.

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Publications:

1. As'ad, F., Avery, P., Farhat, C., Rabinovitch, J., and Lobbia, M., "Validation of a High-Fidelity Supersonic Parachute Inflation Dynamics Model and Best Practice," AIAA 2022-0351
2. Rabinovitch, J., As'ad, F., Avery, P., Farhat, C., Ataei, N., and Lobbia, M., "Update: Modeling Supersonic Parachute Inflations for Mars Spacecraft," AIAA 2022-2746
3. Lobbia, M., O'Farrell, C., Siegel, K., Leylek, E., Ataei, N., As'ad, F., Farhat, C., and Rabinovitch, J., "Supersonic Parachute Design and Analysis to Support Mars Sample Return," IPPW 2022

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