National Aeronautics and Space Administration

Verification and Validation of High-Fidelity Supersonic Parachute Deployment Modeling

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Program: FY21 SURP **Strategic Focus Area: Descent, Ascent**

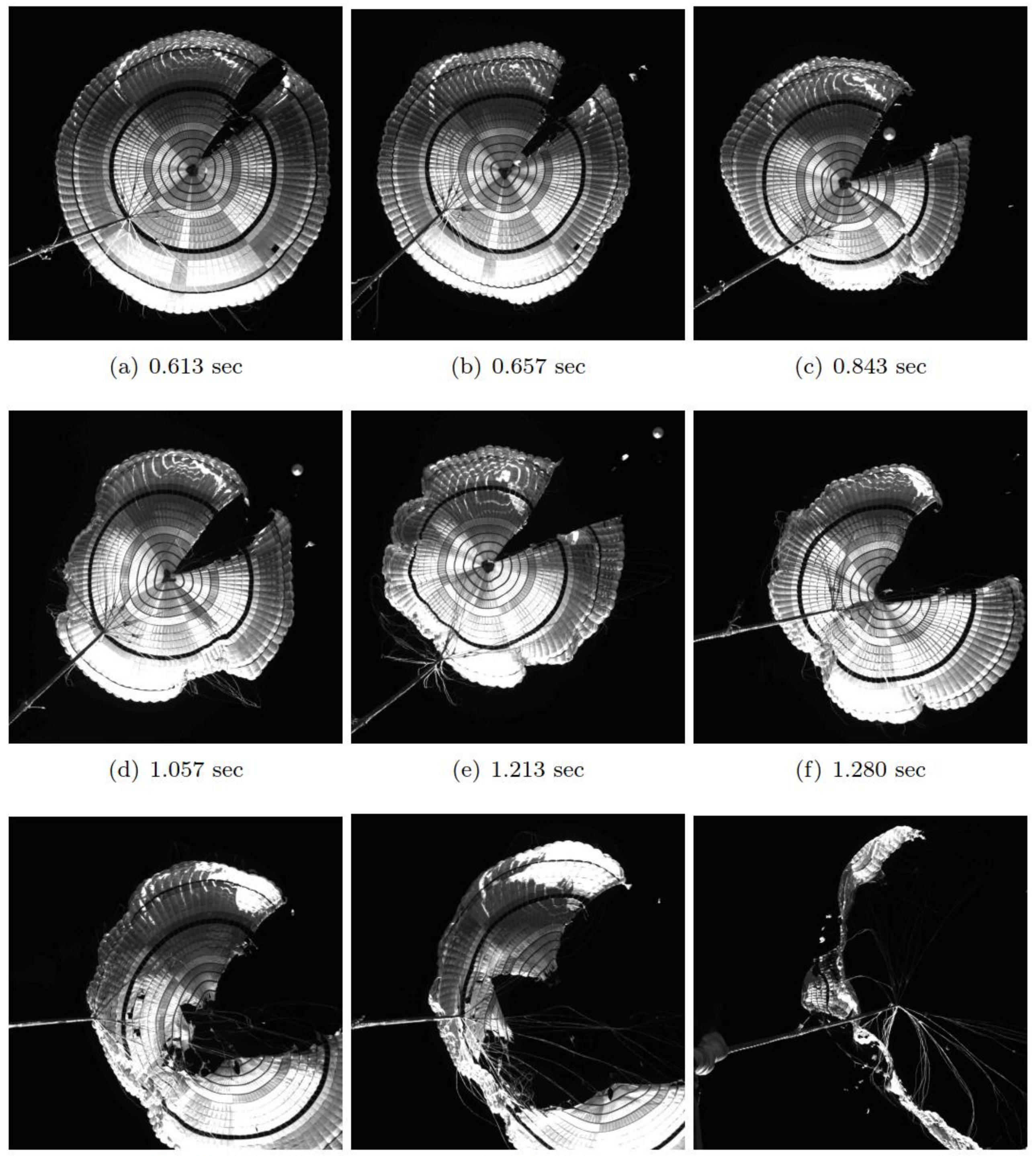

Figure 1 – Snapshots from LDSD parachute failure (O'Farrell et al., AIAA-2016-3242).

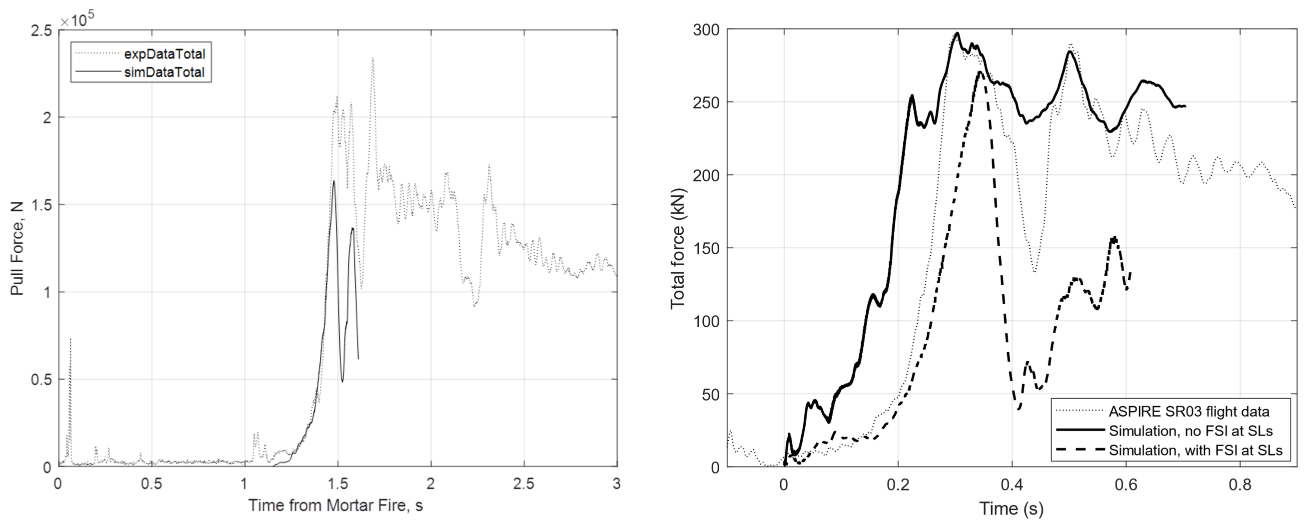

Figure 2 – Examples of Year 1 simulation results for the parachute inflation of ASPIRE SR02 (left: JPL simulation results) and ASPIRE SR03 (right: Stanford simulation results) showing initial comparisons as the FSI models are developed/tested (experimental results reproduced from Sonneveldt et al., AIAA-2019-3482).

Objectives

This project leverages recent investments in the Stanford-developed AERO computational suite that focused on creating the capability to model supersonic parachute inflations. The objective is to focus on validation of the code using existing experimental data (MSL, ASPIRE, and M2020 flight-data), and on uncertainty quantification. This will allow JPL and Stanford to quantify modeling uncertainties for supersonic parachute inflations, and to understand parachute design and modeling sensitivities. The task is also complementary to current internal ESD investments geared towards infusing additional uncertainty quantification practices into the JPL modeling community.

Technical Objectives:

- Compare numerical simulation results and ASPIRE flight test data
- Perform a numerical sensitivity analysis to determine effect of parameters and assumptions (effect of material permeability, structural model, suspension line resolution, etc.)
- Investigate feasibility (by comparing to MSL, ASPIRE, M2020 simulations results) of future parachute designs that will require higher Mach number deployments and increased size, such as those being considered by Mars Sample Return (MSR)

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. Combining the numerical simulation capabilities that the Farhat Research Group posses with the validation data and simulation capabilities at JPL creates a strong team that is capable of validating AERO Suite for supersonic parachute inflations.

In addition, the partnership with the Farhat Research Group will continue to infuse high-fidelity modeling techniques into the JPL work-culture that will allow JPL to continue to improve its modeling capabilities. As a world leader in FSI and computational mechanics, a continuing collaboration with Stanford and Prof. Farhat will increase the technical knowledge of JPL, and allow JPL to continue to increase its ability to accurately model complex physical problems directly related to spacecraft. Finally, this partnership will continue to encourage talented Stanford students to seek careers at JPL.

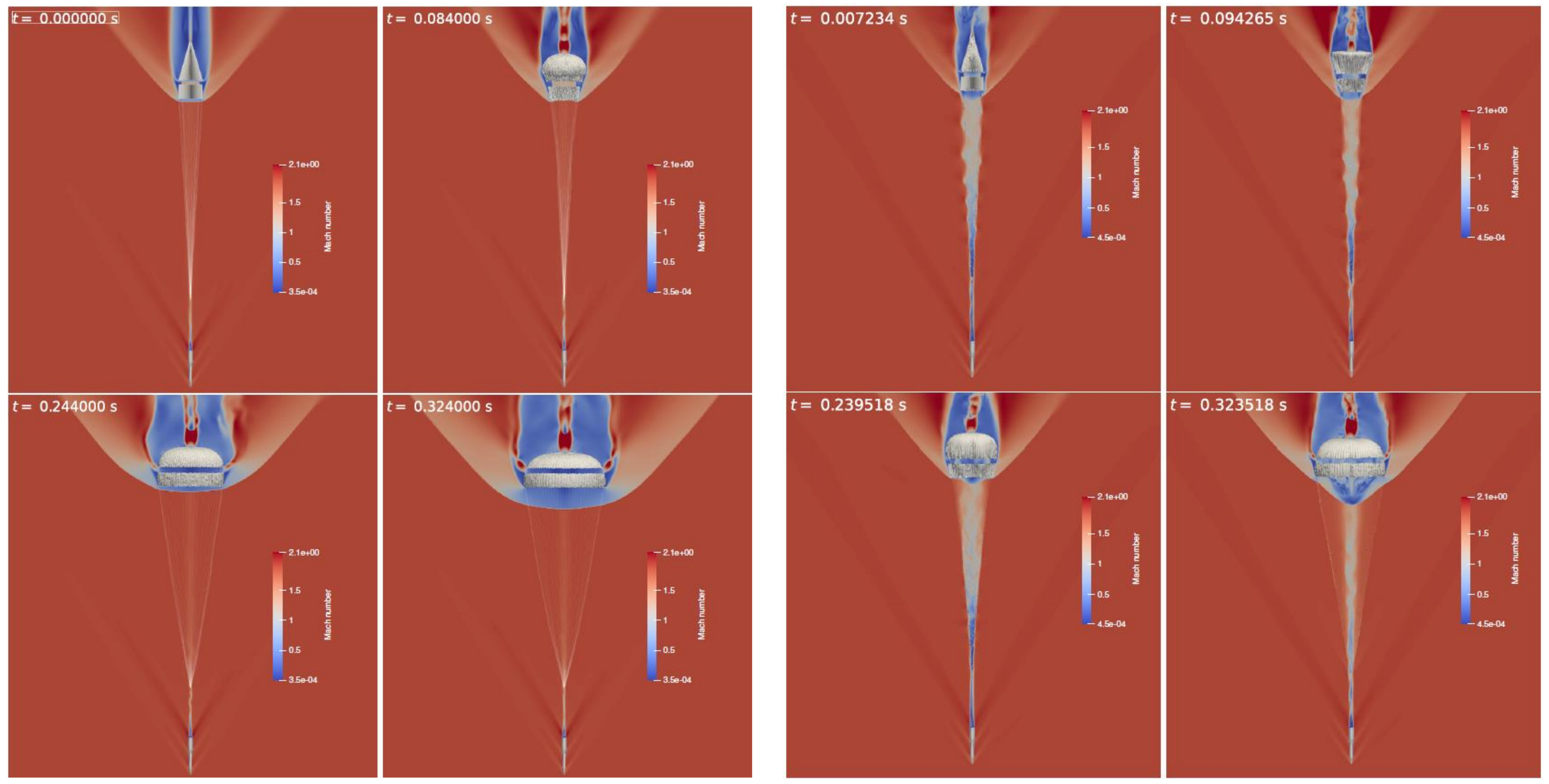

Figure 3 – Mach contour snapshots predicted by numerical simulation with FSI accounted for on the suspension lines (left) and FSI ignored on the suspension lines (right) with ASPIRE SR03 test conditions, highlighting the significant sensitivity of the forebody to this parameter.

Background

The structural failure of the supersonic parachutes (see Fig. 1) on two flight tests during the LDSD project was not predicted by traditional parachute design methods. It appeared that the peak loads on the parachute were during the inflation phase, instead of in the inflated configuration. The LDSD parachute failures motivated JPL to re-consider how parachutes should be qualified for future missions, and motivated a significant investment into the ASPIRE flight test campaign to qualify the Mars 2020 parachute design [1].

Therefore, high-fidelity modeling of fluid-structure interactions (FSI) is a topic of great interest at JPL. Validated modeling tools are crucial for predicting the performance of future parachute designs (such as the MSR parachute), which will be the largest size / highest-Mach number deploy supersonic parachute ever flown to Mars. Validating existing modeling tools is of great practical use to JPL due to the cost, difficulties, and test-as-you-fly exceptions associated with Mars-relevant parachute testing (such as the highly-successful ASPIRE test campaign). The ASPIRE test campaign has provided a unique data set [2] 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

This SURP is planned over three years, with Year 1 focused on allowing the Stanford PhD student to become familiar using the AERO computational suite, and to start modeling the recent ASPIRE supersonic parachute inflations to determine if a good agreement is seen between modeling results and experimental results. Year 2 is planned to focus on sensitivity studies, and uncertainty quantification effort will be performed by the Stanford PhD student in order to quantify the effect of many numerical and physical properties (e.g., CFD mesh resolution, suspension line effects, parachute material permeability, structural modeling parameters, and any other physical or numerical parameters identified through the course of this project. Year 3 is focused on using the AERO suite to model larger parachutes at higher Mach number deployments that would be relevant for a possible Mars Sample Return mission; uncertainties and sensitivities identified from the previous two years will be used assess the predicted performance of parachutes being simulated.

Significant progress was made in Year 1 of this project, even though it was delayed due to COVID and did not start in earnest until January 2021. Faisal As'ad, the Stanford PhD candidate identified to work on this, quickly came up to speed in using AERO Suite. Based on their experience with the simulation of supersonic parachute inflation problems associated with the MSL program, the Stanford-JPL team developed a list of critical modelling and simulation parameters to be investigated, and identified a critical test path. With support from JPL (which included providing updated material properties for parachute components), Mr. As'ad developed FSI simulations of the ASPIRE SR03 configuration and ran calculations to compare key metrics of the inflation process with the test data (see Fig. 2). Comparison of simulations with FSI on the suspension lines ignored versus accounted for (see Fig. 2 for quantitative comparison, see Fig. 3 for qualitative comparison) for the SR03 configuration motivates a deeper investigation into this sensitivity. During the running of these simulations, Stanford modified the source code and added additional features to AERO Suite in order to facilitate supersonic parachute simulations. Additionally, these updates allowed for the movement of the embedding fluid mesh according to the rigid body modes of the capsule in an Embedded-ALE (Arbitrary Lagrangian-Eulerian) framework, in order to capture the deceleration effects and changing free-stream conditions.

JPL has also run simulations of the ASPIRE SR02 configuration to investigate the effects of different test conditions (see Fig. 2), as well as running different mesh resolutions to start quantifying these effects on results. Additionally, with assistance from Stanford, JPL developed a documented process for installing the AERO Suite on different High-Performance Computing (HPC) clusters, and applied-for/was-awarded 3 years of access to NASA's highest-performance HPC system, Pleiades, for supersonic parachute FSI simulations. This significant increase in computational resources will help support sensitivity studies and uncertainty quantification efforts planned for Years 2 and 3 of the project.

Publications

[A] As'ad, F., Avery, P., Farhat, C., Lobbia, M., and Rabinovitch, J., "Validation of a High-Fidelity Supersonic Parachute In□ation Dynamics Model and Best Practice," submitted to AIAA SciTech Forum 2022, San Diego, CA, 2022.

References

[1] Tanner, Christopher L., Ian G. Clark, and Allen Chen. "Overview of the Mars 2020 parachute risk reduction activity." 2018 IEEE Aerospace Conference. IEEE, 2018.

[2] Rabinovitch, J., Griffin, G. S., Seto, W., O'Farrell, C., Tanner, C. L., Clark, I. G., "ASPIRE Supersonic Parachute Shape Reconstruction," AIAA SciTech 2019 Forum, 7-11 January 2019, San Diego, California.

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Clearance Number:
RPC/JPL Task Number: SP21008