National Aeronautics and Space Administration

Advanced Modeling of Supersonic Parachute Inflation

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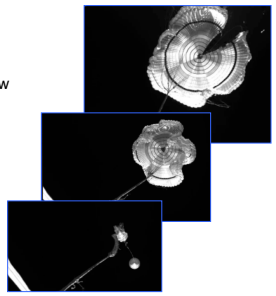
Program: Strategic Initiative

Project Objectives:



- Develop, verify and validate a new numerical simulation capability in high speed fluid-structure interaction (FSI) for softgoods
- Enable the modeling and simulation of parachute deployment for planetary entry
- Enable the prediction of material and parachute performance margins for softgoods during planetary entry

FY18/19 Results:

- **System Modeling**: Developed and demonstrated a 3D simulation of the inflation of the Curisosity Mars rover parachute under flight conditions
  - "Stretched" initial condition
  - Self-contact of the canopy
  - Turbulence and wake flow (LES)
  - Resolution of suspension lines in flow field
- **Adaptive Meshing**: Developed and demonstrated new adaptive meshing methods for resolving fine flow detail around the parachute canopy, suspension lines, and the vehicle
- **Software Implementation**: Demonstrated scalability to thousands of processors for a fine mesh that resolves both flow boundary layers and structural stress during inflation
- **Validation**: Favorable validation by comparison with MSL flight data

Benefits to NASA and JPL:

- Unexpected parachute failures have occurred which appeared to be during the inflation phase, instead of in the inflated configuration, as traditional analyses expect.
- There is no current capability demonstrated for modeling inflation of a parachute in supersonic flow
- New capability aims to provide confidence in the expected margins in supersonic parachute decelerators for planetary entry

Publications:

1. Borker, R., Huang, D., Grimberg, S., Farhat, C., Avery, P., Rabinovitch, J., "Mesh Adaptation Framework for Embedded Boundary Methods for CFD and Fluid-Structure Interaction," International Journal for Numerical Methods in Fluids, 19 March 2019.
2. Derkevorkian A., Rabinovitch J., Peterson L. D., Avery P., Farhat C., "Evaluation of an Advanced Suite of Numerical Codes for Structural Simulation of Parachute Fabric," 2018 AIAA Aerospace Sciences Meeting, 8-12 January, Kissimmee, Florida (AIAA 2018-1541).
3. Derkevorkian, A., Hill, J., Rabinovitch, J., Peterson, L., Avery, P., Farhat, J., "Studies into Computational Modeling of Seams in a Parachute Canopy," Proceedings of 2019 AIAA Aerospace Sciences Meeting, AIAA SciTech Forum, San Diego, California, 2019.
4. Derkevorkian, A., Peterson, L., Rabinovitch, J., Huang, D., Avery, P., Farhat, J., "Effects of Structural Parameters on the FSI Simulation of Supersonic Parachute Deployments," Proceedings of 2019 AIAA Aviation Forum, Dallas, Texas, 2019.
5. Derkevorkian, A., Rabinovitch, J., Peterson, L., Avery, P., Farhat, J., "Evaluation of an Advanced Suite of Numerical Codes for Structural Simulation of Parachute Fabric," Proceedings of 2018 AIAA Aerospace Sciences Meeting, AIAA SciTech Forum, Kissimmee, Florida, 2018.
6. Huang Z., Avery P., Farhat C., Rabinovitch J., Derkevorkian A., Peterson L. D., "Simulation of Parachute Inflation Dynamics Using an Eulerian Computational Framework for Fluid-Structure Interfaces Evolving in High-Speed Turbulent Flows," 2018 AIAA Aerospace Sciences Meeting, 8-12 January, Kissimmee, Florida (AIAA 2018-1540).
7. Peterson L. D., Derkevorkian A., Rabinovitch J., Farhat C., Avery P., "Model Verification and Validation Assessment for a Simulation of Supersonic Parachute Inflation during Martian Entry," 2018 AIAA Aerospace Sciences Meeting, 8-12 January, Kissimmee, Florida (AIAA 2018-1539).
8. Rabinovitch J., Huang Z., Avery P., Farhat C., Derkevorkian A., Peterson L. D., "Preliminary Verification and Validation Test Suite for the CFD Component of Supersonic Parachute Deployment FSI Simulations," 2018 AIAA Aerospace Sciences Meeting, 8-12 January, Kissimmee, Florida (AIAA 2018-1542).
9. Rabinovitch, J., Huang, D. Z., Borker, R., Avery, P., Farhat, C., Derkevorkian, A., Peterson, L. D., "Towards a Validated FSI Computational Framework for Supersonic Parachute Deployments," AIAA Aviation 2019 Forum, 17-21 June 2019, Dallas, Texas

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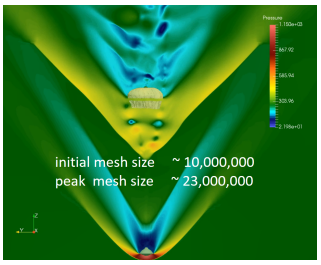
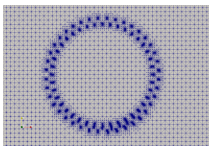
Resolution of Turbulent Flow Field (LES)

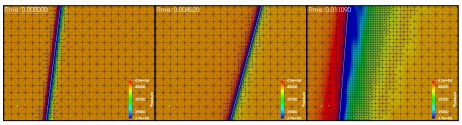
- Adaptive meshing enables resolution of turbulent flow field
- Includes mesh refinement and coarsening as structure passes through fluid cells
- Periodic rebalancing of the mesh across processors ensures scalability



Adaptive Mesh Refinement Around Suspension Lines

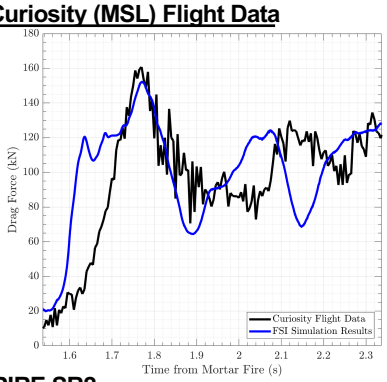
- Image at right shows a crossection through the fluid mesh around the suspension lines
- Animation frames below shows mesh adaptation for a simulation of a singlesuspension line





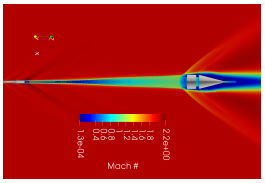
Comparison with Curiosity (MSL) Flight Data

- Plot compares simulated reaction force to data from the Curiosity Mars entry flight data



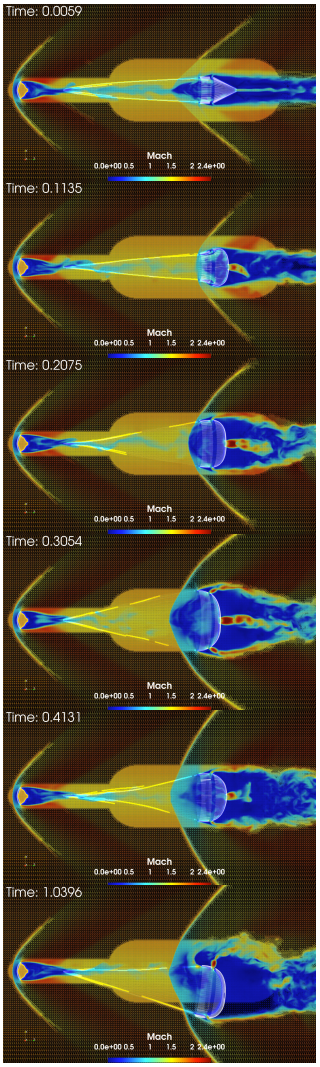
Application to ASPIRE SR2

- New, higher resolution mesh allows the simulation to start from an "80 degree fold" initial configuration
- Image at right shows the initial flow field for an initially rigid structure that is the initial condition for the simulation



Simulation of Curiosity Parachute Inflation (YZ Planar Slice of the Mesh)

- Simulation begins at "60 degree fold" condition
- Suspension lines and shocks appear as high density mesh regions (YZ plane slice)



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