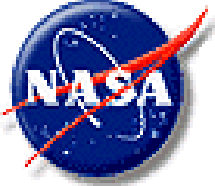


A Fluid-Structure Interaction Study of Re-entry Vehicles with Inflatable Decelerators and Validation of Methodologies against Wind Tunnel Test Data, Past, and Future

Sasan Armand, Ph.D.
NASA Langley Research Center

June 7–9, 2011



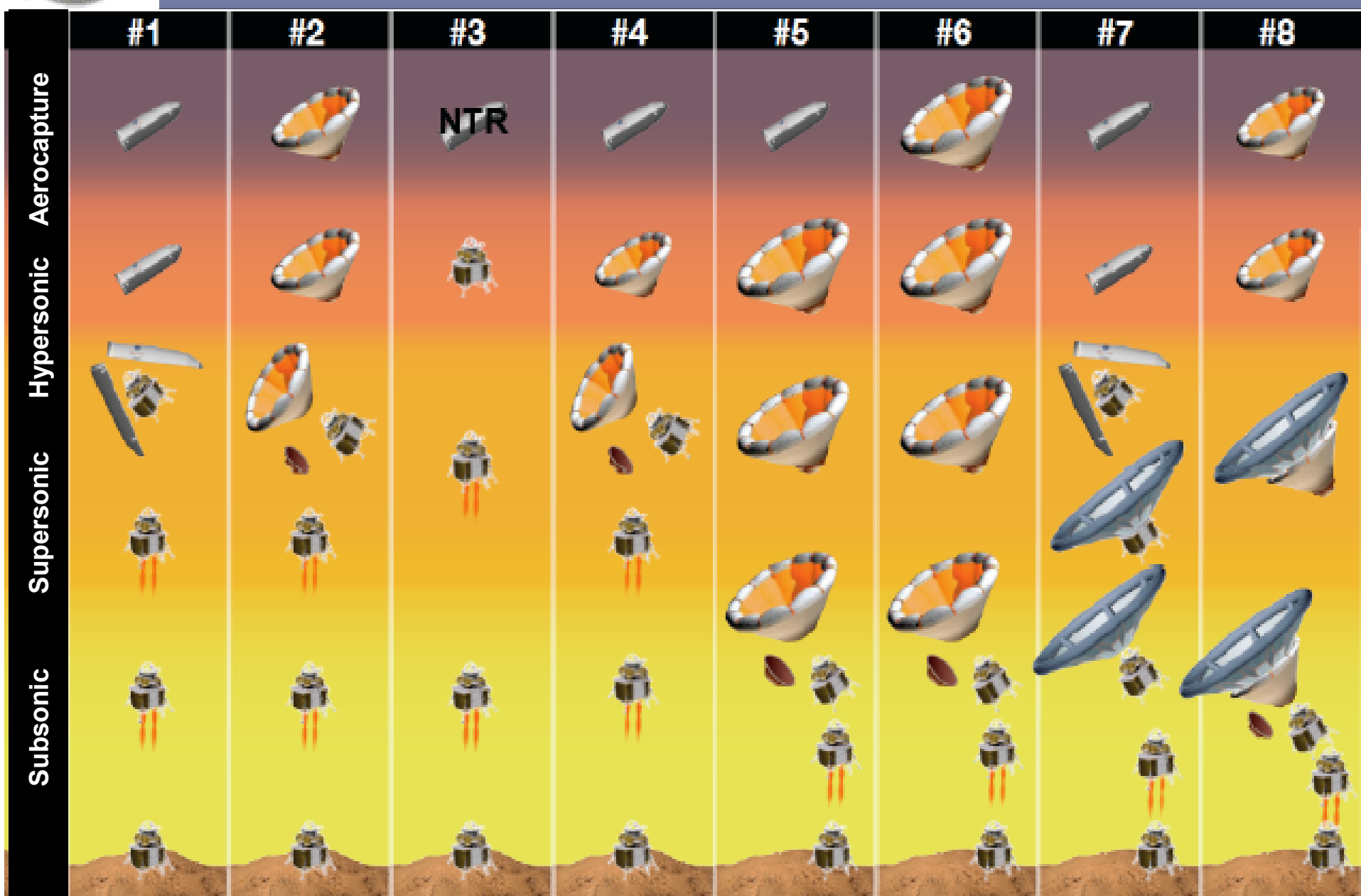


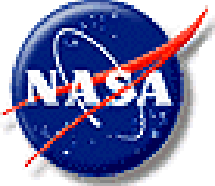
Outline

- Current Re-Entry Concepts
- Methodology
- Studies of Trailing Inflatable (48-m by 6-m, 5 mil Kapton)
 - Mach 30, Full inflatable, attempt towards a design
- Validation of Methods to Mach 6 Test of an Attached Inflatable
- Current and Future Work
- Concluding Remarks

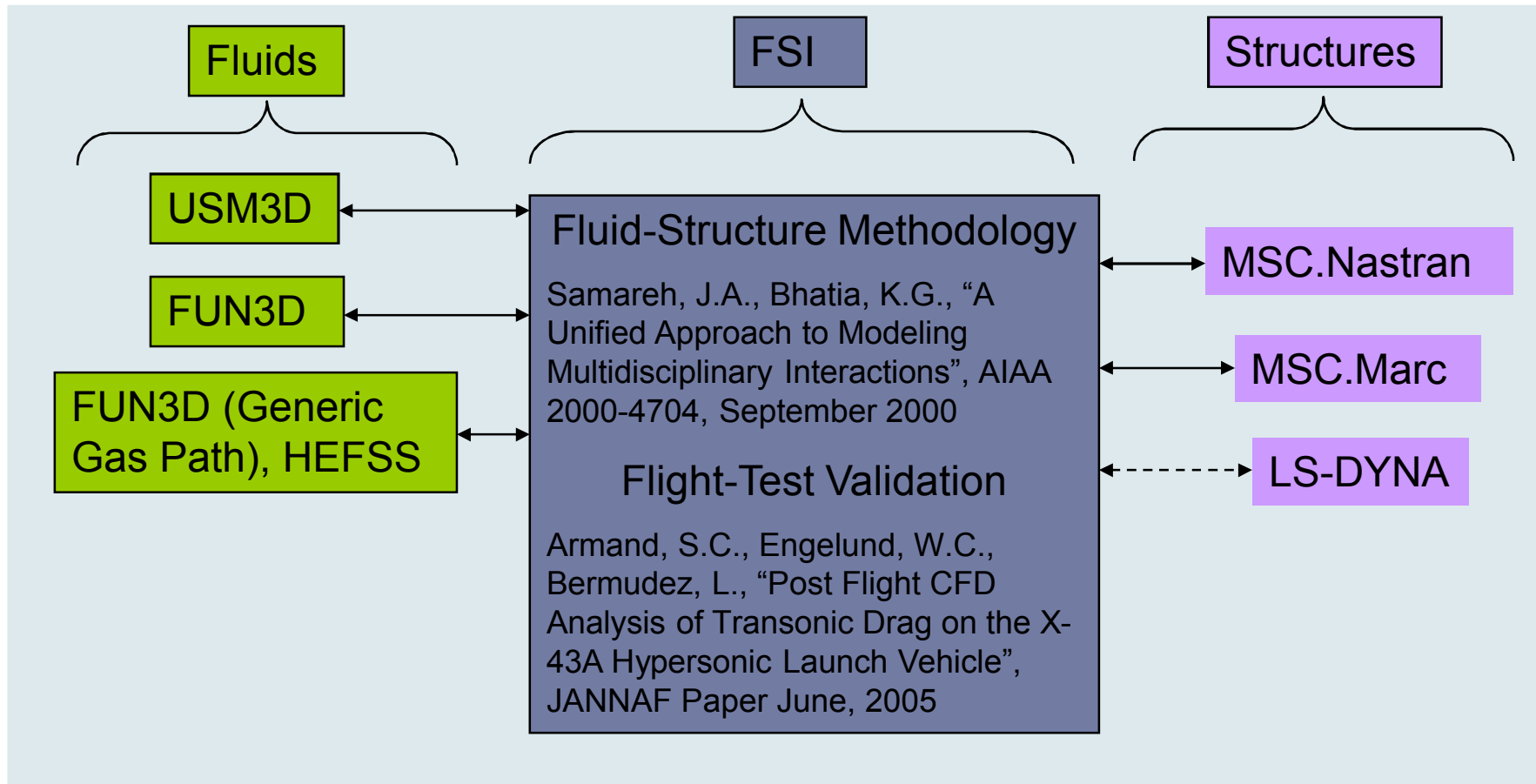


Recent Concepts for Inflatable-Assisted Re-Entry Vehicles per NASA/TM-2010-216720





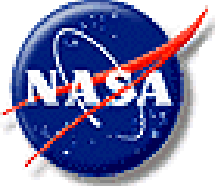
Fluid-Structure Interaction (FSI) Environment



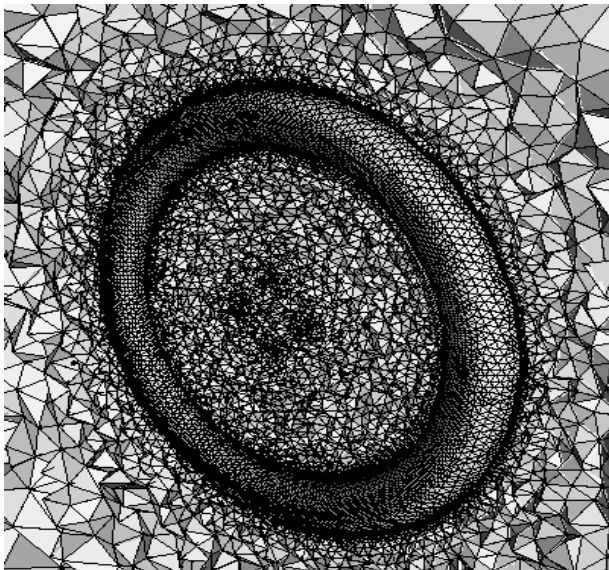
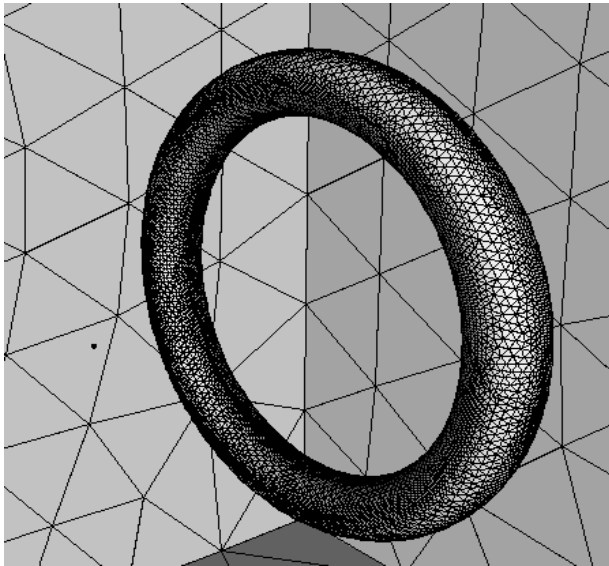
- Conservation of loads and virtual work @ machine accuracy
- Application of pressure and viscous loads (heat fluxes: work in progress)



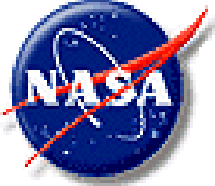
Example:
Mach 30, Trailing Inflatable



Mach 30, CFD Model



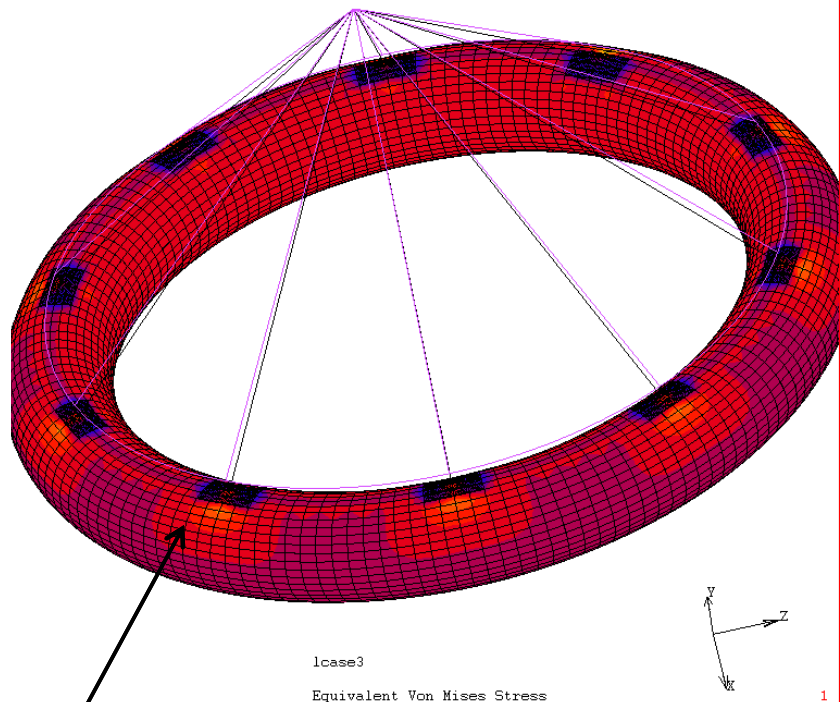
- One full-span CFD model for FUN3D & USM3D
 - 2.4 Million elements
 - 35 Element layers in viscous layer
 - 10Xs Size flow domain box
 - Specified conditions
 - Mach No. = 30
 - Alt. = 300,000 ft (90 km)
 - Vel. = 26,610 ft/sec (8.1 km/s)
 - $q = 2.0$ psf
 - Five species were used (N_2 , N, O_2 , O, NO)



Mach 30, Inflatable Results

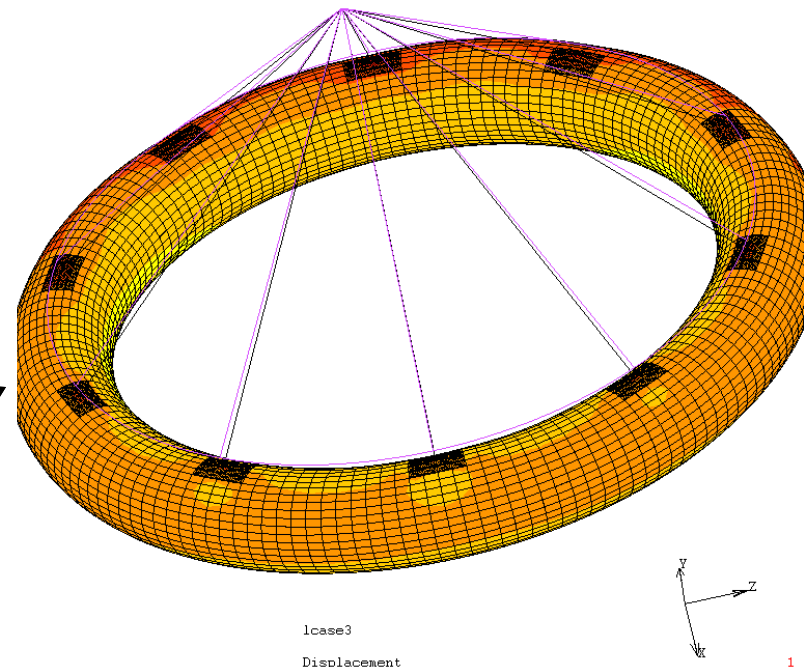
Computational structural model (CSM)

- Total drag load is 22,680 lb
- Stress at 12,600 psi
- Displacement at 47 inch



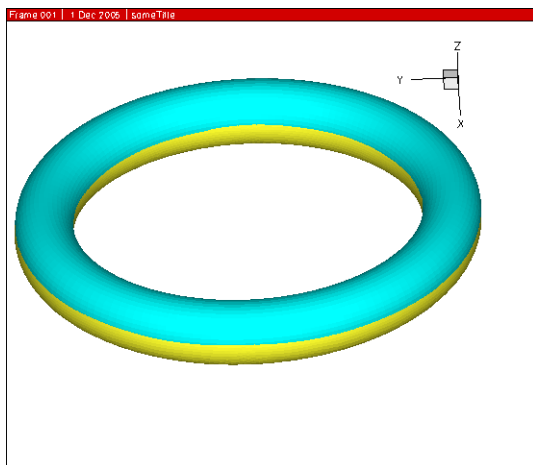
Stress Plot

Displacement Plot

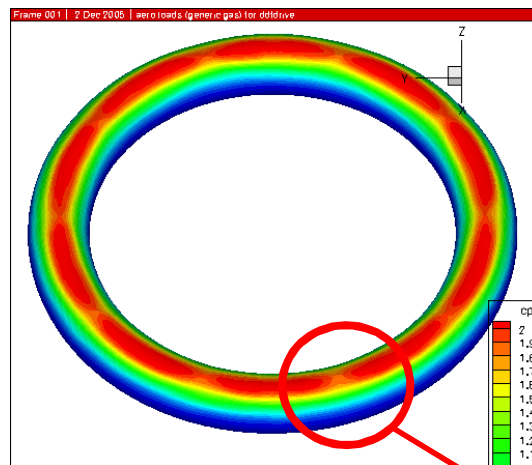




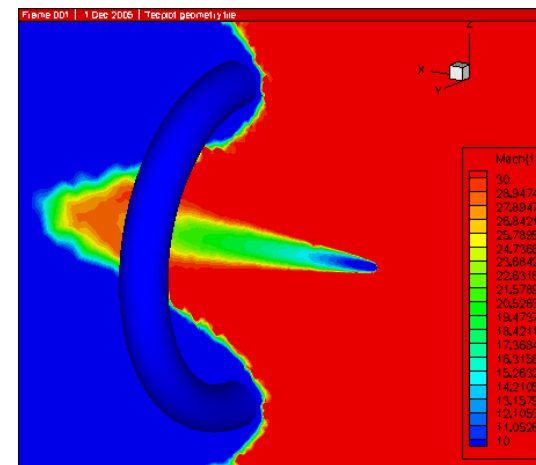
Mach 30, Inflatable Results



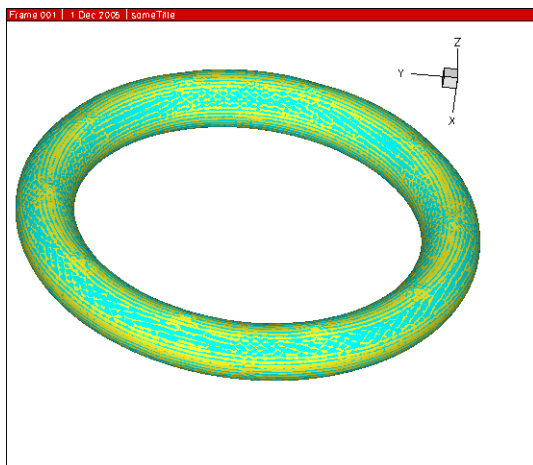
a) Deflected (blue) CSM superimposed on Un-deflected CSM (yellow)



c) Cp plot in Cycle 1

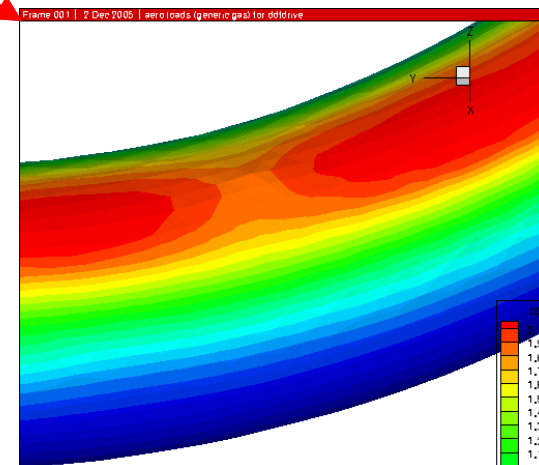


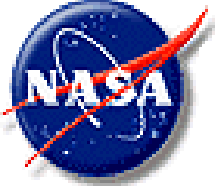
d) Mach No. Plot



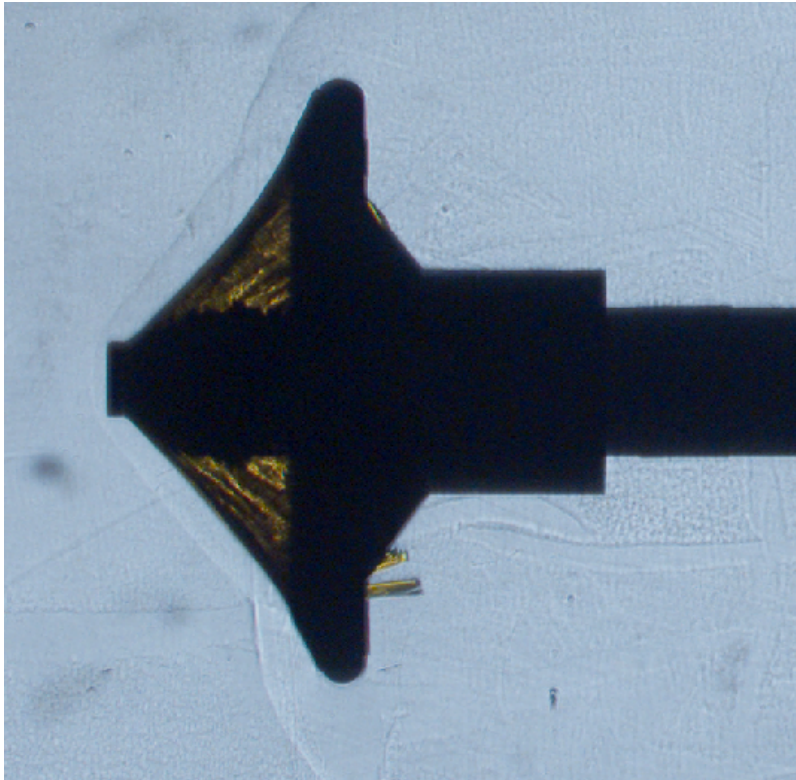
b) Stretched (aqua) CFM superimposed on deflected CSM (yellow)

- Inflatable displaced by nearly 1/4 of the diameter
- 19,000 lb due to pressure
- FSI derived Cp pattern around the towlines at Mach 30 shows lower loads
- Shock adaptation used for Mach 30 case

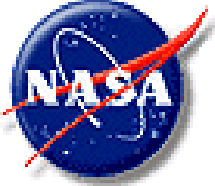




Test-Validation of Methodology

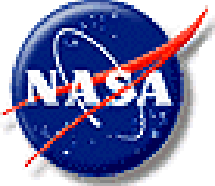


- Hypersonic test conducted at Mach 6 Mach 10 WTT facilities
- Mach 6 test data selected for validation process because of larger test article size



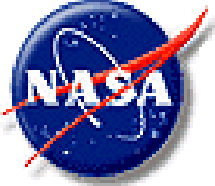
Test-Validation Requirements

- Use conditions from highest dynamic pressure test run
 - Condition will produce maximum deflections and wrinkling
- Model sizes reduced so FSI analysis cycle <12-hours (wall-clock time for CFD and CFM)
- Elements in CFM and CSM were reduced by:
 - Grid stretching in the CFM
 - Ignoring blunt edges in the CFM
 - Replacing portions with significantly higher stiffness with structural constraints
 - Framework of test article does not deflect sufficiently to influence overall deflections of the membrane.

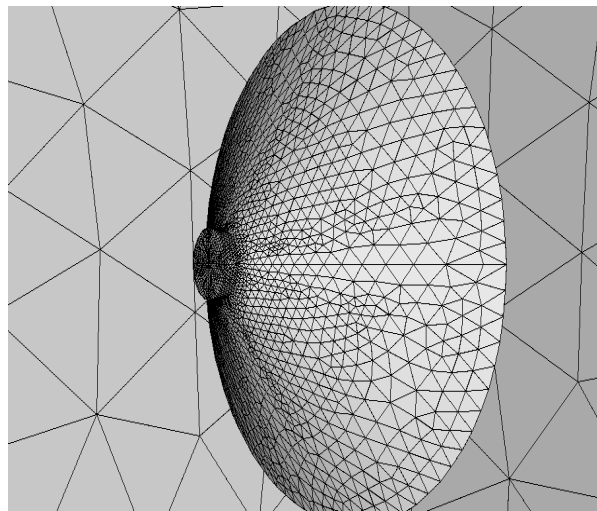


Test Validation Acceptance Criteria

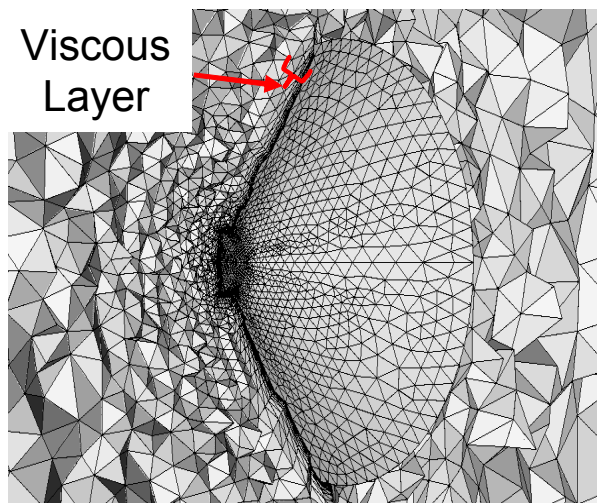
- Deflections from CSM under load to be within 10% of deflections measured during wind tunnel test at maximum dynamic pressure
- Wrinkle pattern from the analyses should reasonably be similar to that obtained from wind tunnel test



CFM Description

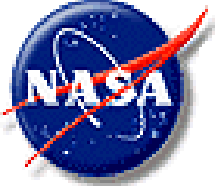


Surface Mesh

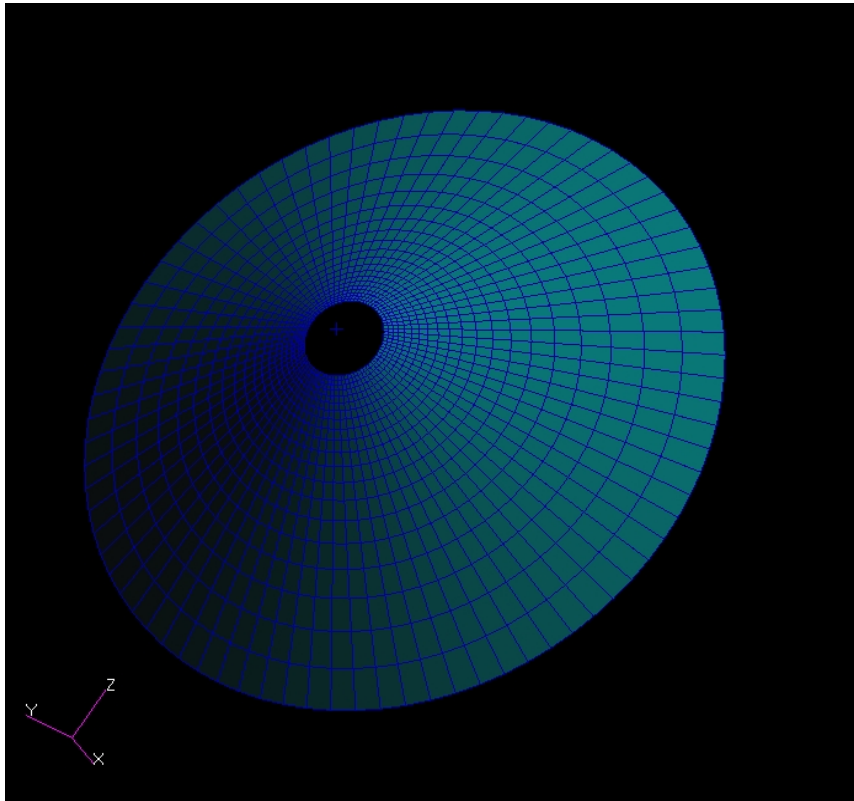


Superimposed Slice of
Volume Mesh

- Full span CFM was built for Mach 6 condition
- Boundary layer was generated at $Y^+ = 1$ and appropriate for wind tunnel Re
- Moderate grid stretching used
- Viscous layers were generated aggressively (12 layers) to reduce number of elements and CPU time
- CFM contains 350,000 tetrahedral elements representing the 1-mil Kapton film

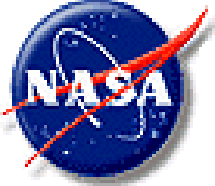


CSM Description

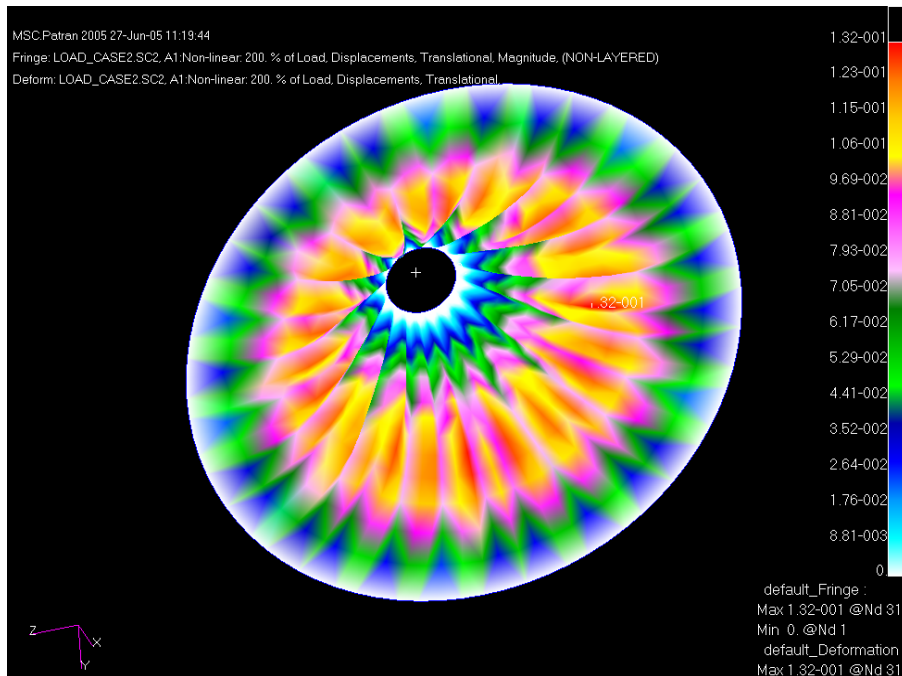


CSM Mesh

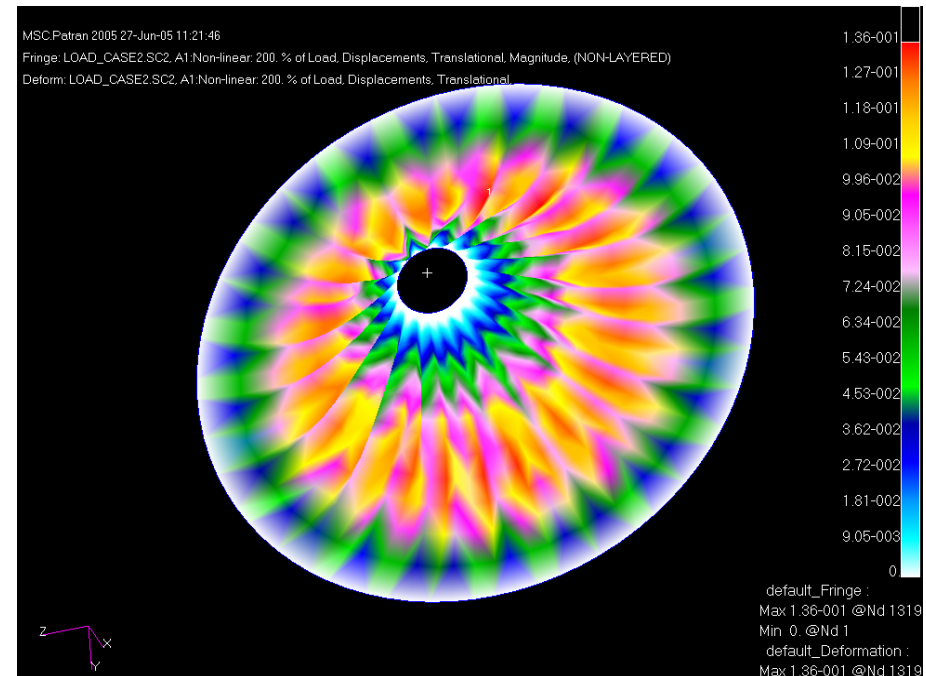
- Full span CSM was built for MSC.Nastran.
- 1600 shell elements representing the 1-mil thick Kapton film
- Model was run with large displacement and follower forces options activated.



Test Validation Results

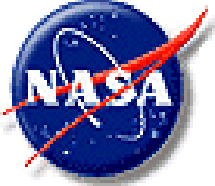


Cycle 1: Displacement Contour Plot



Cycle 2: Displacement Contour Plot

- Displacement contour (wrinkle patterns) from one cycle to the next changes
 - Change may be attributed to ill-conditioning of stiffness matrix and near-zero bending stiffness of the membrane
 - Vibration frequencies and mode shapes are susceptible to change accordingly

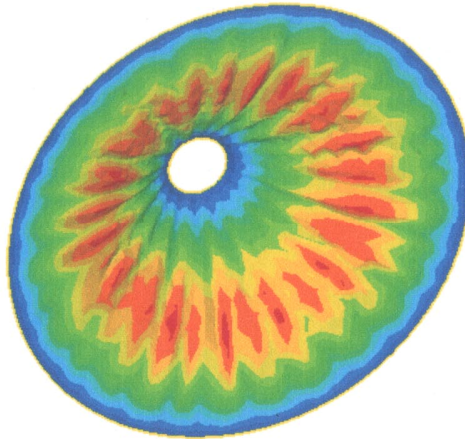


Test-Validation Results

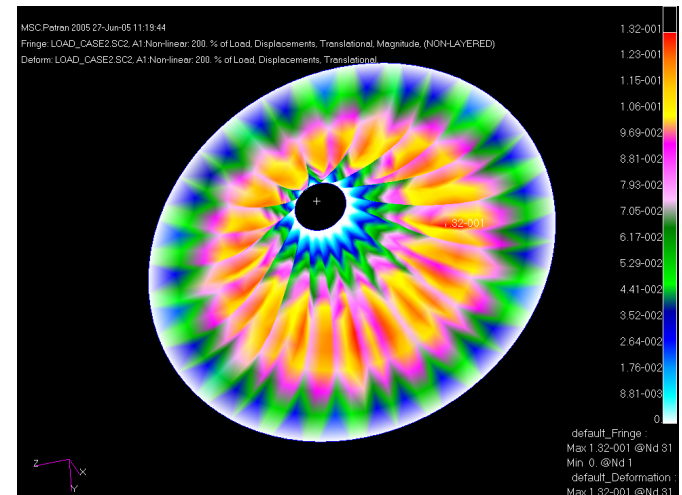
Wrinkle Pattern and Displacement Comparisons



Test Article



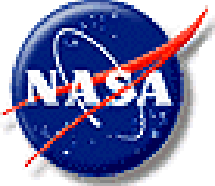
CFM stretched
surface mesh



CSM displacement Contour Plots

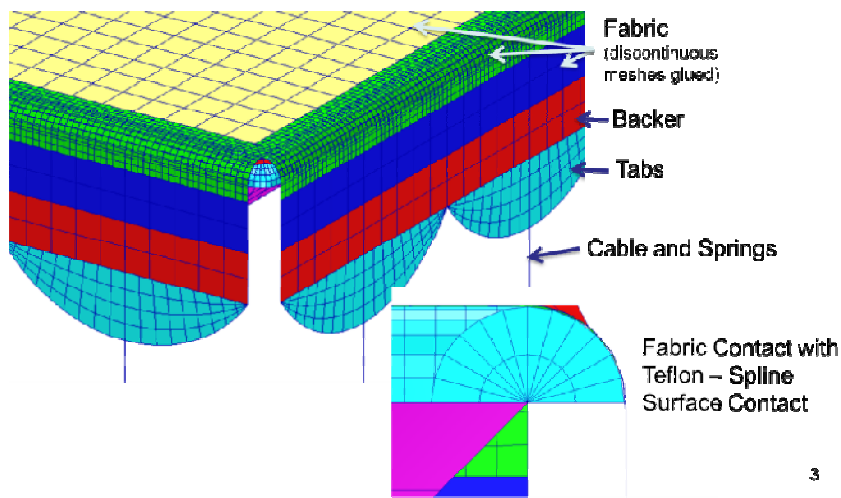
- 0.15 inch max. displacement
- No. of wrinkles = 16

- 0.14 inch max. displacement
- No. of wrinkles = 16

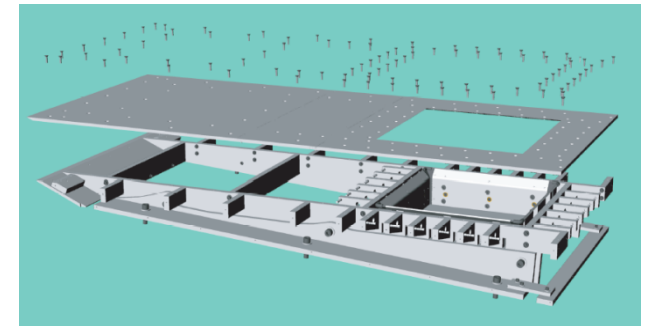


Current Work, Model

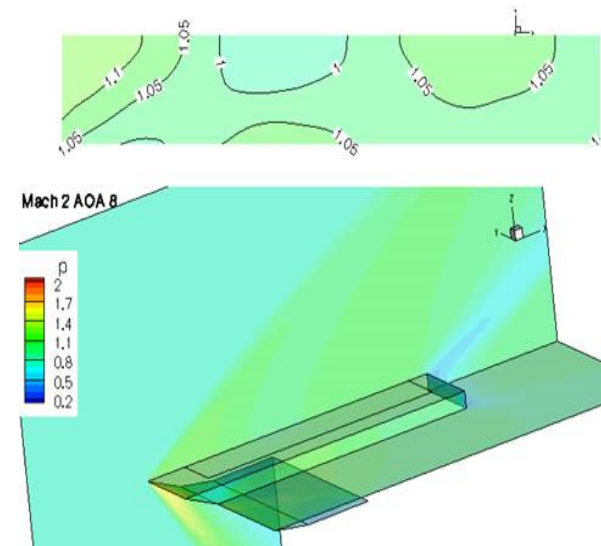
- Designed and built a membrane for a supersonic test at LaRC Unitary wind tunnel
- Perform modal survey of article and correlate CSM
- Deliver test-correlated model for FSI and wind tunnel test



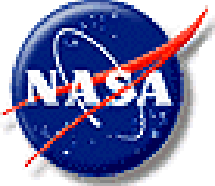
Structural Model



Design of a Test Model and Wind Tunnel Testing (WTT)



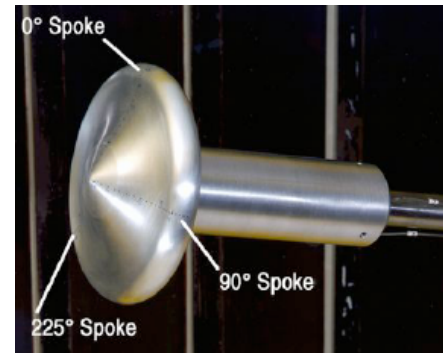
CFD Model



Current Work, Tests

- CFD validation against LaRC Unitary WTT
 - Mach no. range from transonic to high supersonic
 - Challenge: selection of turbulence, flux, and execution schemes
- To date, CFD shows up to 2.5% difference on drag and lift

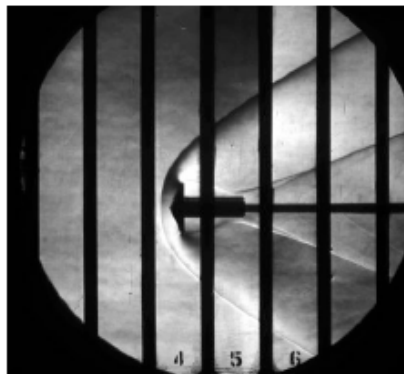
Rigid Test
Article



Schlieren
Images



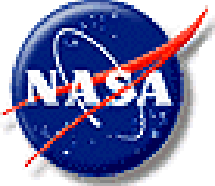
Mach 1.6



Mach 2.5

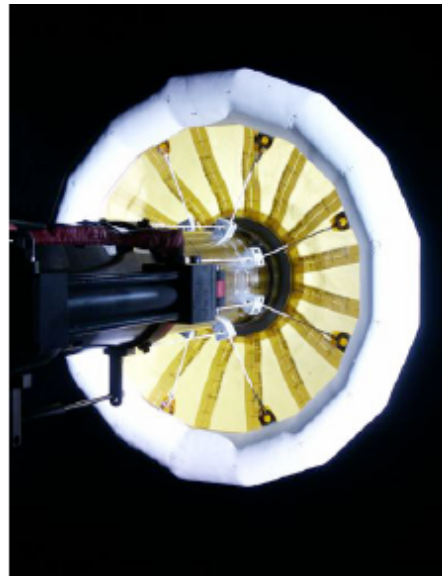
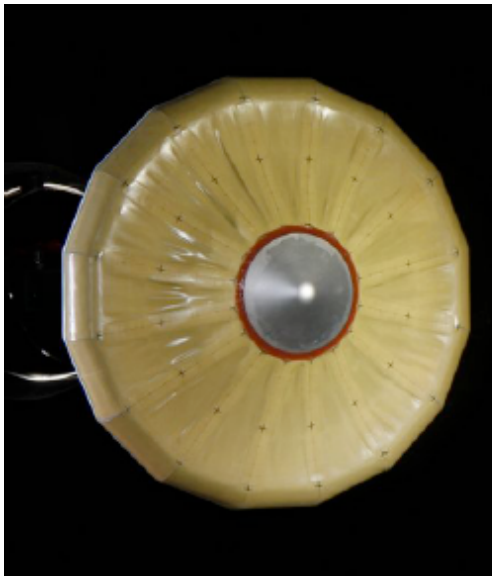


Mach 4.5

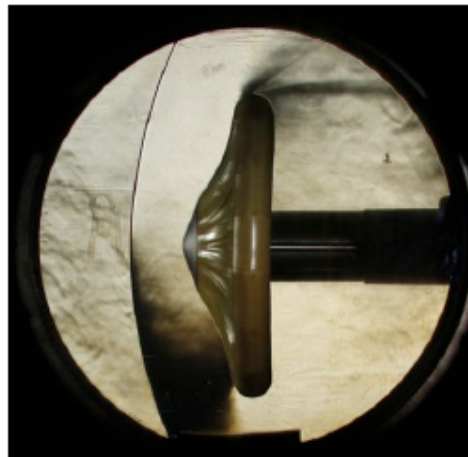
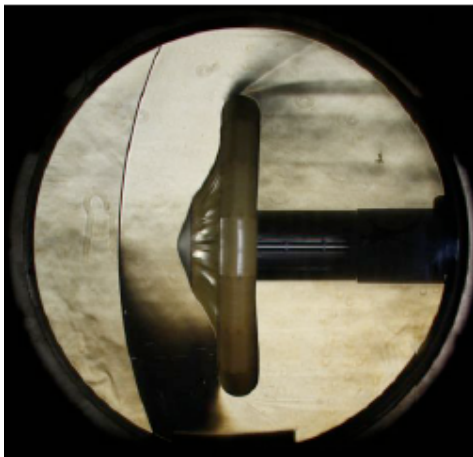


Future Work

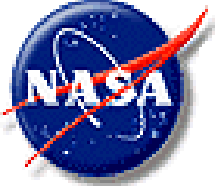
- FSI validation against NASA/Glenn Research Center WTT



Inflatable
Test Article



Schlieren
Images



Concluding Remarks

- FSI is validated against flight test WTT and flight
- Allows for mixing various CFD and FE software during computations
- Matches aerodynamic loads between CFD and FEA within machine accuracy
- Allows for application of loads due to pressure, viscous forces, and heating
- Additional verification required and is planned to be compared to various validation tests

SCM
Thank you

