NASA Aerosciences Activities to Support Human Space Flight

Gerald J. LeBeau
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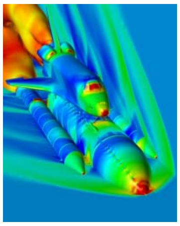
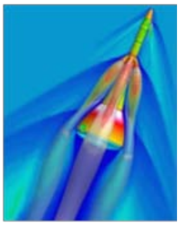
The Lyndon B. Johnson Space Center (JSC) has been a critical element of the United State's human space flight program for over 50 years. It is the home to NASA's Mission Control Center, the astronaut corps, and many major programs and projects including the Space Shuttle Program, International Space Station Program, and the Orion Project. As part of JSC's Engineering Directorate, the Applied Aeroscience and Computational Fluid Dynamics Branch is charted to provide aerosciences support to all human spacecraft designs and missions for all phases of flight, including ascent, exo-astmospheric, and entry.

The presentation will review past and current aeroscience applications and how NASA works to apply a balanced philosophy that leverages ground testing, computational modeling and simulation, and flight testing, to develop and validate related products. The speaker will address associated aspects of aerodynamics, aerothermodynamics, rarefied gas dynamics, and decelerator systems, involving both spacecraft vehicle design and analysis, and operational mission support.

From these examples some of NASA leading aerosciences challenges will be identified. These challenges will be used to provide foundational motivation for the development of specific advanced modeling and simulation capabilities, and will also be used to highlight how development activities are increasing becoming more aligned with flight projects. NASA's efforts to apply principles of innovation and inclusion towards improving its ability to support the myriad of vehicle design and operational challenges will also be briefly reviewed.

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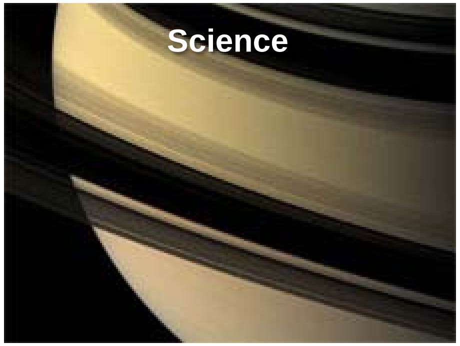
Presented at JAXA Tsukuba Space Center
November 21, 2011

NASA Centers and Mission Directorates



Johnson Space Center

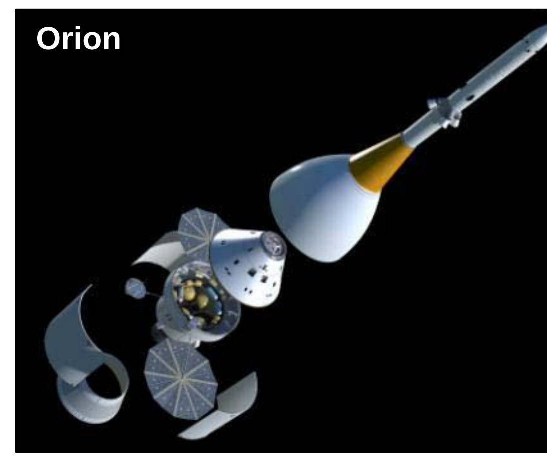

Apollo

Space Shuttle


International Space Station


Mission Control

Astronauts


Orion

NASA/JSC Aerosciences

Aerodynamic Characterization
Rarefied Gas Dynamics
Aerothermodynamic Heating
Decelerator Systems

Ground Testing

Modeling and Simulation

Flight Testing

NASA/JSC Aerosciences

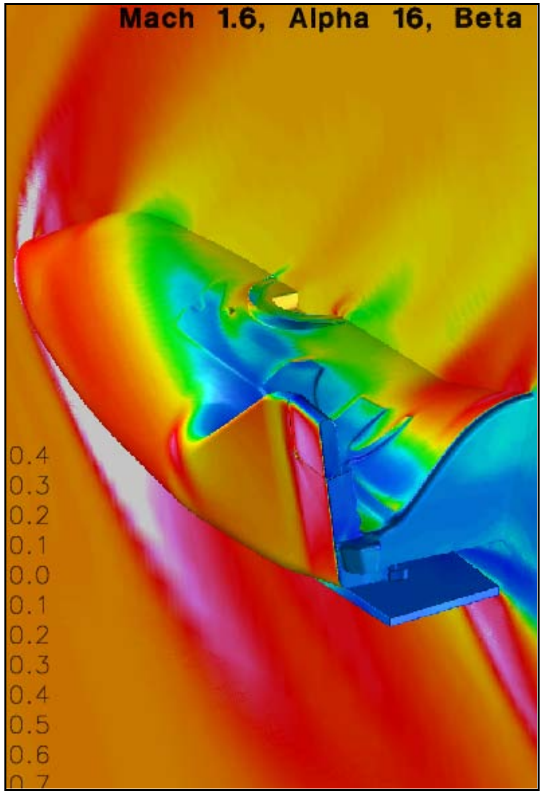
Aerodynamic Characterization

Rarefied Gas Dynamics

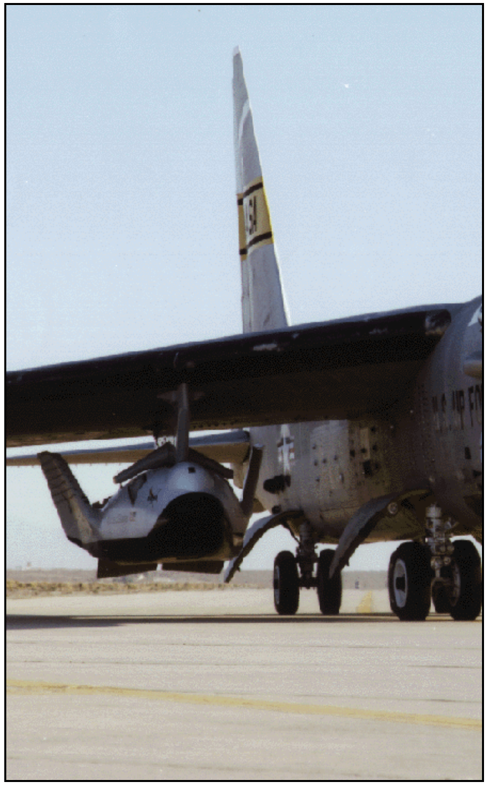
Aerothermodynamic Heating

Decelerator Systems

Ground Testing



Modeling and Simulation

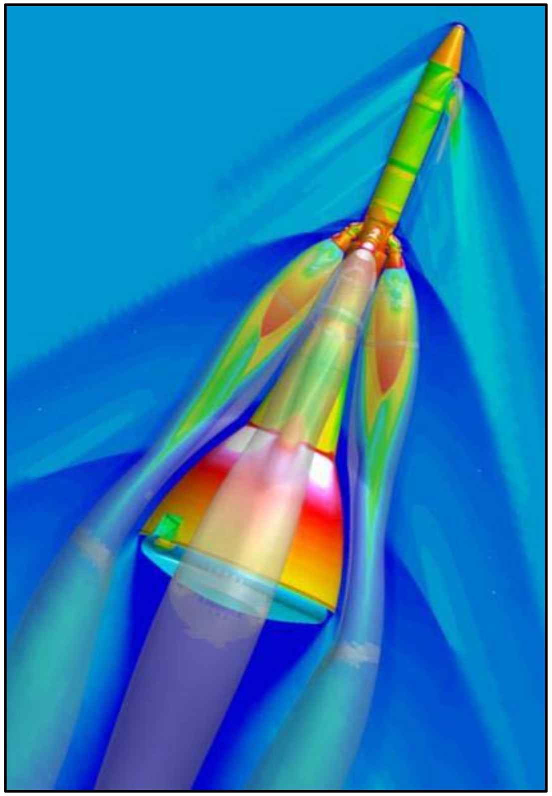


Flight Testing

NASA/JSC Aerosciences

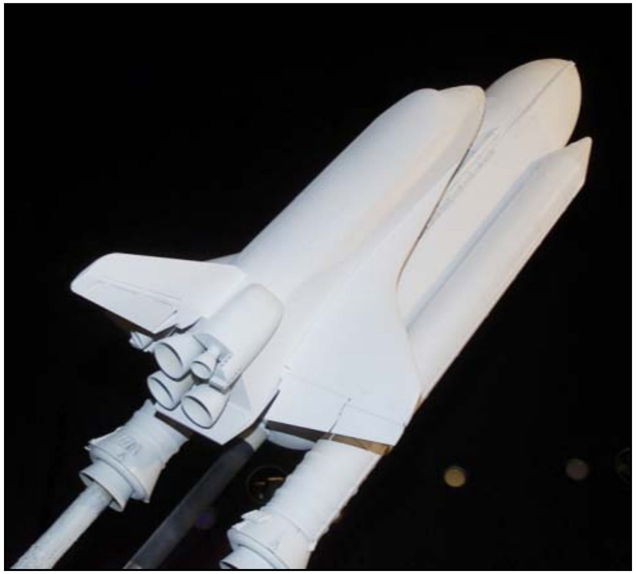
Aerodynamic Characterization
Rarefied Gas Dynamics
Aerothermodynamic Heating
Decelerator Systems

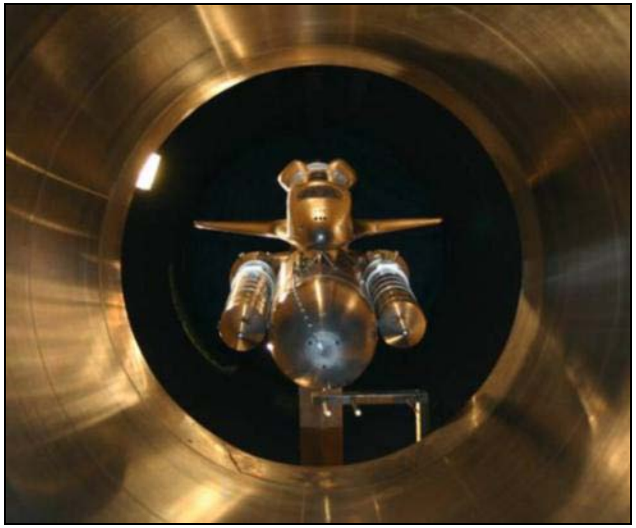

Ground Testing


Modeling and Simulation


Flight Testing

Ground Testing





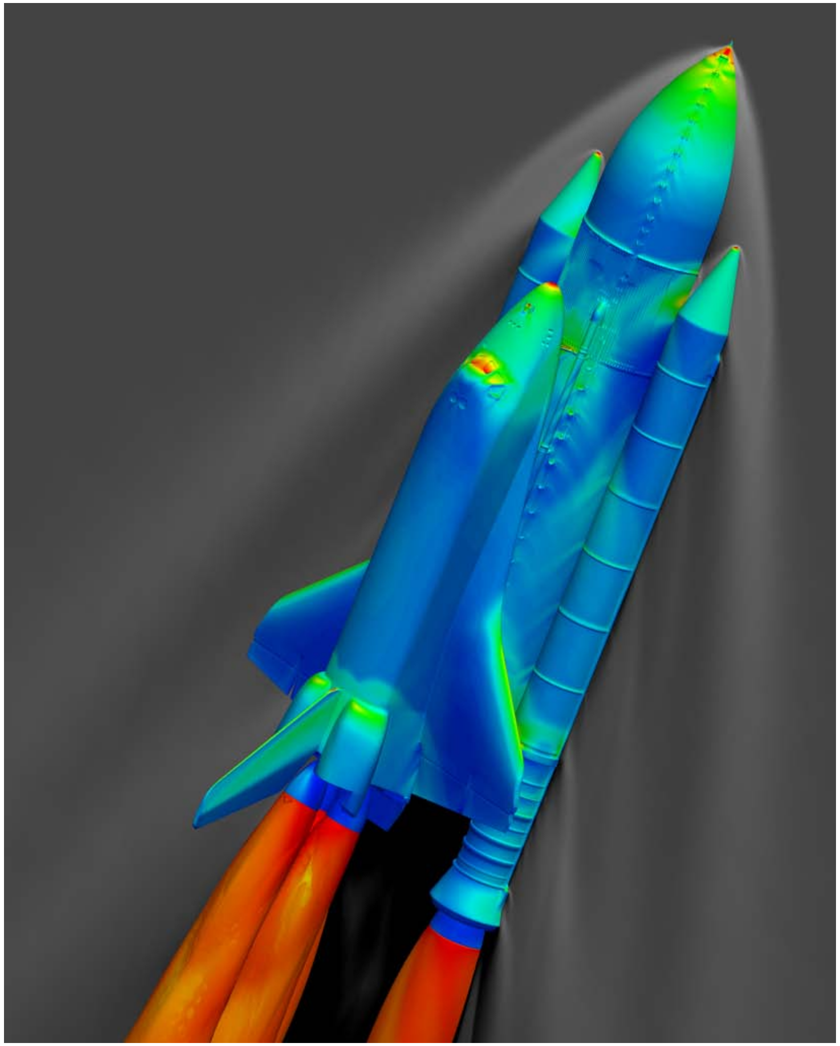
Primary CFD Codes Used at JSC

Overflow
Overset grid Navier-Stokes
NASA Langley Research Center

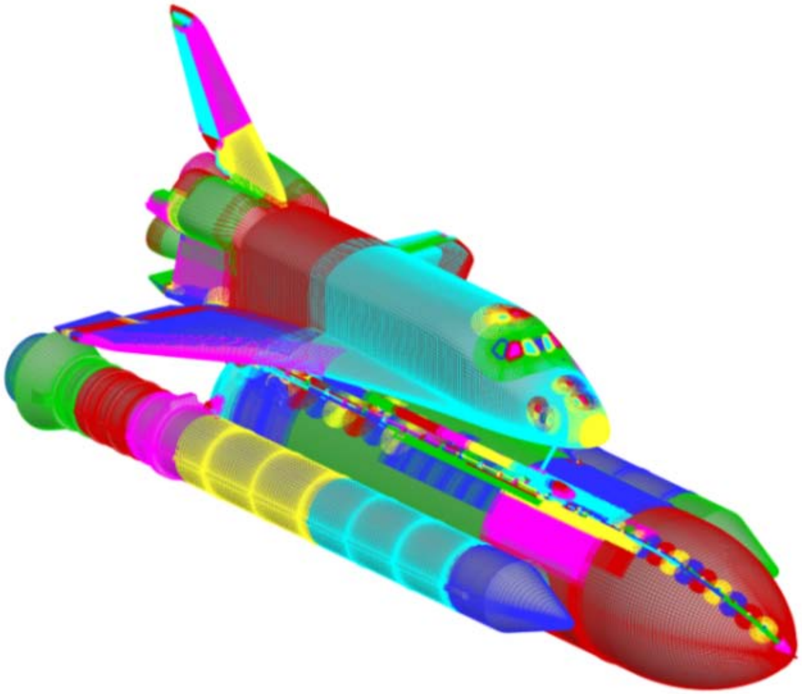
Cart3D
Cartesian inviscid compressible
NASA Ames Research Center

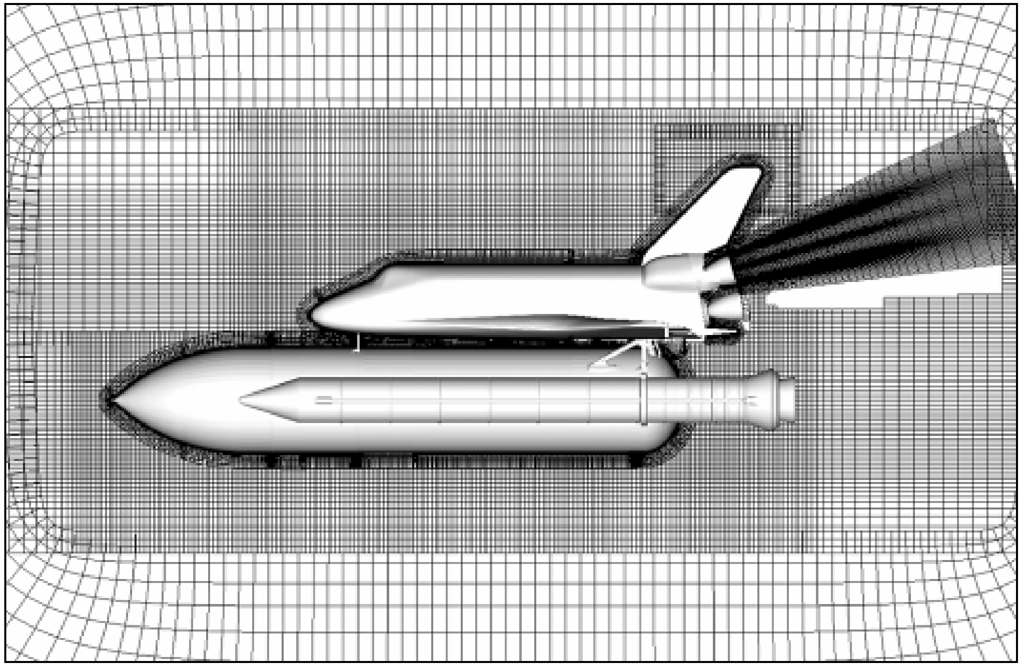
DPLR (Data Parallel Line Relaxation)
Multi-block hypersonic non-equilibrium
NASA Ames Research Center

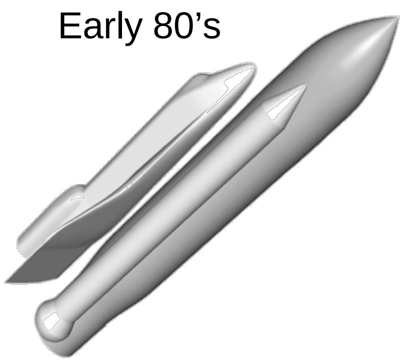
DAC (DSMC Analysis Code)
Rarefied gas dynamics solver
NASA Johnson Space Center



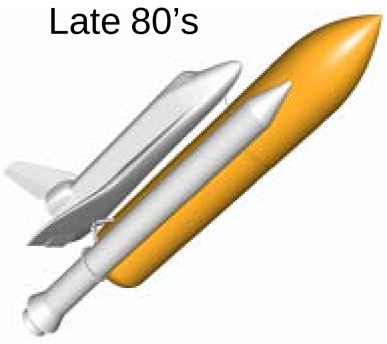
Space Shuttle Overset CFD Development



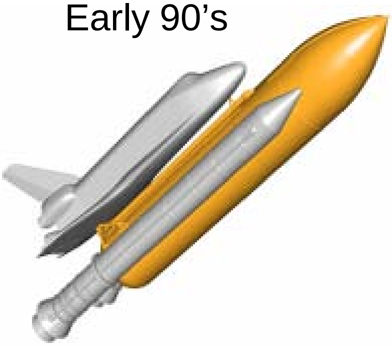




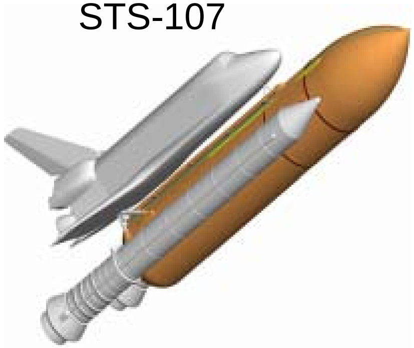
3 Grids
0.3 million volume cells



14 Grids
1.6 million volume cells

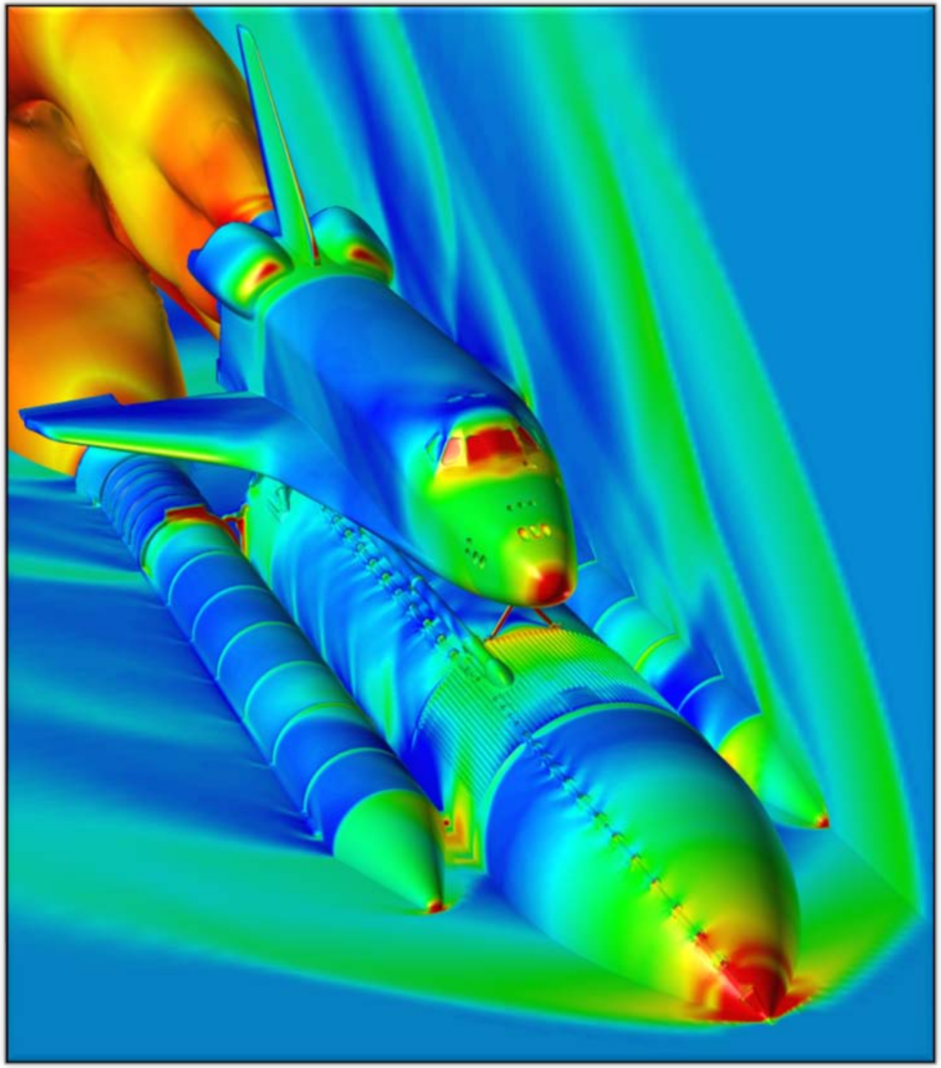


113 Grids
16.4 million volume cells



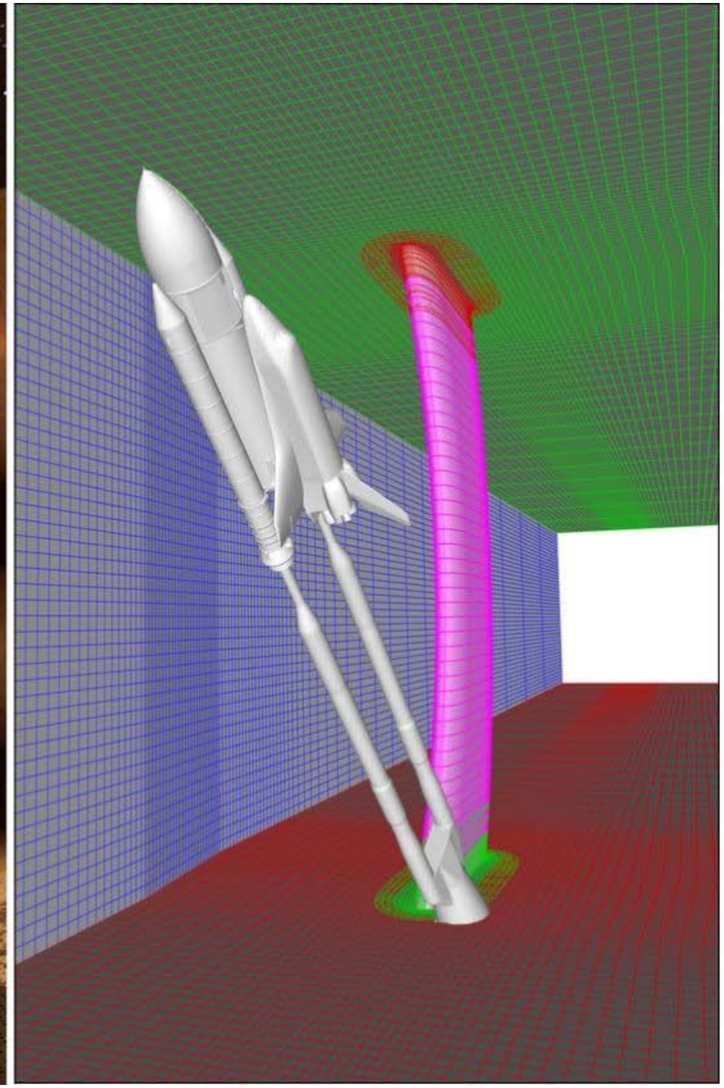
267 Grids
34.8 million volume cells

Return to Flight Geometric Enhancements



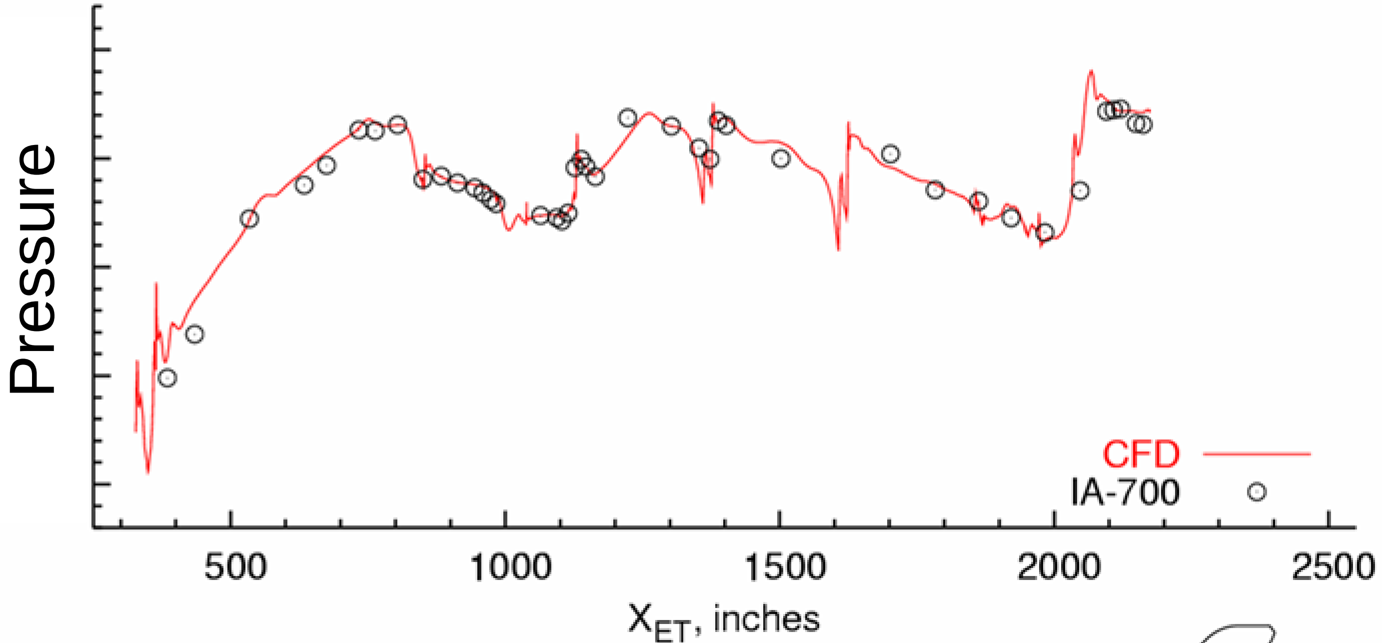
605 Overlapping Grids
96.4M Volume Cells

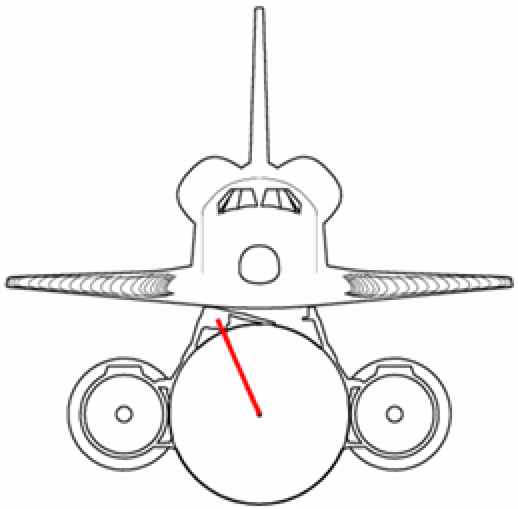
Validation and Ground to Flight Traceability

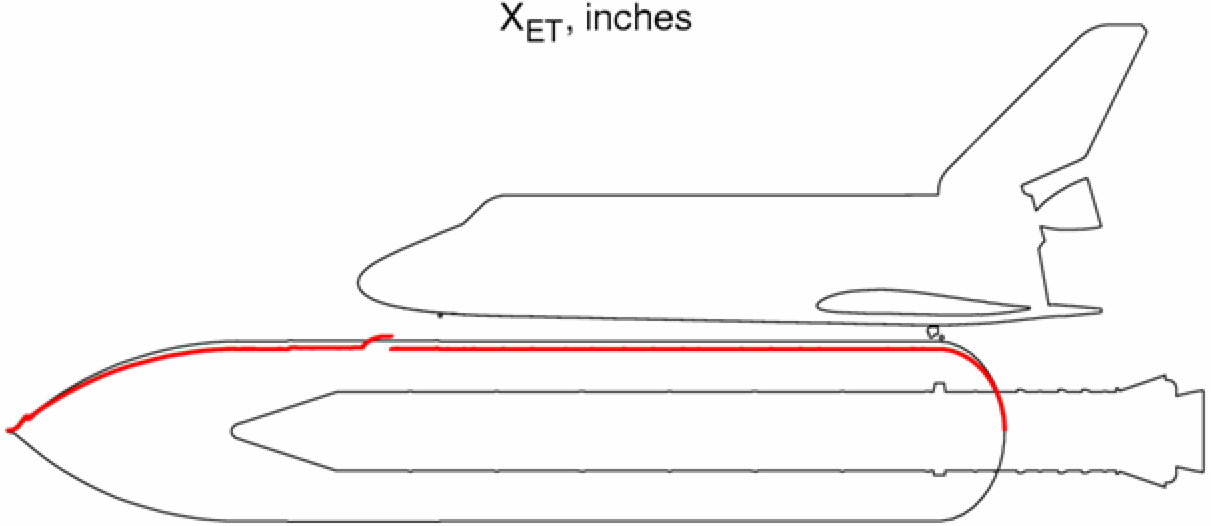


Experimental Validation and Traceability

IA700 Wind Tunnel Test
Mach = 1.55
Re = 2.5E6/ft



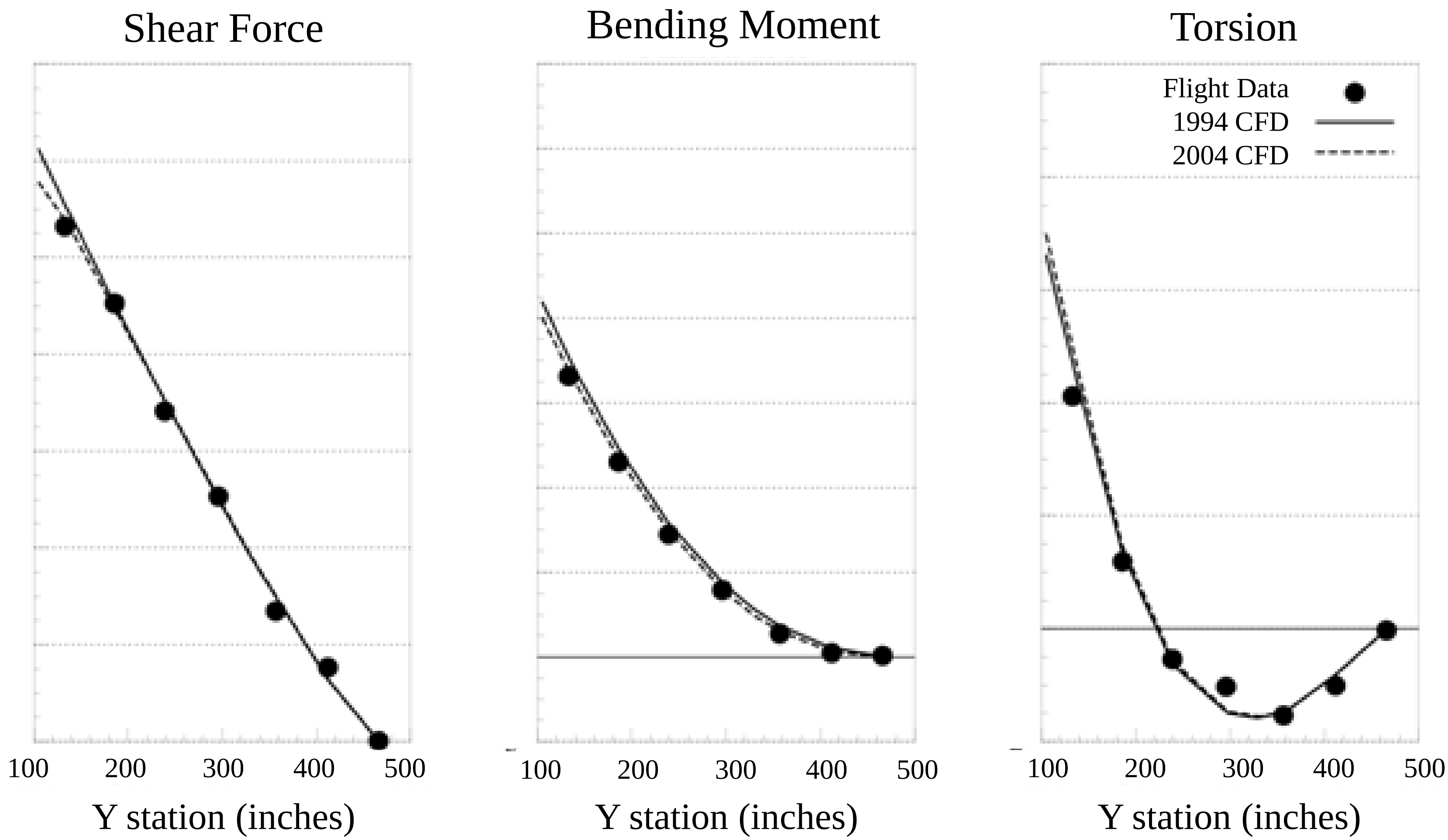




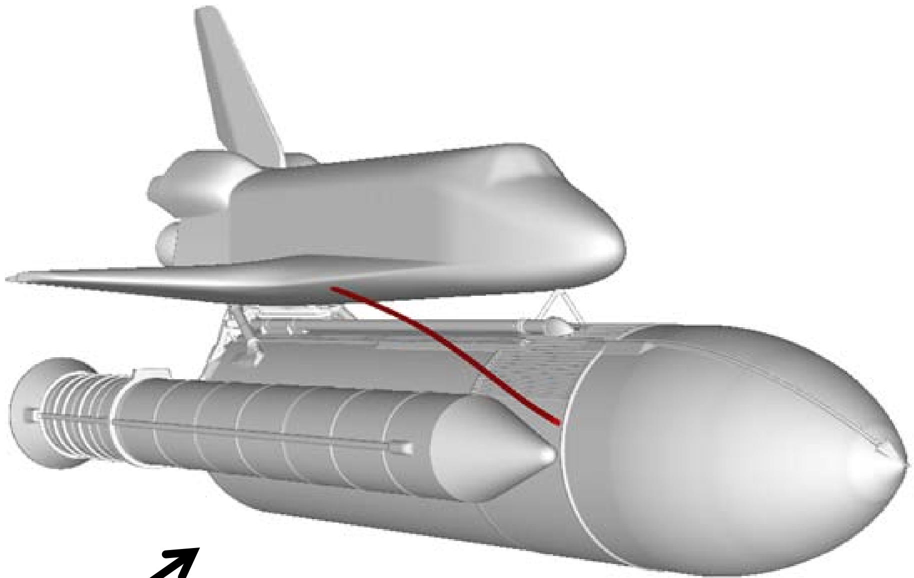
Flight Data Validation

STS-50 Orbiter Wing Running Loads

Mach 1.25, Alpha -3.3, Beta 0.0, $\delta_{ei/o}$ = 10.5/6.25, Qbar = 640.7 psf



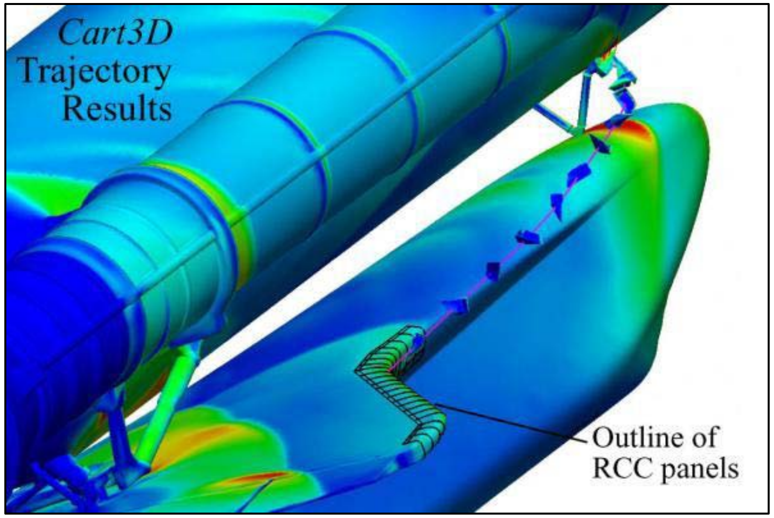
Pre-Columbia Debris Transport Analysis



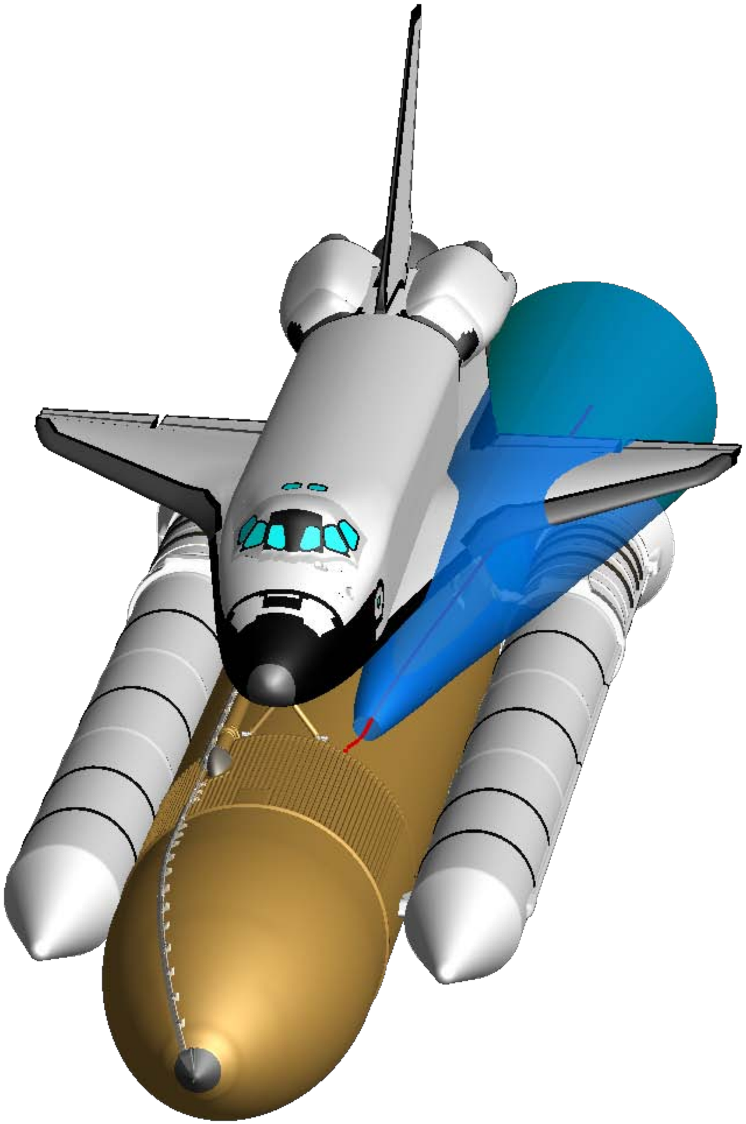
Post Flight Damage Assessment

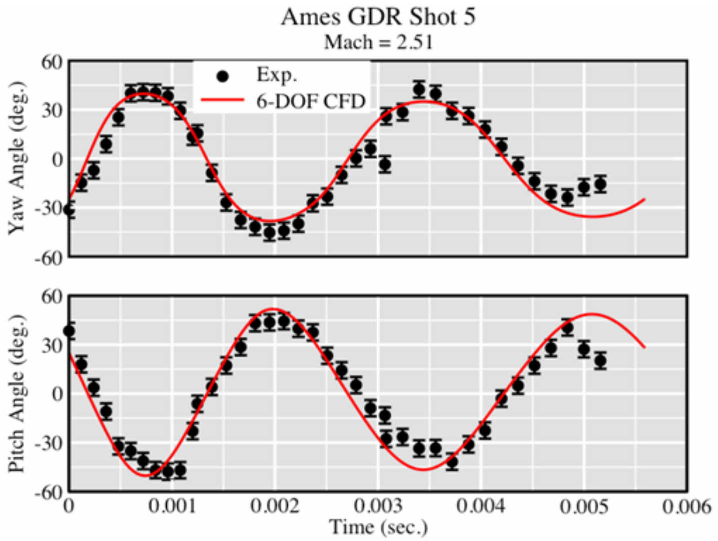
Liberation Source Identification

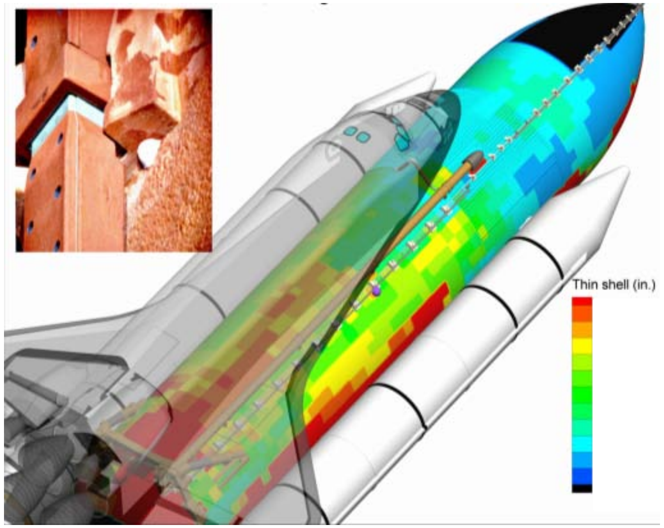
STS-107 DTA Event



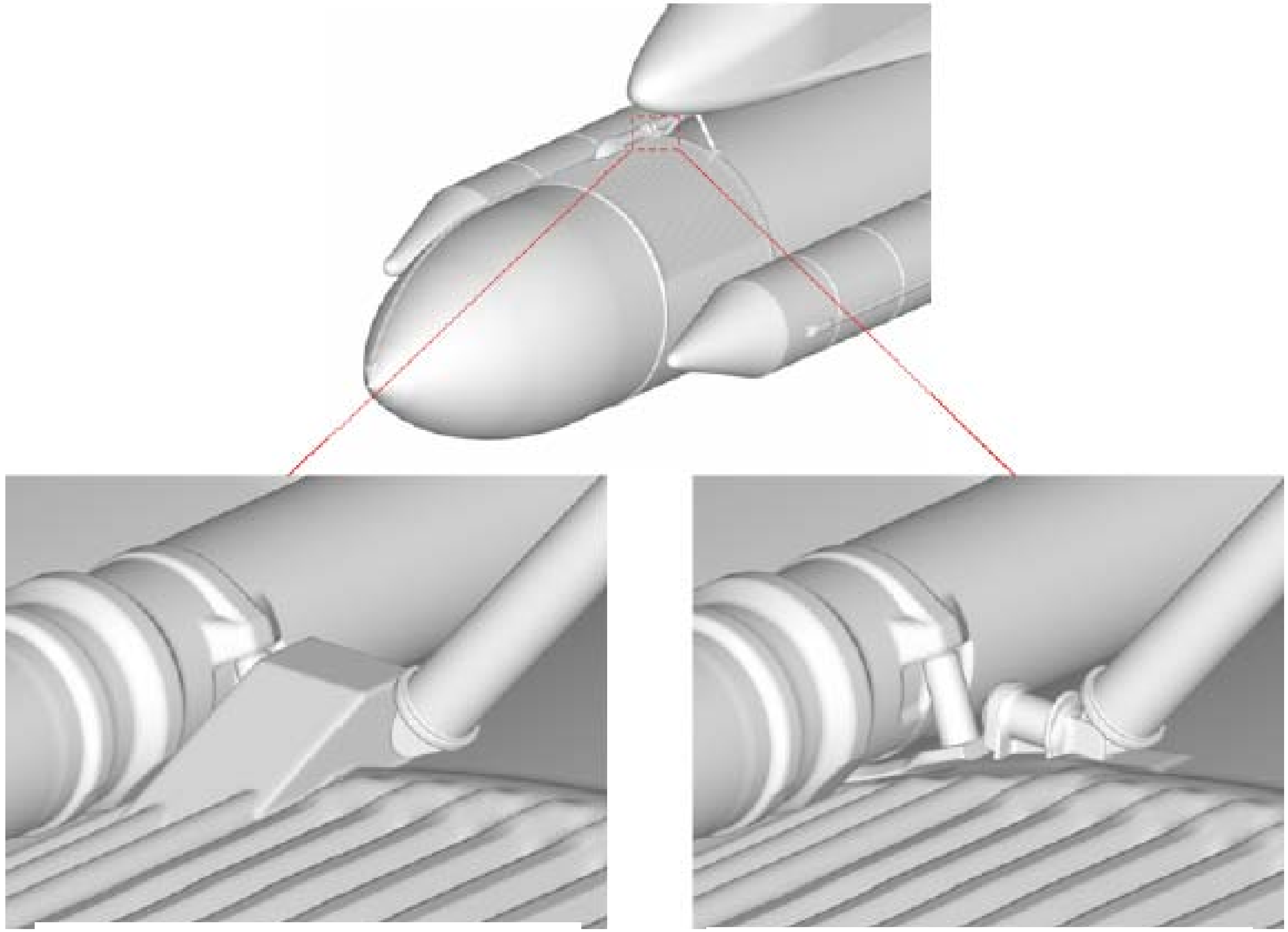
Post Columbia Accident DTA







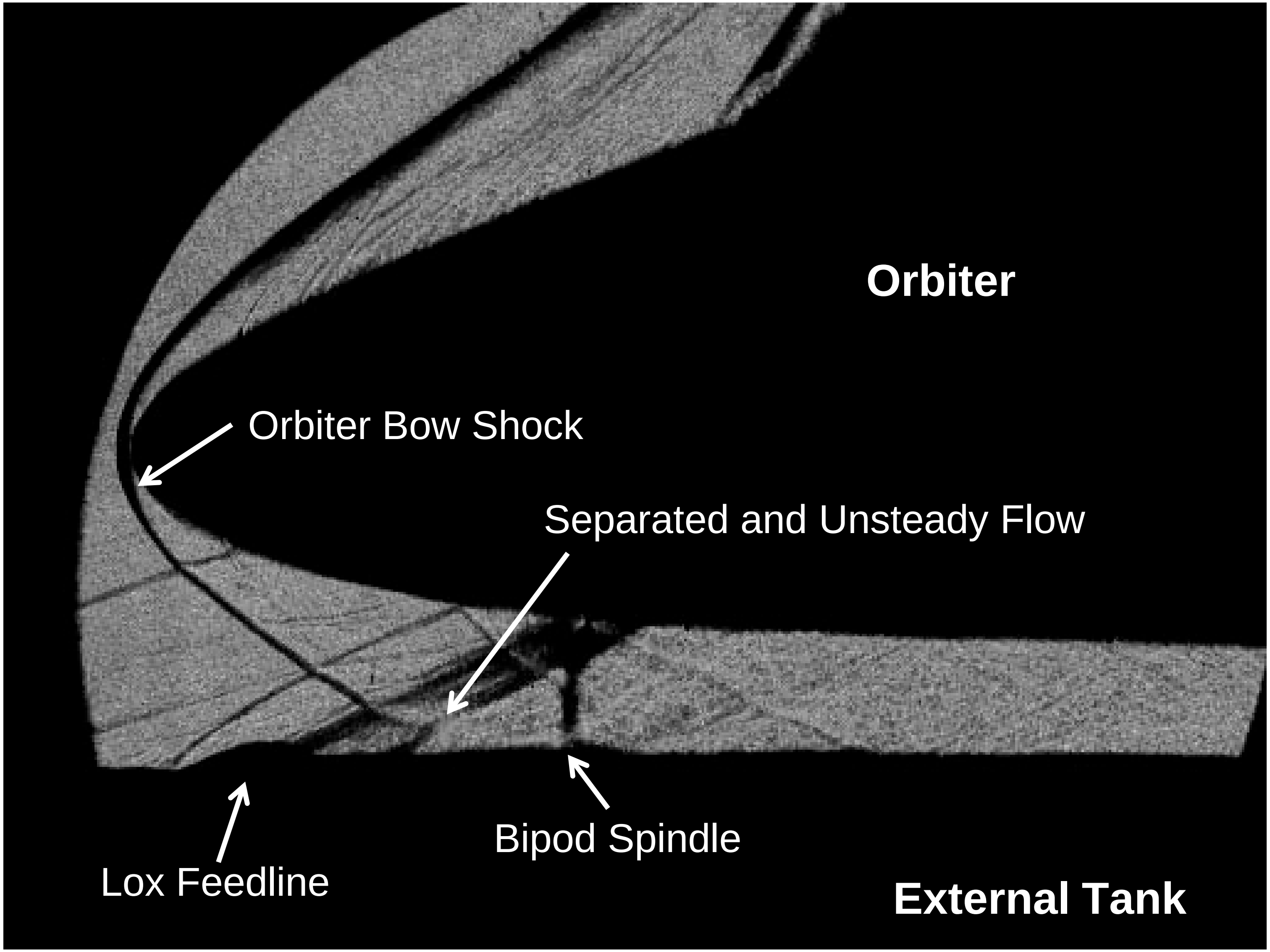
Bipod Redesign Environment Updates



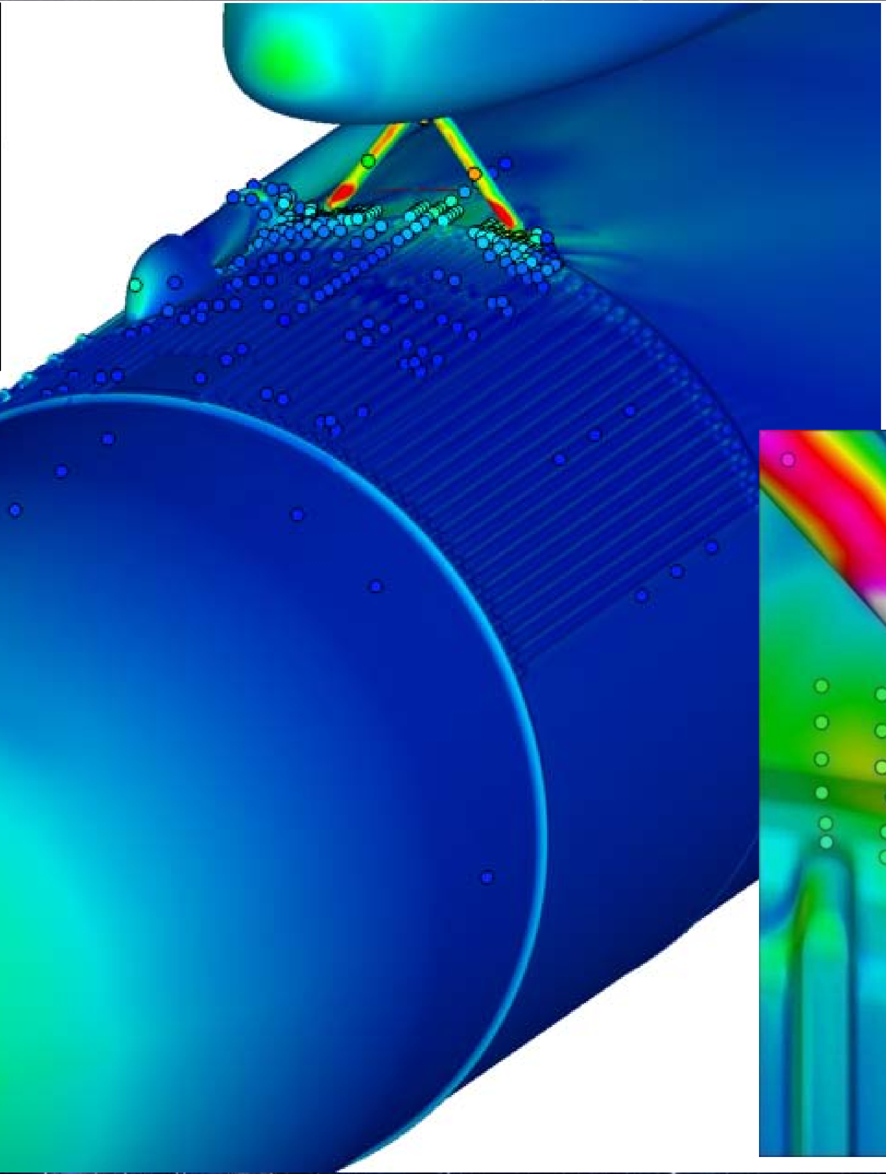
Old Configuration
Bipod Ramps

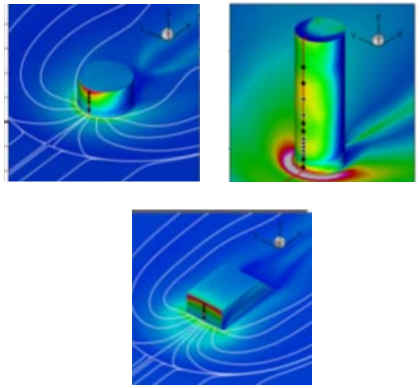
New Configuration
Bare Spindle

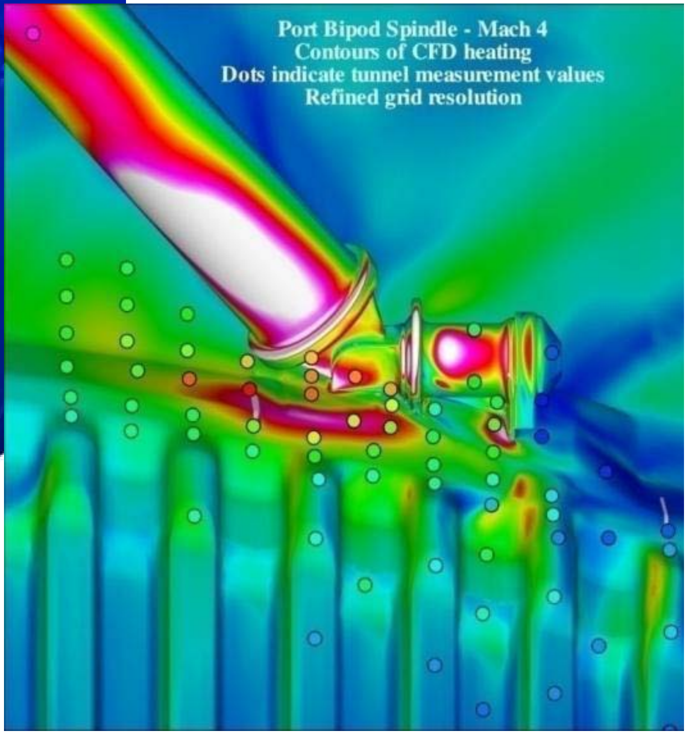
Shock Boundary Layer Interaction



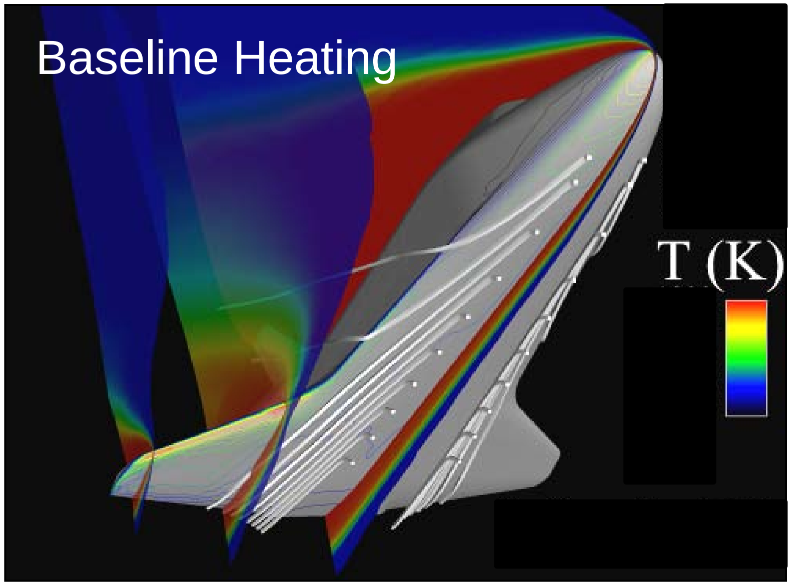
Ascent Aeroheating

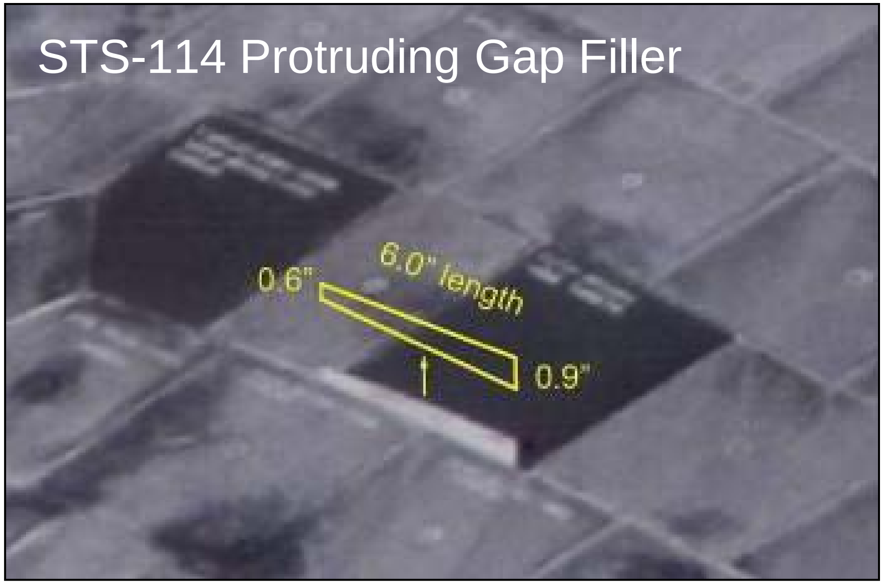




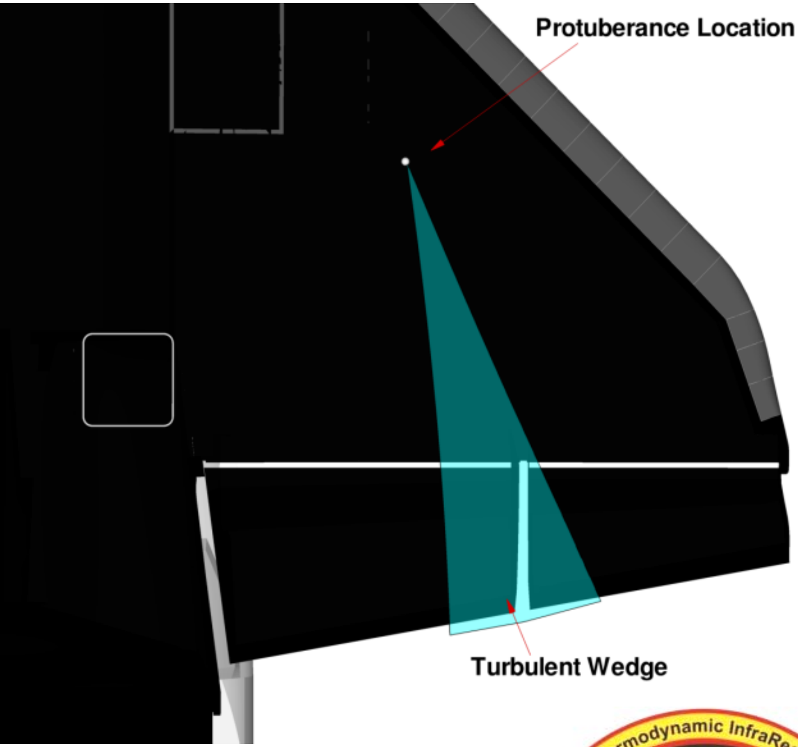


Mission Support / Damage Assessment



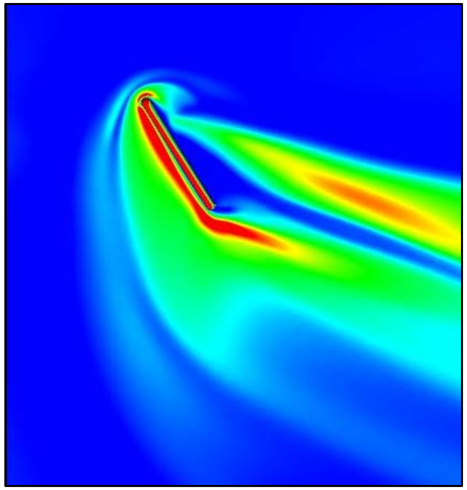


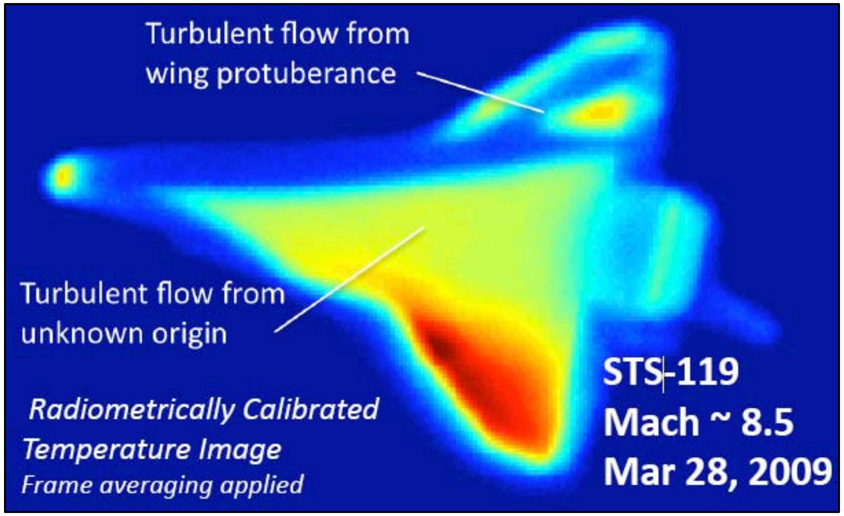
Boundary Layer Transition Flight Experiment



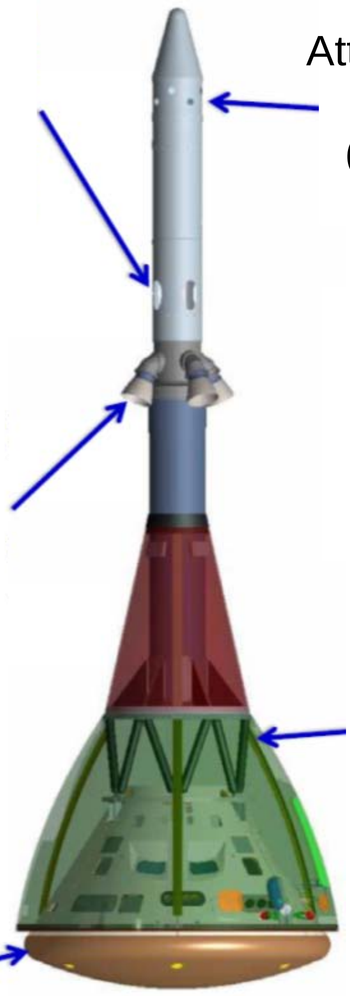
Modified Tile

CFD prediction

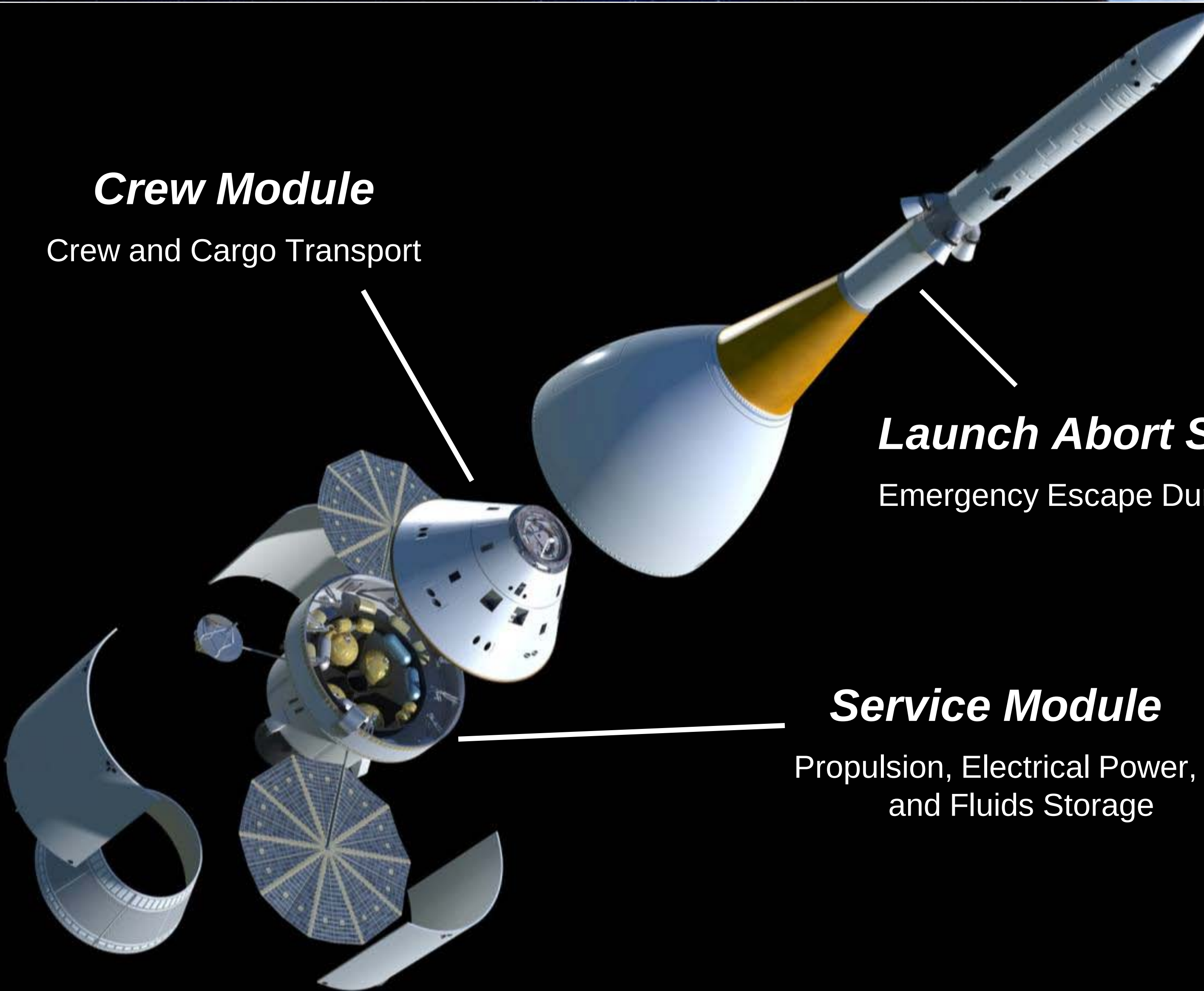




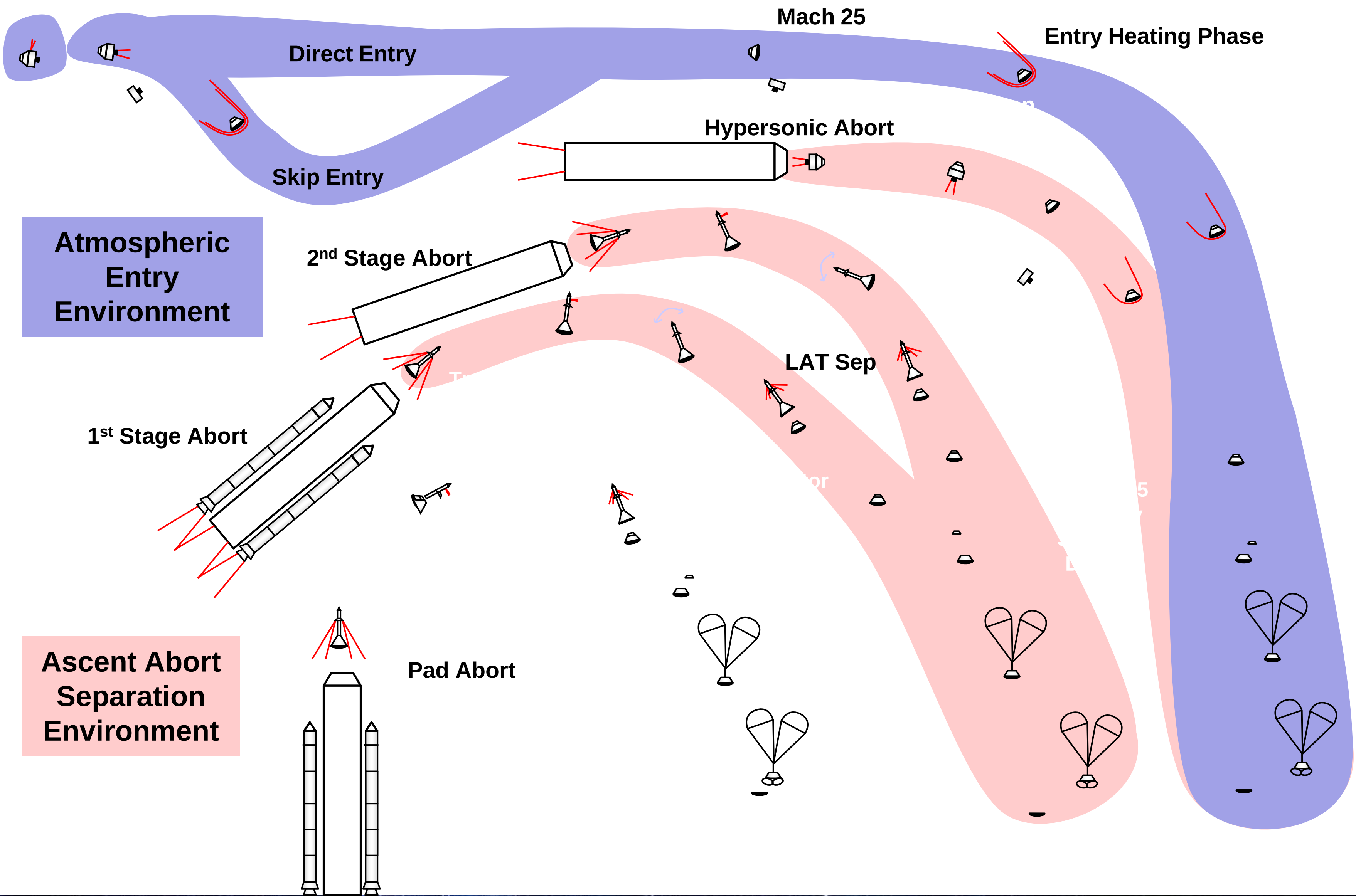
Space Launch System / Orion



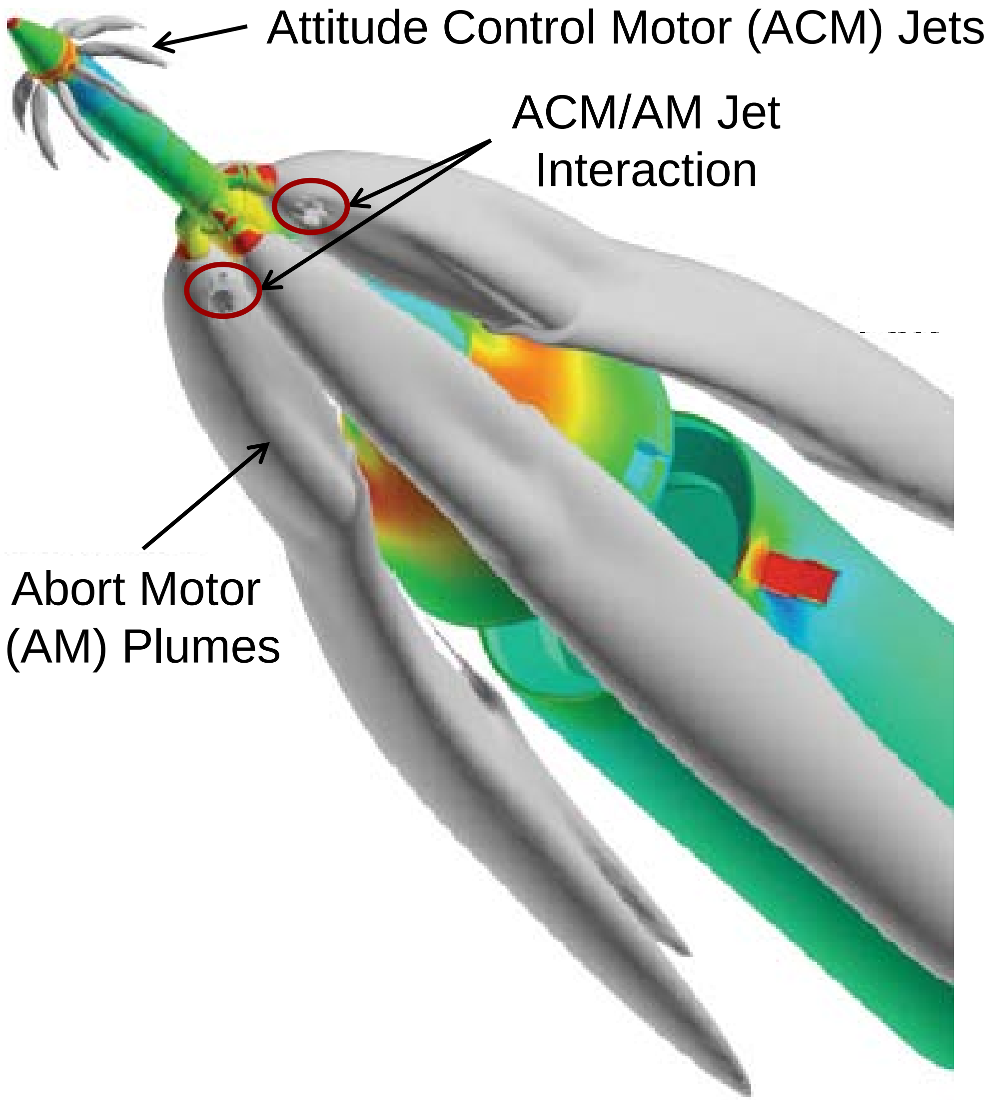
Orion Project Elements

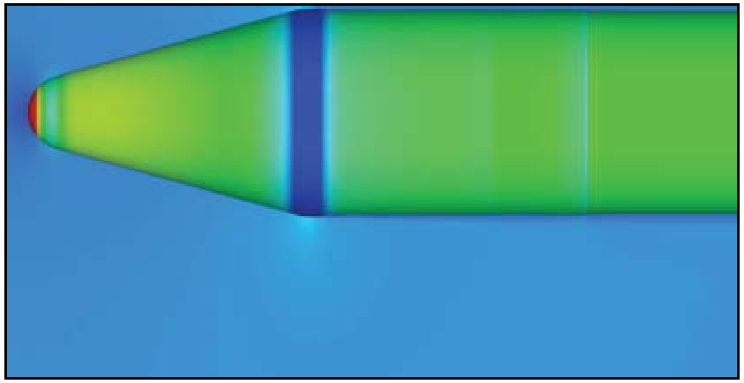


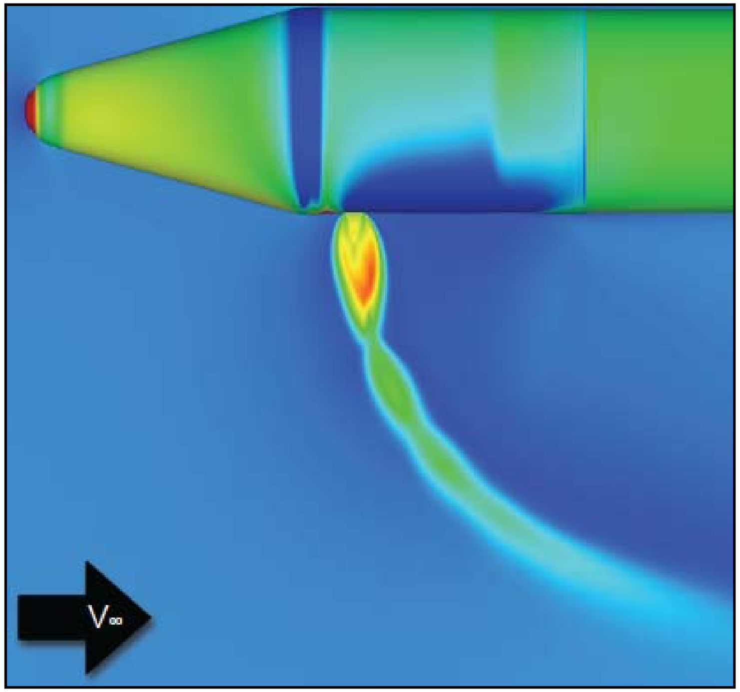
Orion Aerosciences Trajectory Space



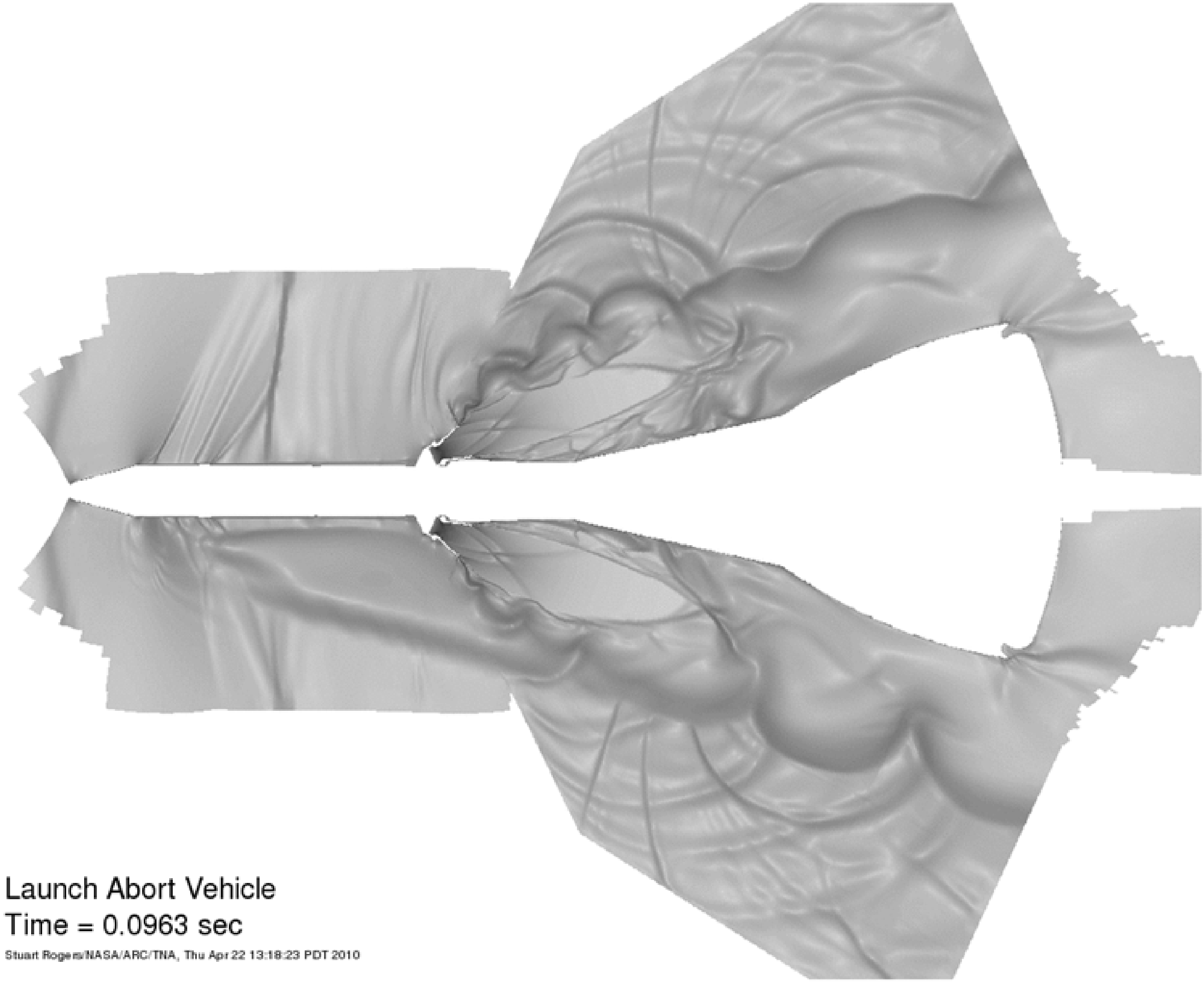
LAS Freestream – Jet Interaction



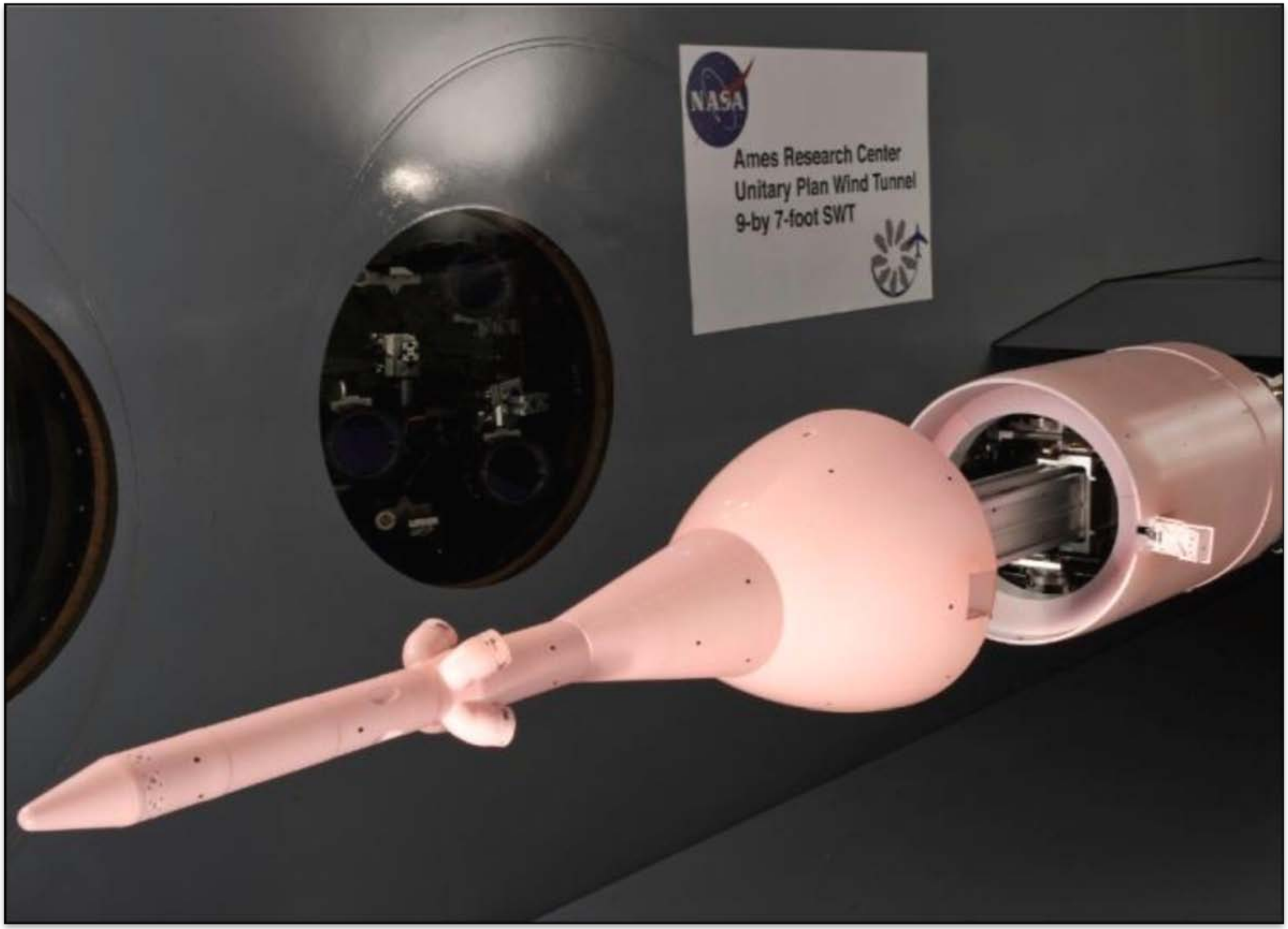




CFD “Schlieren” of Plume Interaction

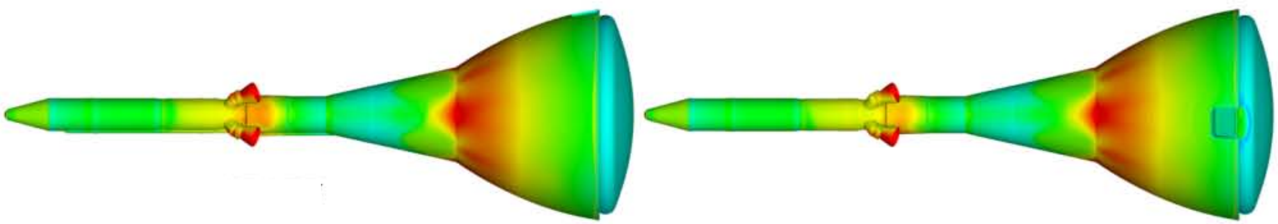


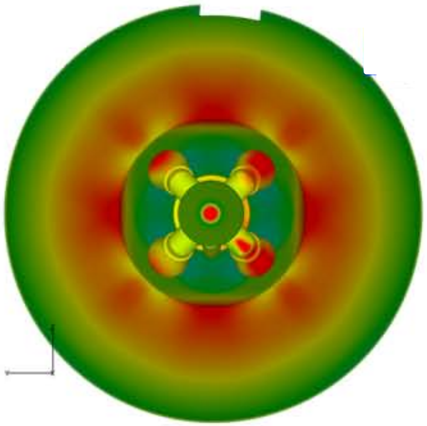
Integrated Abort Vehicle Wind Tunnel Test



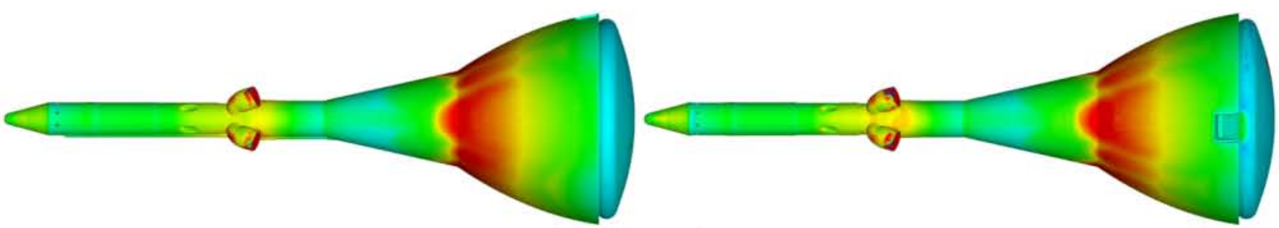
CFD vs. Pressure Sensitive Paint

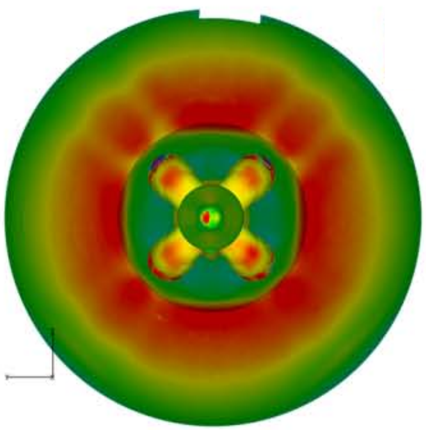
Simulation – Computational Fluid Dynamics





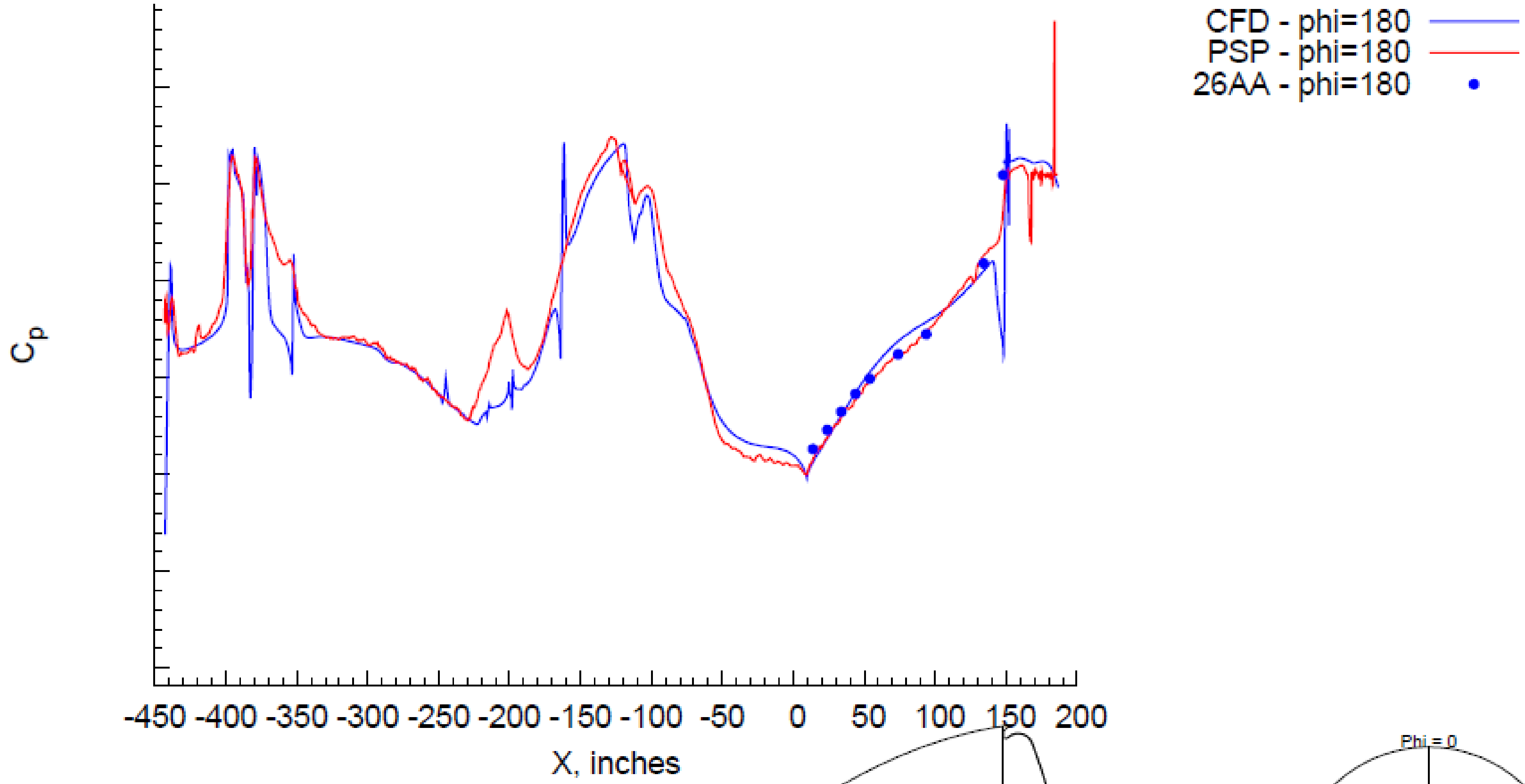
Mach 1.3 Pressure Distribution

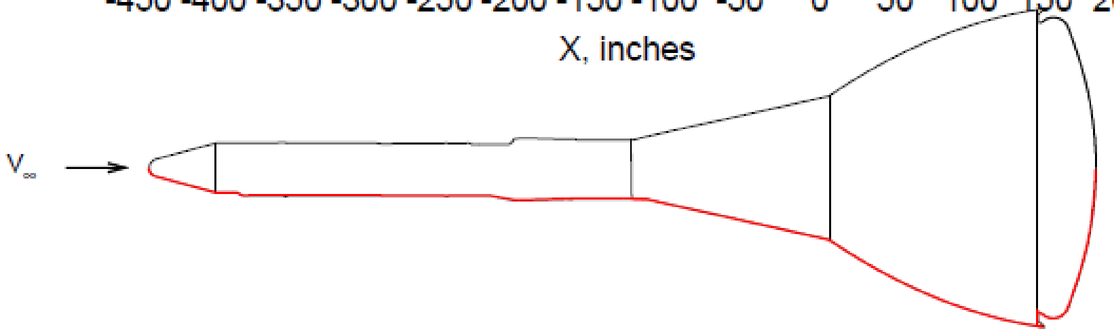


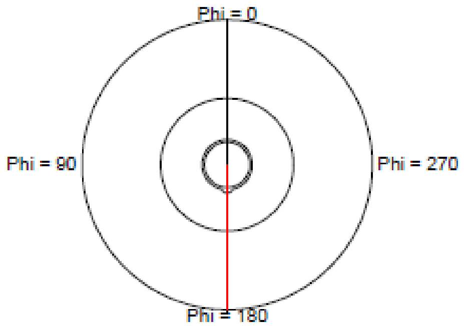


Experimental - Pressure Sensitive Paint

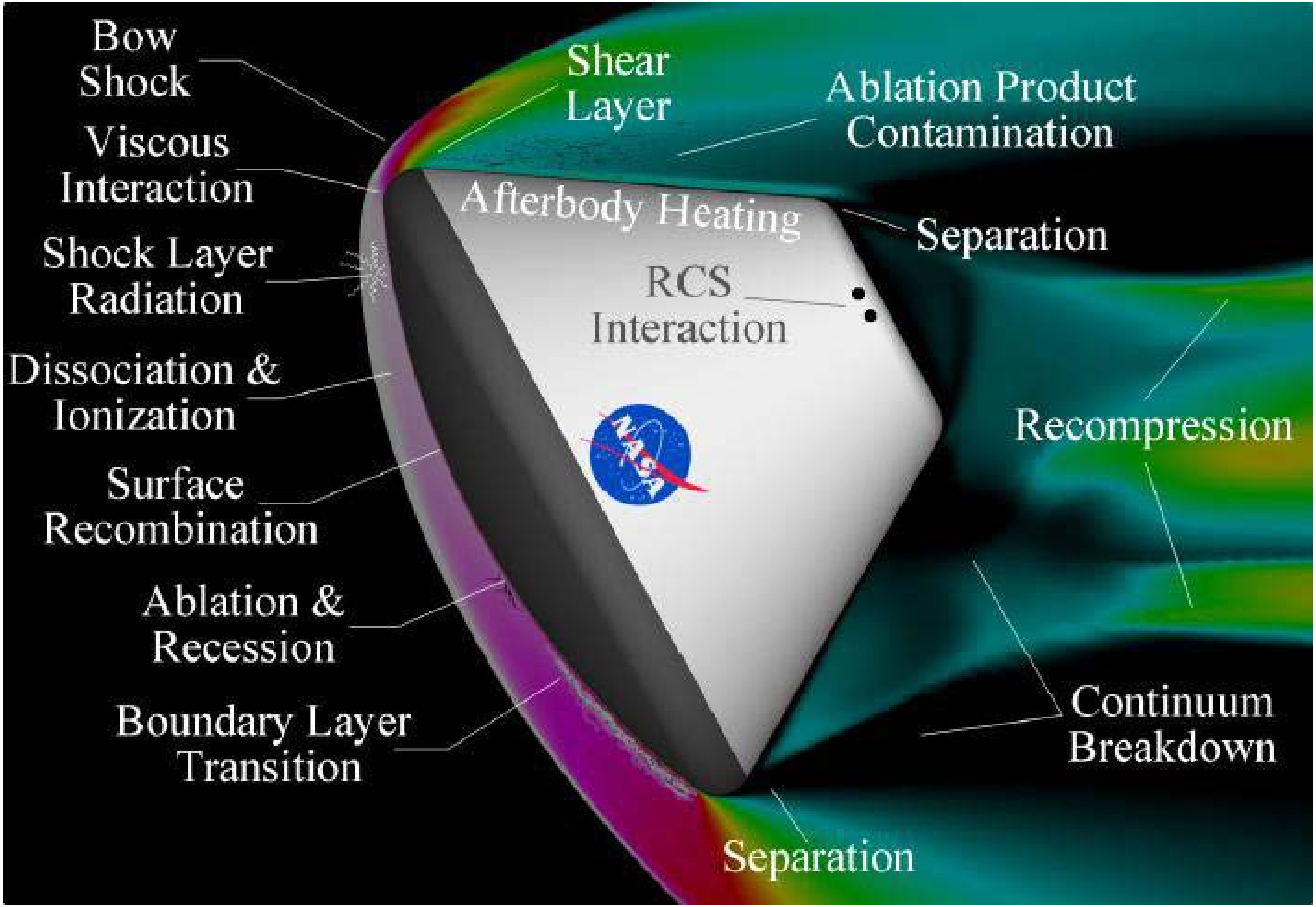
CFD vs. PSP vs. Pressure Tap



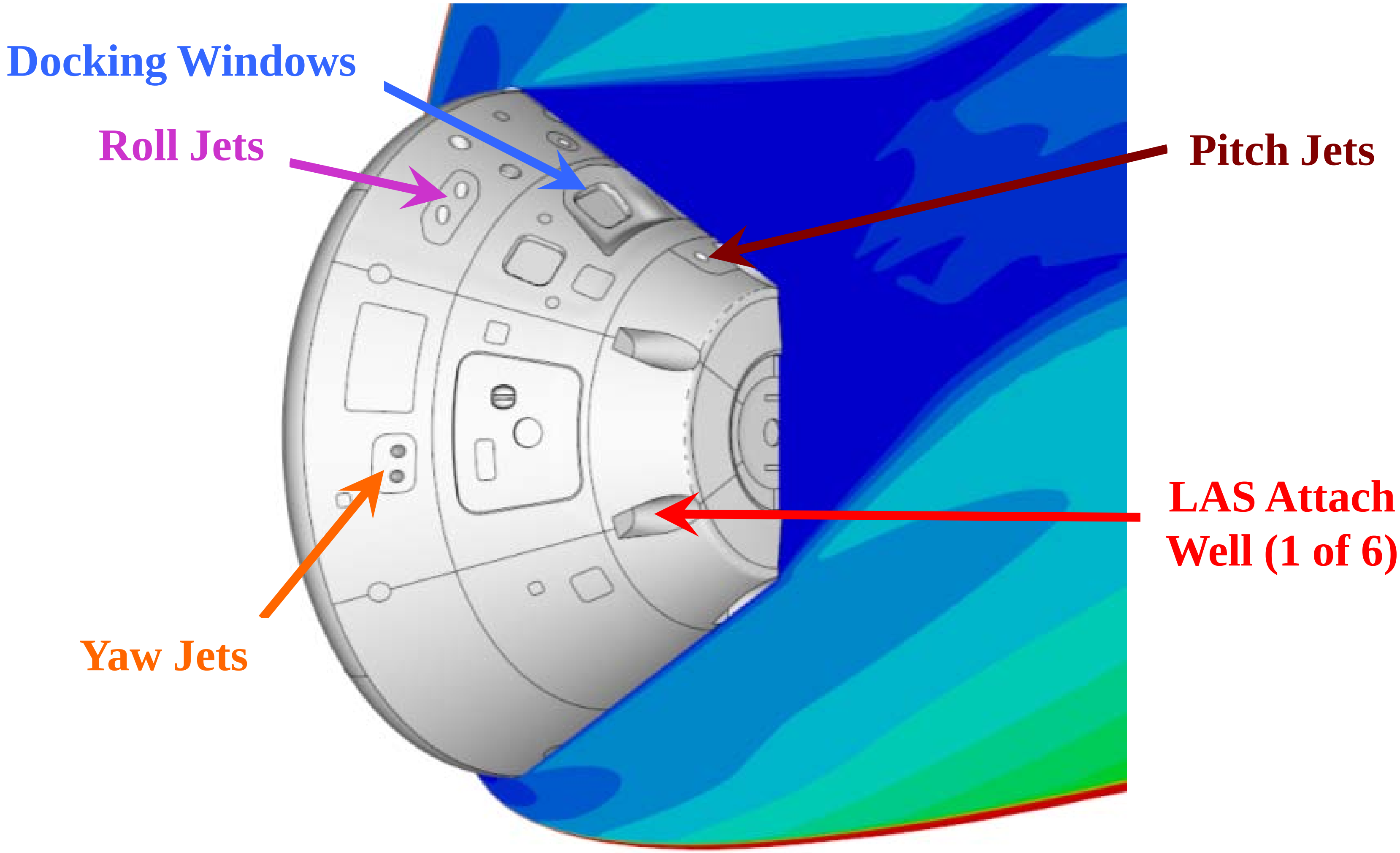




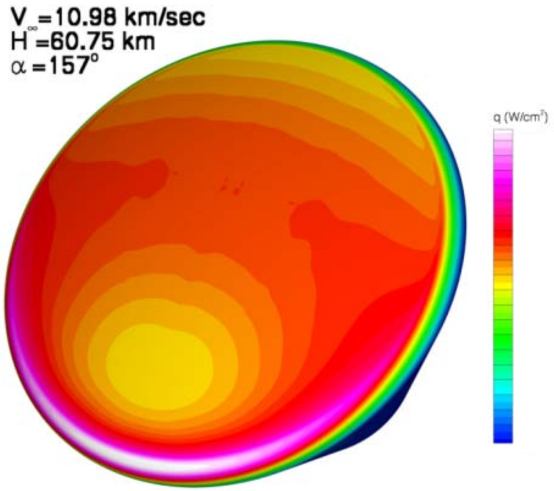
Entry Physics



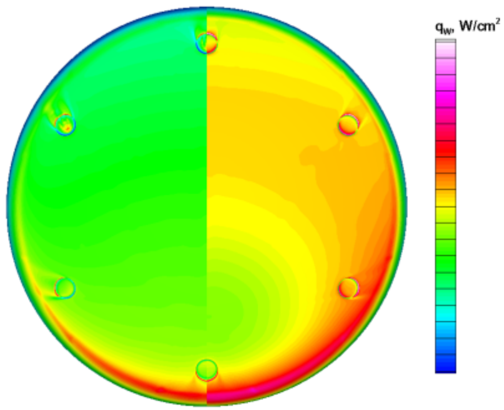
Crew Module Backshell



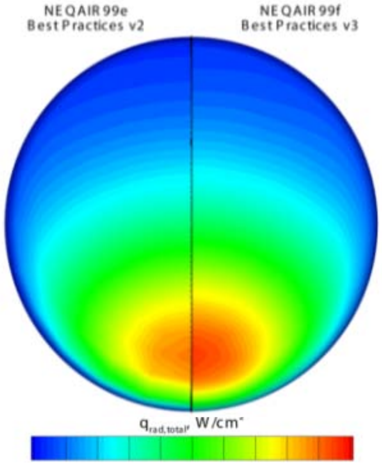
Orion Heating Environments



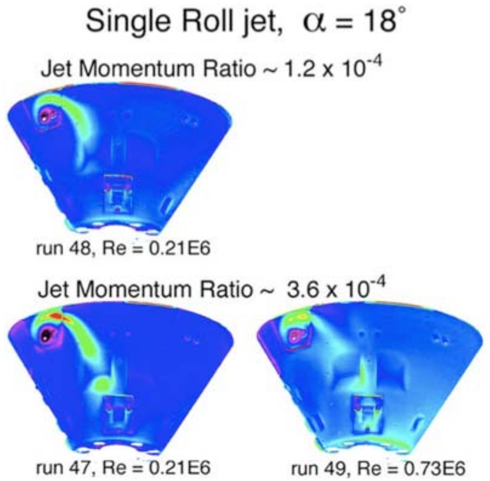
Smooth Body Convective



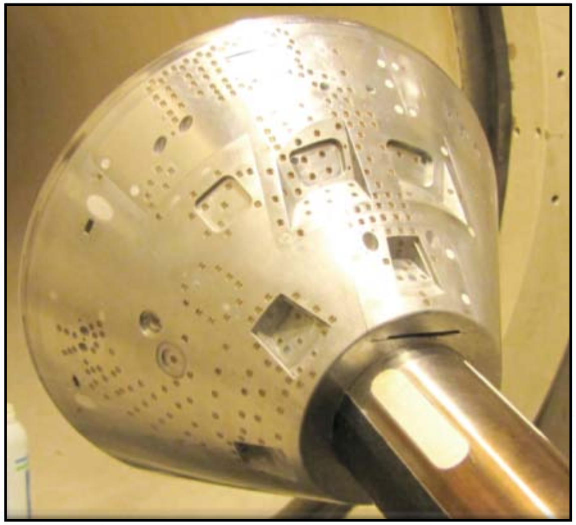
Compression Pad CFD

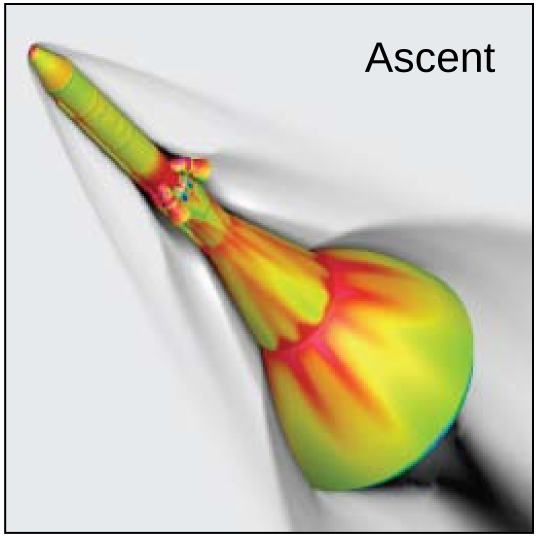


Radiation



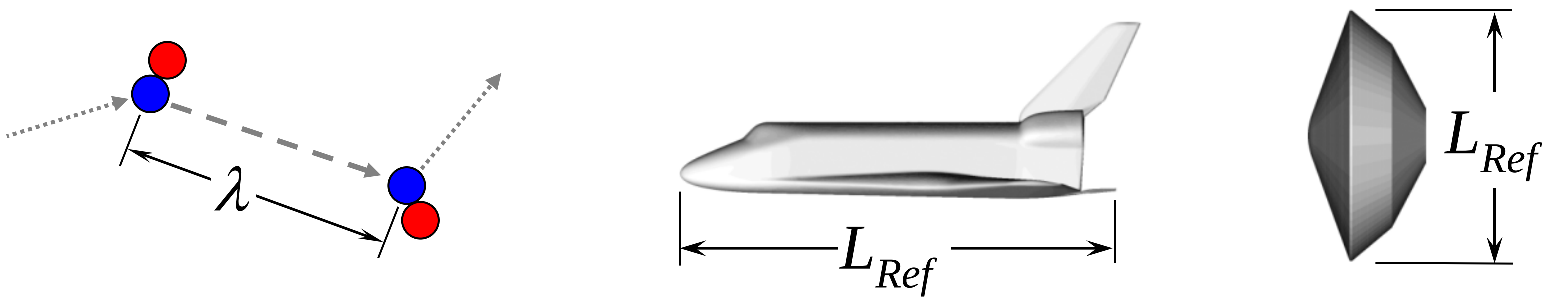
RCS Interaction





Rarefied Gas Dynamics

Characterized by Knudsen number: $\mathrm{Kn} \equiv \dfrac{\lambda}{L_{Ref}}$



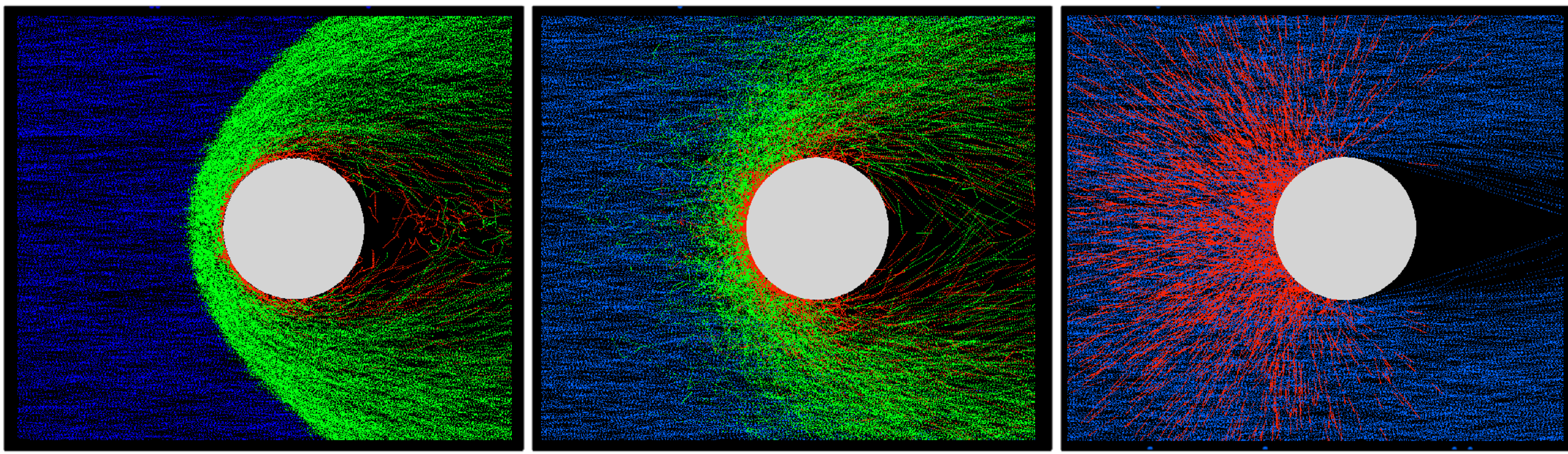
Continuum Flow | Transitional Flow | Free Molecular Flow

~ 0.01 | ~ 100 | Kn

RGD Flow Regimes

Computed Using NASA's Direct Simulation Monte Carlo (DSMC) Analysis Code (DAC) Software

Near Continuum | Transitional | Free Molecular

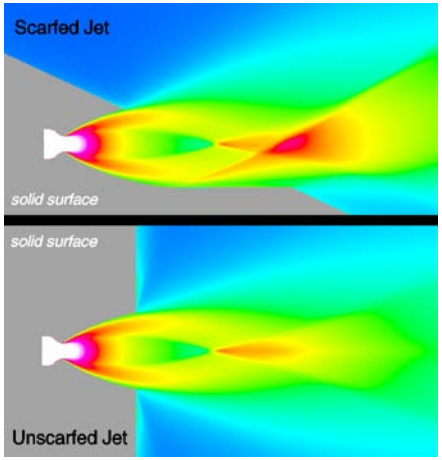


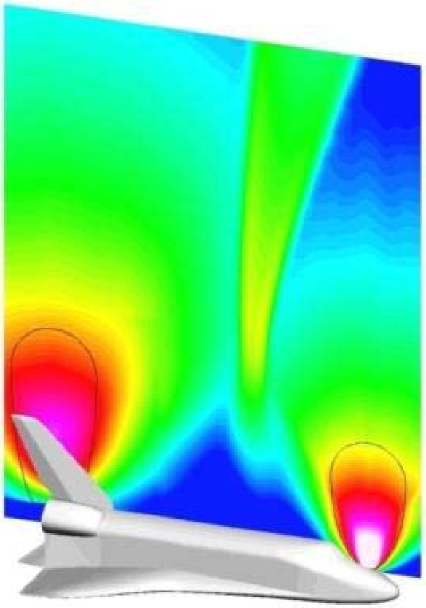
Undisturbed freestream molecules

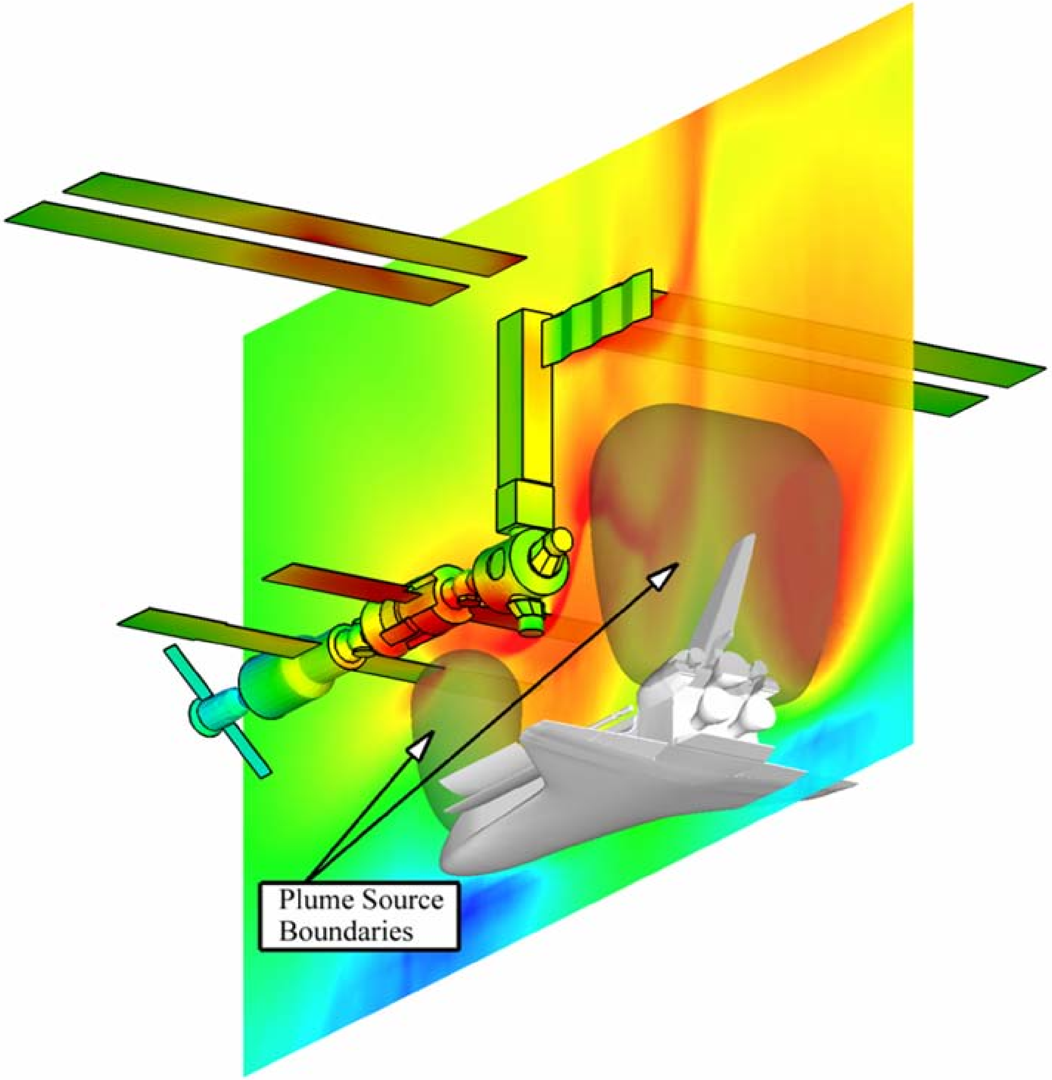
Molecules that have collided with the surface

Molecules that have been indirectly influenced by the surface

Rendezvous and Docking Plume Impingement

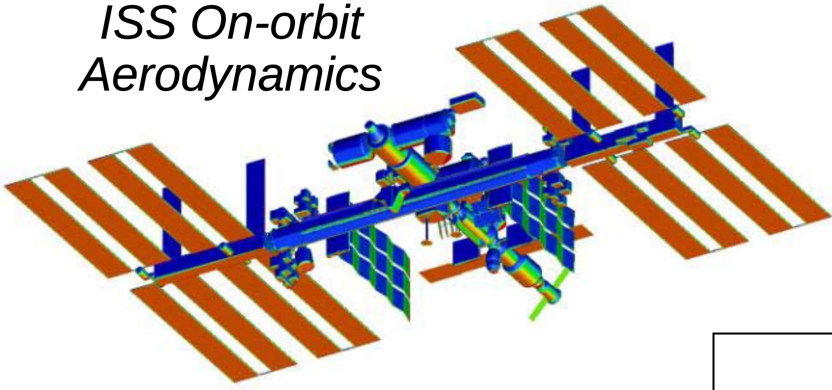




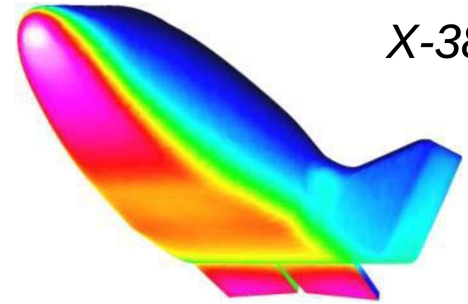


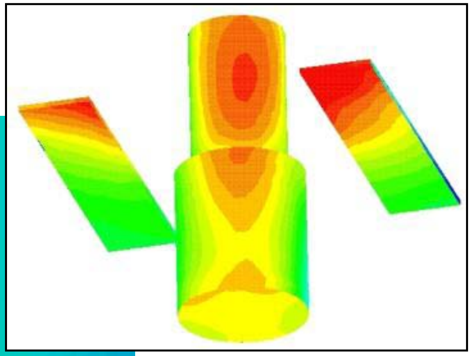
Additional DSMC Applications

ISS On-orbit Aerodynamics

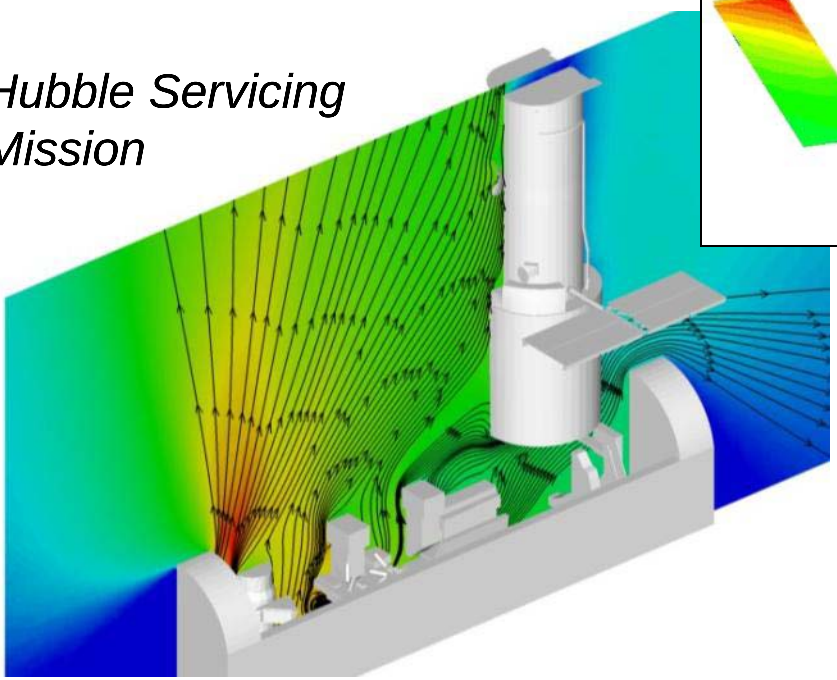


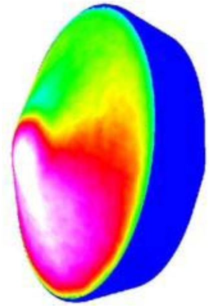
X-38





Hubble Servicing Mission



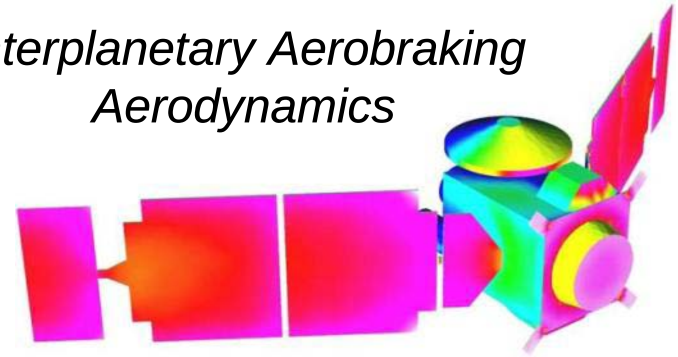


Genesis

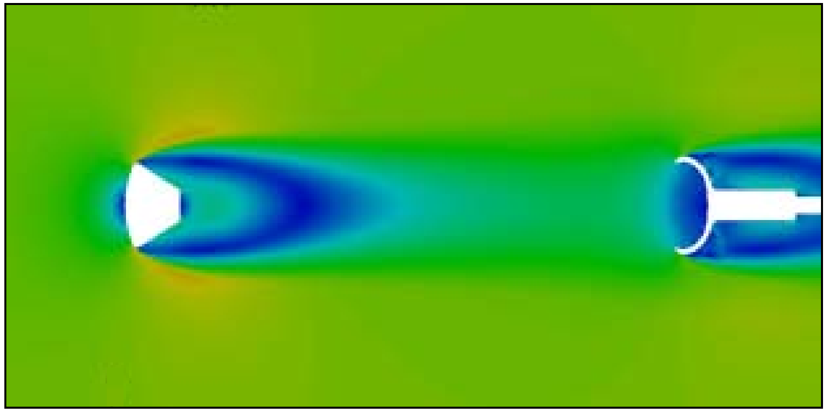
Stardust

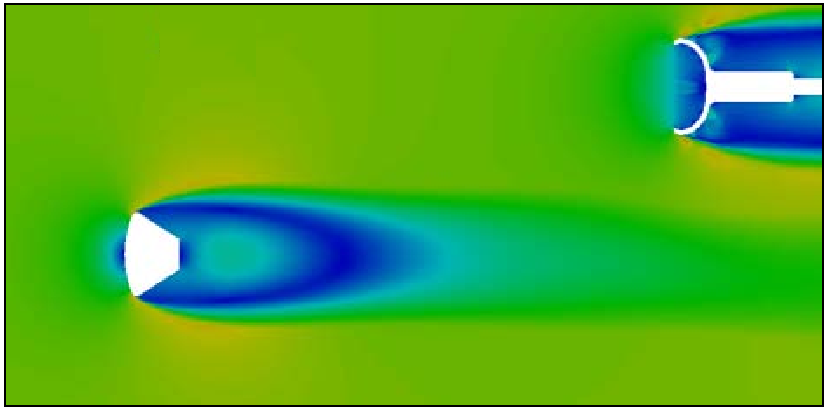
Mars - Pathfinder

Interplanetary Aerobraking Aerodynamics



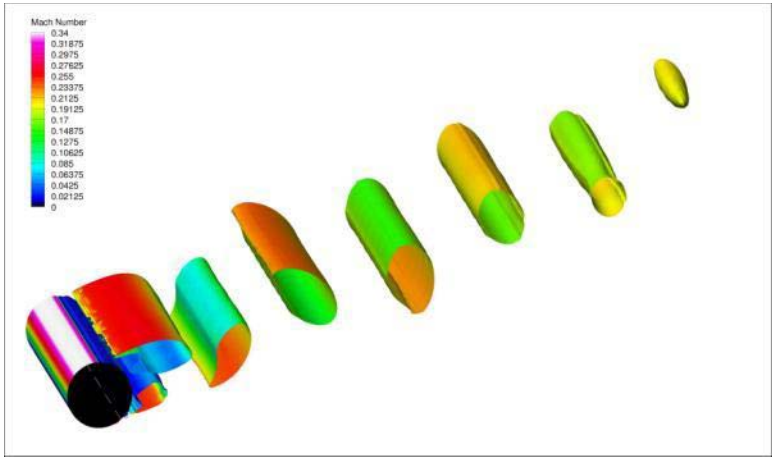
Orion Parachute System Development

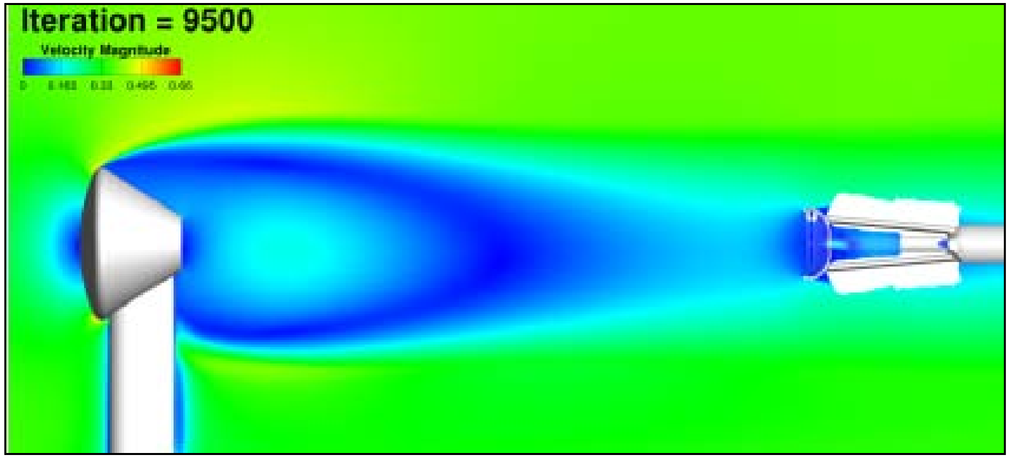


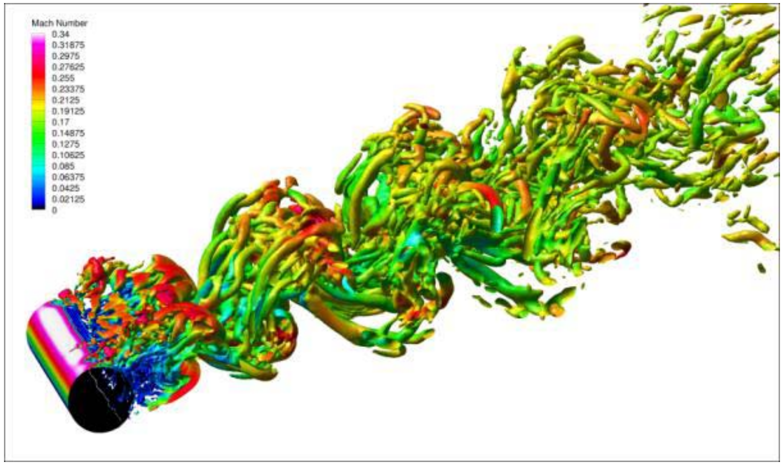


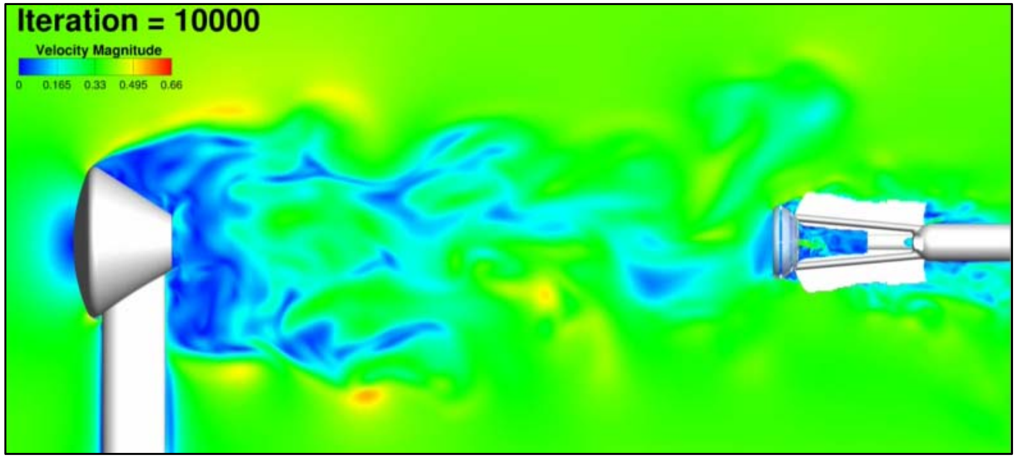
Capsule Wake Modeling

Reynolds Averaged Navier Stokes







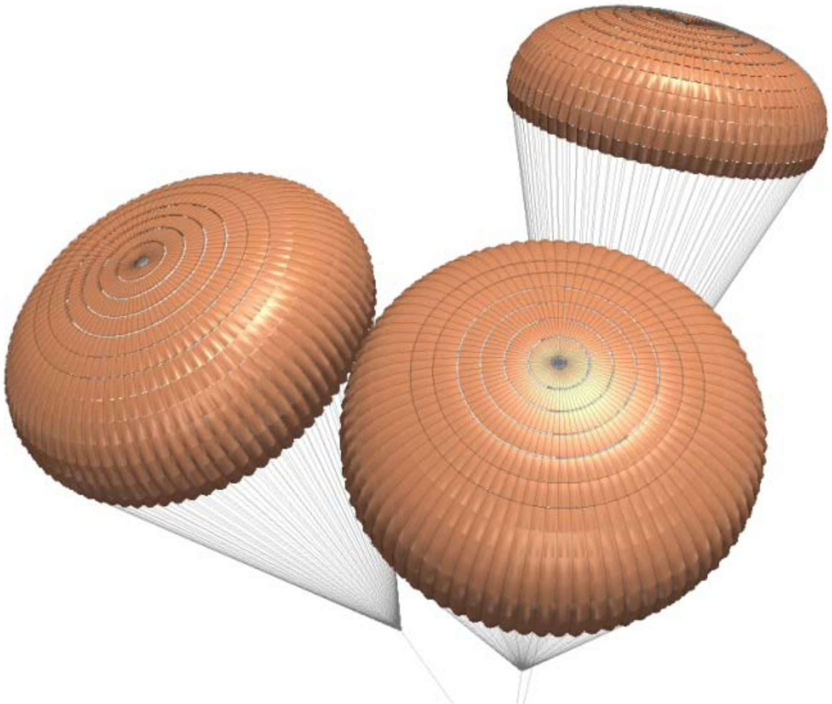


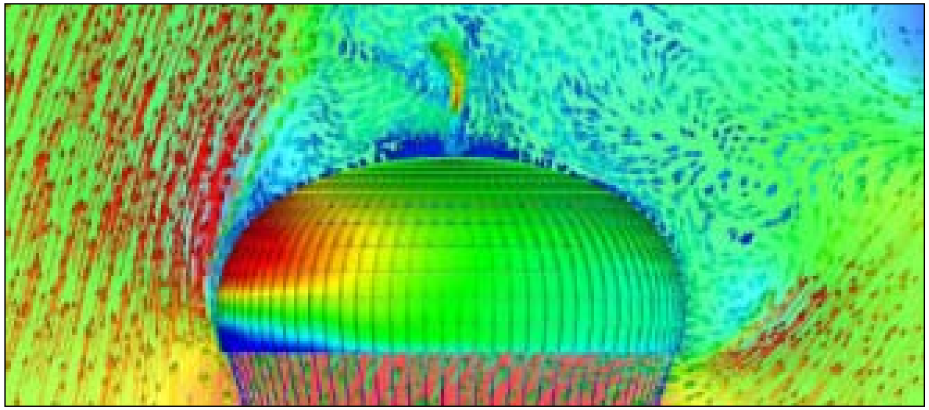
Detached Eddy Simulation

Fluid Structure Interaction (FSI)

Professor Tayfun Tezduyar

Professor Kenji Takizawa





NASA's Top Aerosciences Challenges

Aerodynamic Predictions

- Aero-plume interactions
- Massively separated flow behind bluff bodies
- Strong shockwave boundary layer interactions
- Aeroacoustic and buffet environments
- Fluid-structure interactions

Aerothermodynamic Predictions

- Boundary layer transition
- Protuberance and cavity heating
- Ablative thermal protection system performance
- Shock layer radiative heating

Uncertainty quantification and validation remain generic foundational challenges!

Trends in Computational Aerosciences

Forcing Function

- Transition from steady to unsteady simulations
- Increased parametric analysis
- More complex geometries
- Increase computational capacity

Anticipated Response

- Time accurate, low dissipation, higher order methods
- Higher order turbulence modeling
- Automated surface and volume grid generation
- Adjoint methods for parameter sensitivity and solution adaptation
- Coupled multi-physics simulations

Shift in Modeling Maturation

Develop → Validate → Apply

Pros:

- Logical
- Systematic
- Ensures end-users have a product that is ready for release

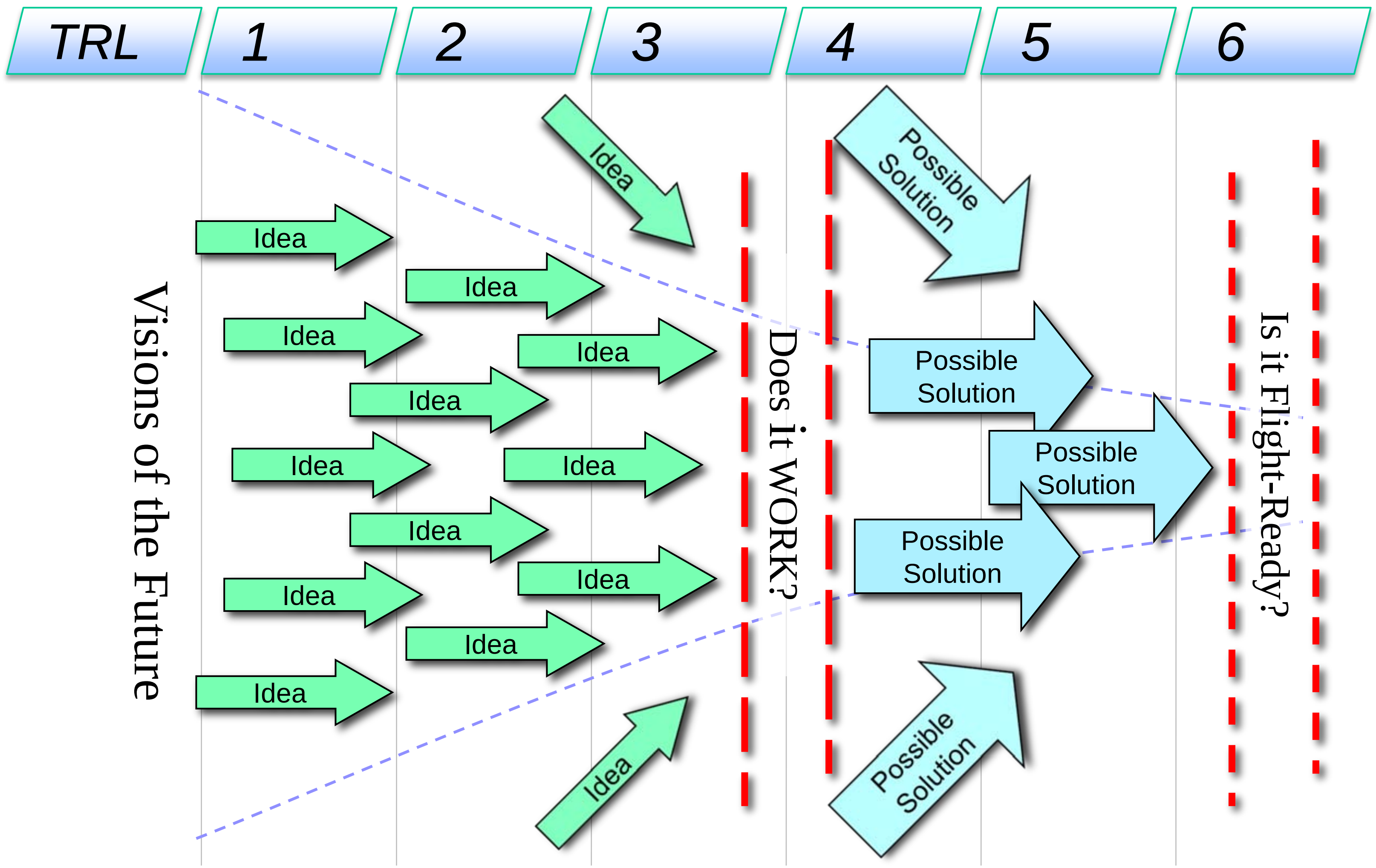
Cons:

- Developers can be separated from users
- Always a struggle to advocate for resources to proceed in this mode

Develop → Apply → Validate

- NASA has seen explosive growth in the application of CFD
- Extremely difficult to be fully validated for every application
- Insufficient validation leads to large data uncertainties and design margins
- Acquiring test data to validate analysis becomes a project priority
- Roadmaps for future modeling and simulation development become more clear

Innovation and Inclusion



TRL – Technology Readiness Level

We Must Not Ever Forget…

Space Shuttle Challenger Crew

Lost January 28, 1986

Space Shuttle Columbia Crew

Lost February 1, 2003

Thank you.