National Aeronautics and
Space Administration

Lyndon B. Johnson Space Center

Applied Aeroscience and CFD Branch Overview

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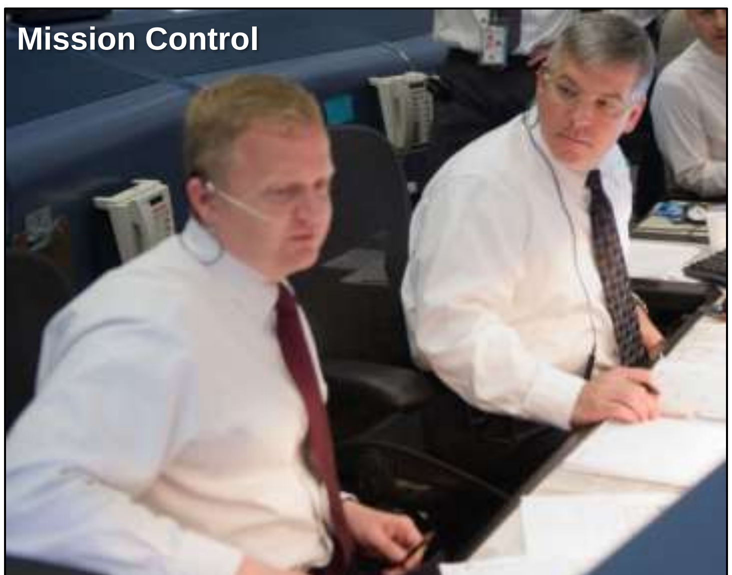
Lyndon B. Johnson Space Center
Principal Mission: Human Spaceflight


International Space Station


MPCV Orion


Commercial Crew


Mission Control


Astronauts

The Future of Human Space Exploration

NASA's Building Blocks to Mars

U.S. companies provide affordable access to low Earth orbit

Learning the fundamentals aboard the International Space Station

Expanding capabilities by visiting an asteroid in a Lunar distant retrograde orbit

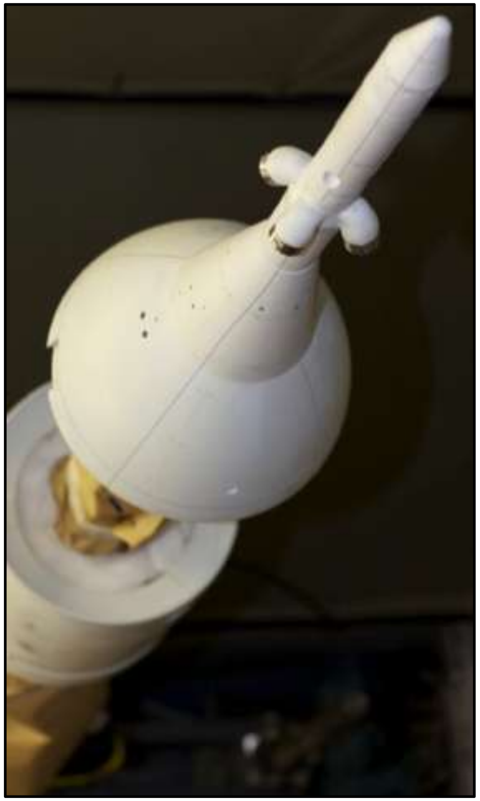
Traveling beyond low Earth orbit with the Space Launch System rocket and Orion crew capsule

Exploring Mars and other deep space destinations

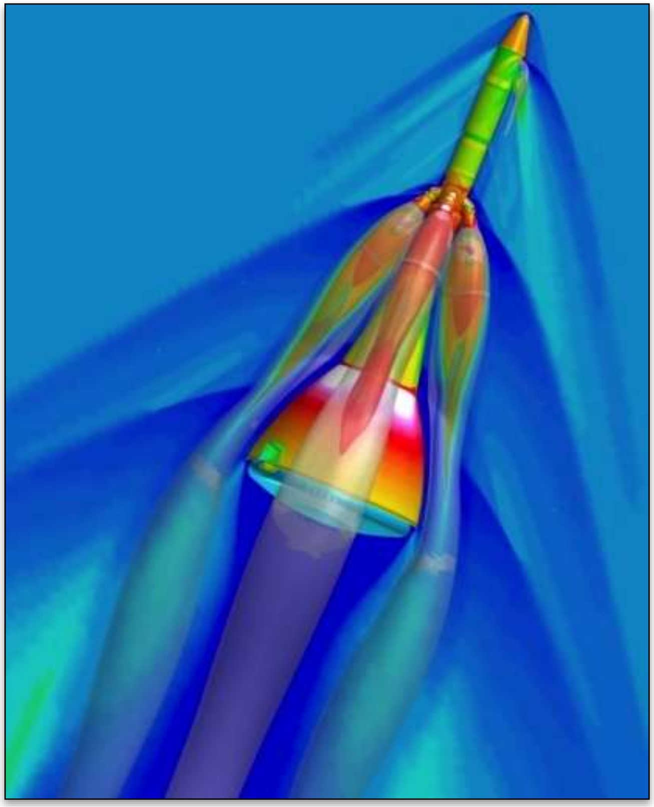
Earth Reliant	Proving Ground	Earth Independent
Missions: 6 to 12 months *Return: hours*	*Missions: 1 month up to 12 months* *Return: days*	*Missions: 2 to 3 years* *Return: months*

Aeroscience Technical Competencies

(1) Aerodynamic Characterization **(2) Aerothermodynamic Heating**
(3) Rarefied Gas Dynamics **(4) Decelerator (Parachute) Systems**



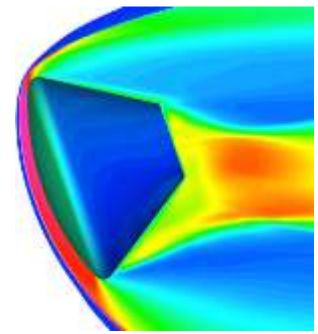
Ground Testing



Modeling and Simulation

Flight Testing

Principal JSC Initiatives & Aeroscience Support



1. Operate the International Space Station
- Aerodynamic & aerothermodynamic response for rarefied flows
- Plume modeling for visiting vehicles
- ISS end-of-life disposal

2. Develop the Multipurpose Crew Vehicle *Orion*
- Develop aerodynamic & aeroheating databases
- Support development of the parachute recovery system

3. Enable Commercial Access to Space
- Develop system requirements and assess design compliance
- Perform IV&V of partner aerosciences products
- Support reimbursable activities to commercial partners

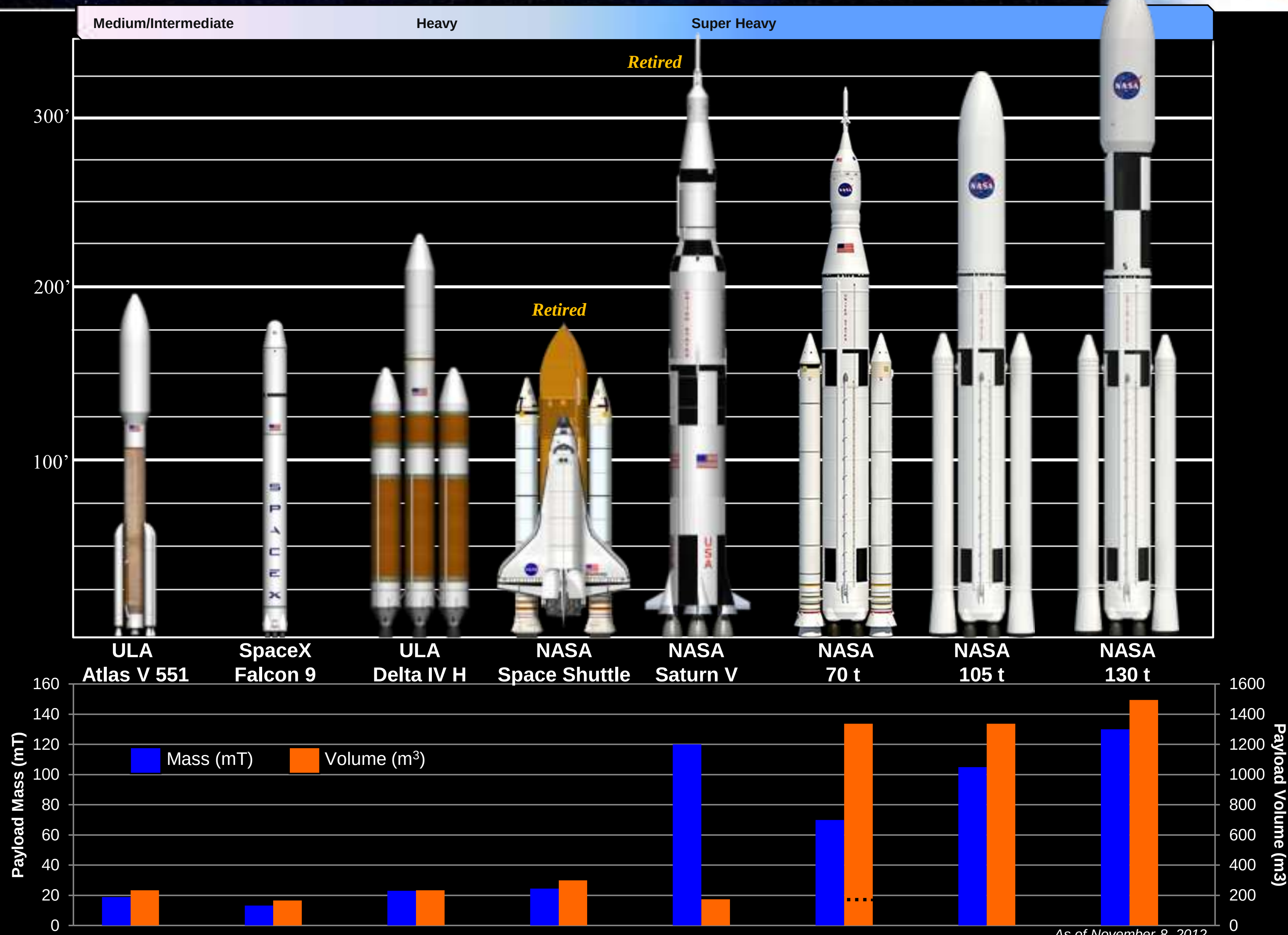
International Space Station Operations

Commercial Crew Program

NASA's Exploration Architecture

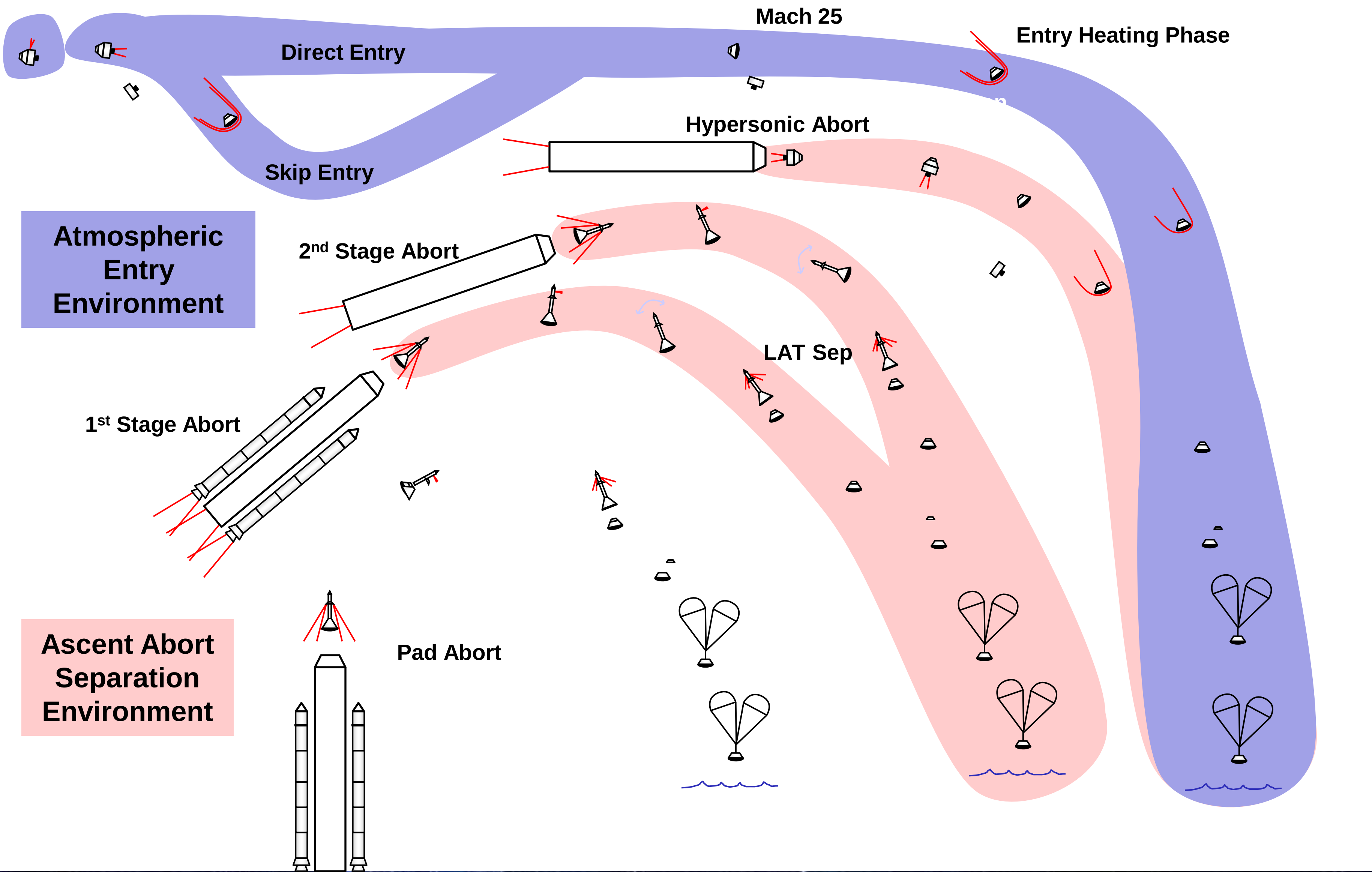
ORION | SPACE LAUNCH SYSTEM

Capability Comparison

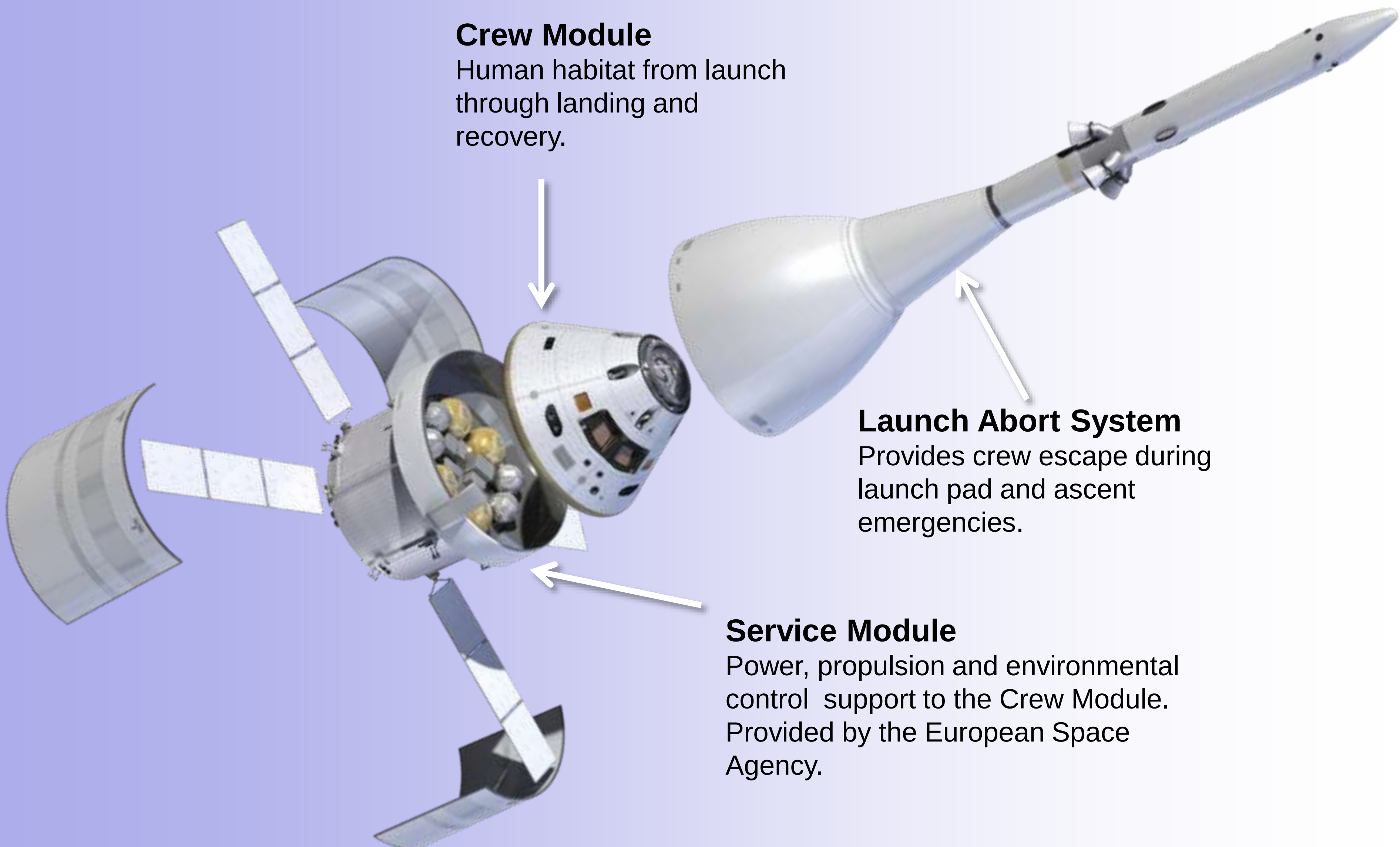


As of November 8, 2012

Orion Aerosciences
JSC Responsible Flight Regimes



The Orion Spacecraft



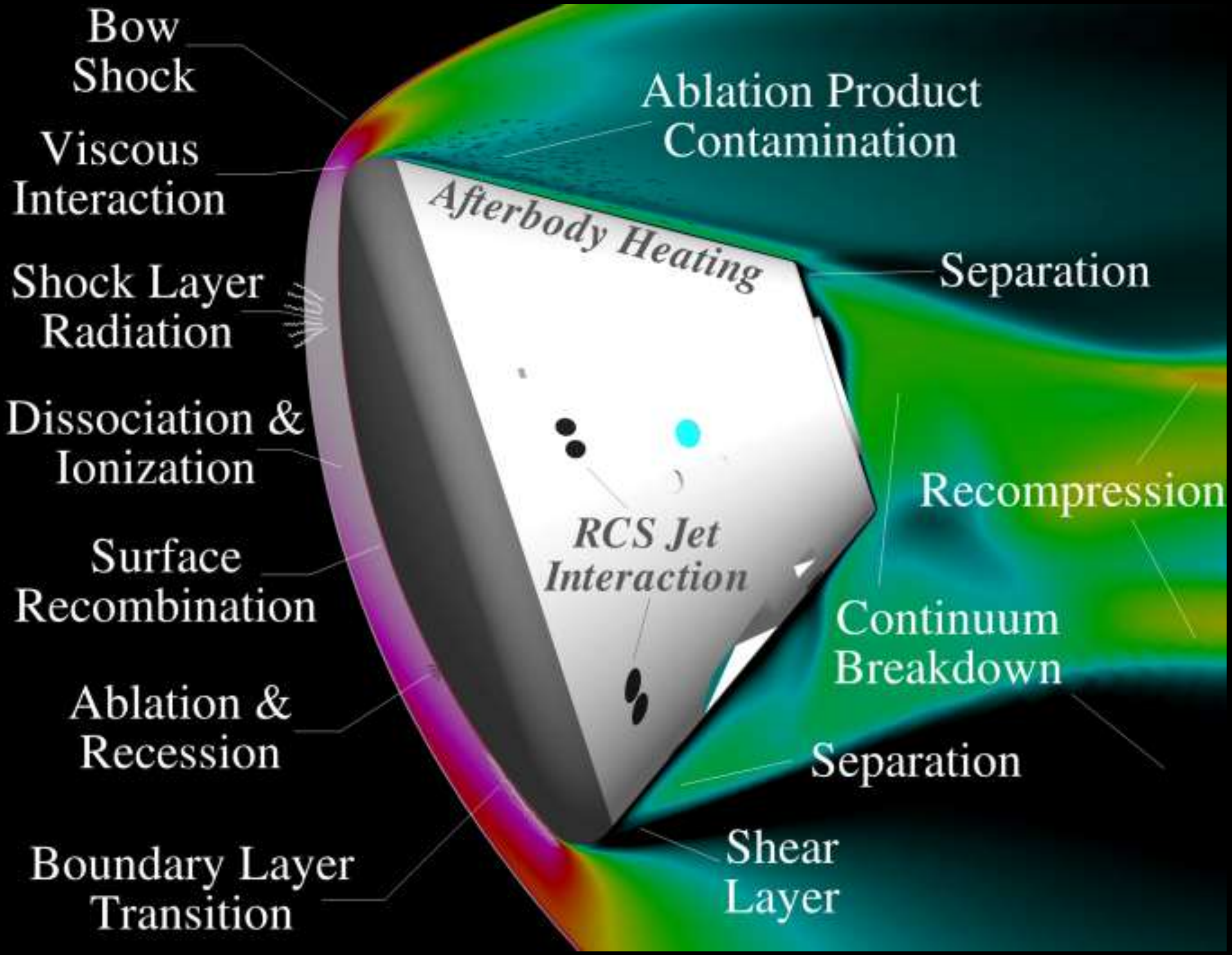
Crew Module
Human habitat from launch through landing and recovery.

Launch Abort System
Provides crew escape during launch pad and ascent emergencies.

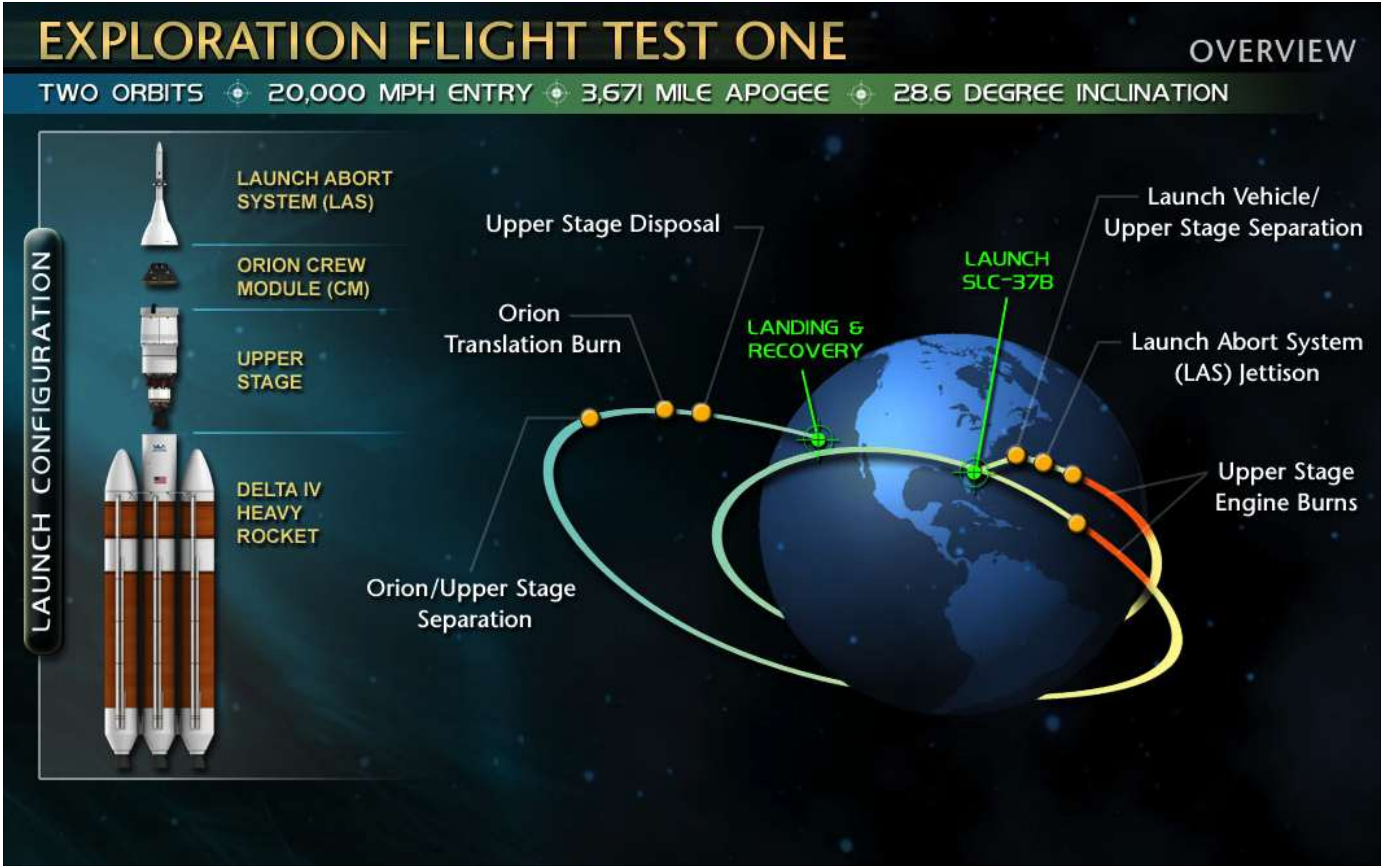
Service Module
Power, propulsion and environmental control support to the Crew Module. Provided by the European Space Agency.

Orion Pad Abort Test

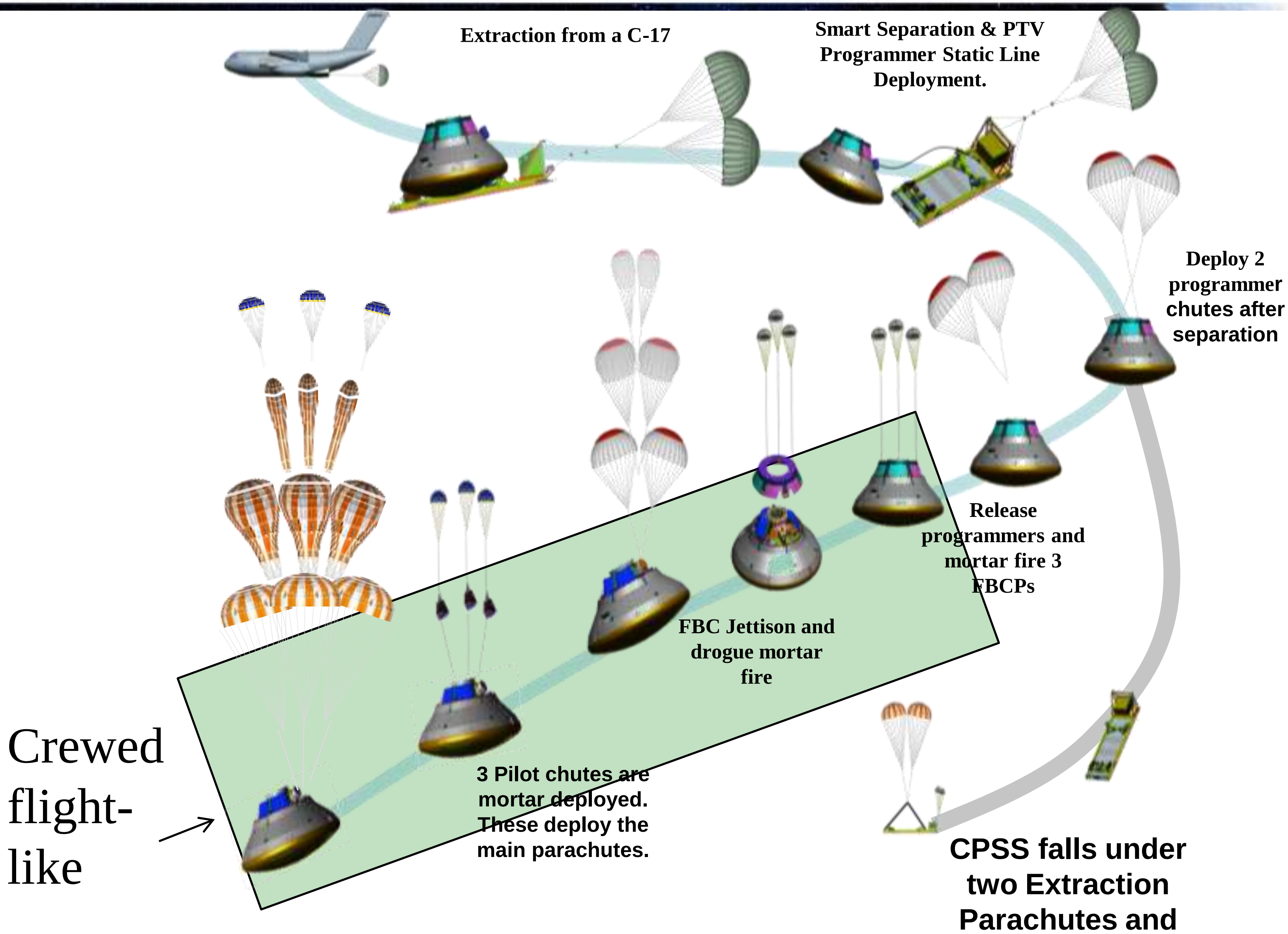
Entry Aerothermodynamic Modeling



Orion Exploration Flight Test 1
Upcoming December 2014



Parachute Recovery System Development



Technical Competencies

Aerodynamics

Aerothermodynamics

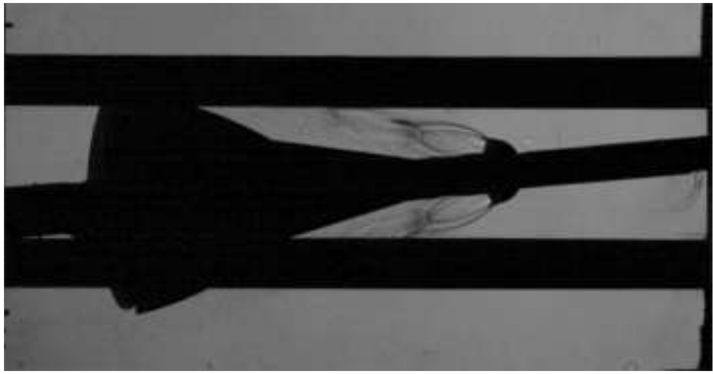
Rarefied Gas Dynamics

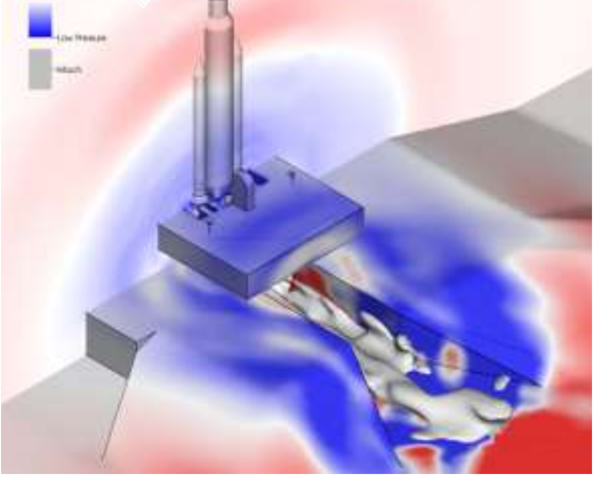
Decelerator Systems

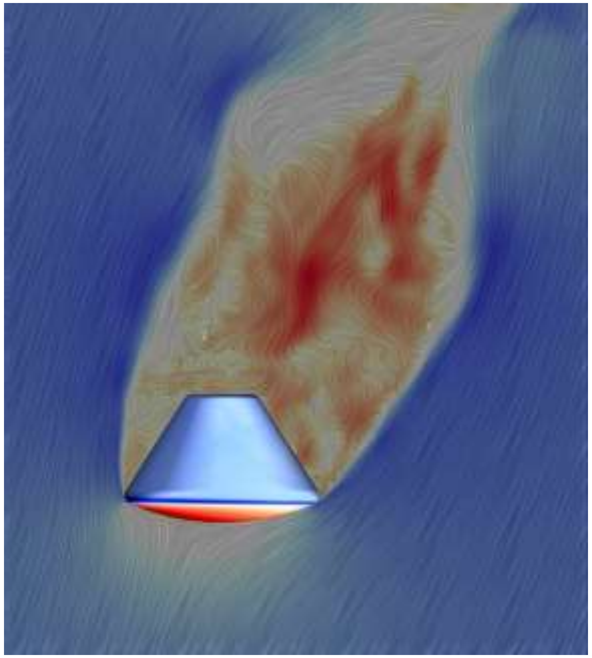
Aerodynamics Discipline Overview

- Provide comprehensive aerodynamic induced environments from ascent through entry and landing to **Trajectory** and **Structural analysts**.
- Products include
  - Ascent, entry and **abort** aerodynamics, external pressure distributions, protuberance air loads, **stability derivatives**, **acoustics/overpressure**, venting, **plume effects**, prelaunch wind effects and **wake environments** for parachute analysis.
- Tools
  - Computational Fluid Dynamics codes
  - Wind tunnels from subsonic through hypersonic regimes.
  - Flight tests

Aerodynamics Discipline Overview

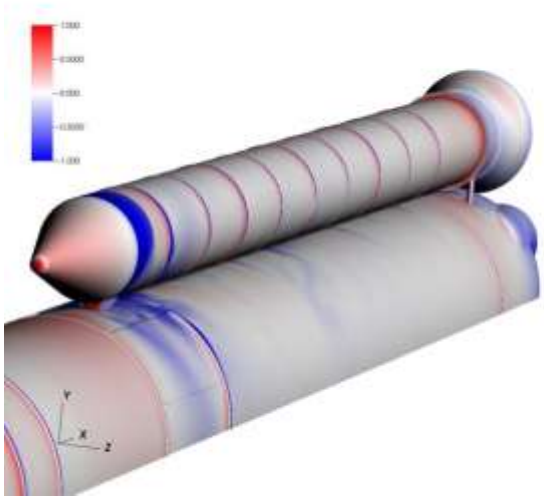




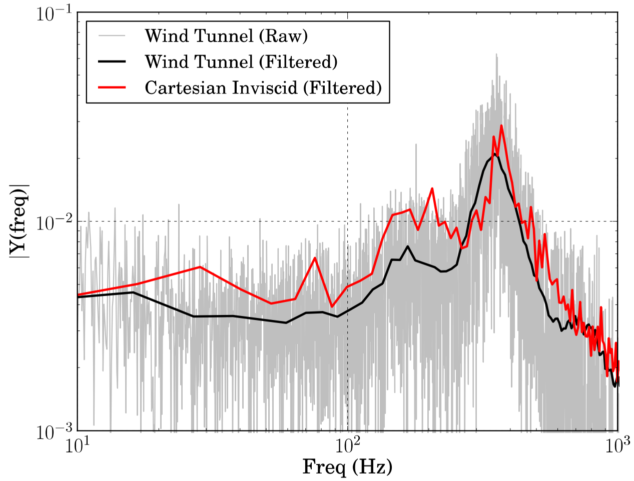


Aerodynamics Challenge: Launch Acoustics

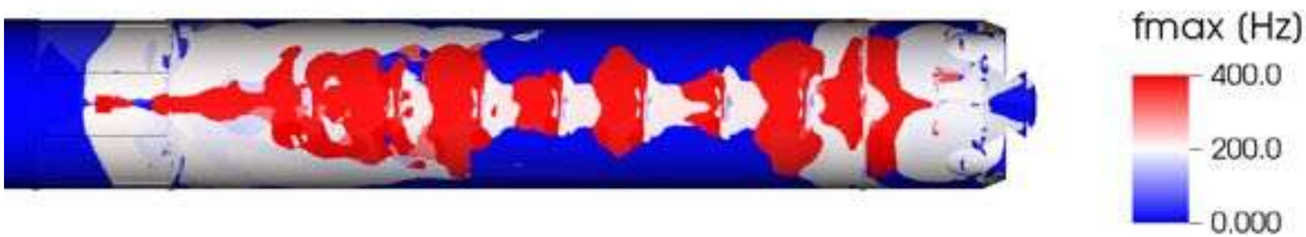
- Accurate, efficient prediction of unsteady transonic environments
  CFD requires small time steps to accurately capture physics.
  Wind tunnel testing requires ≈ 5 seconds of physical time to achieve statistical convergence.



(a)



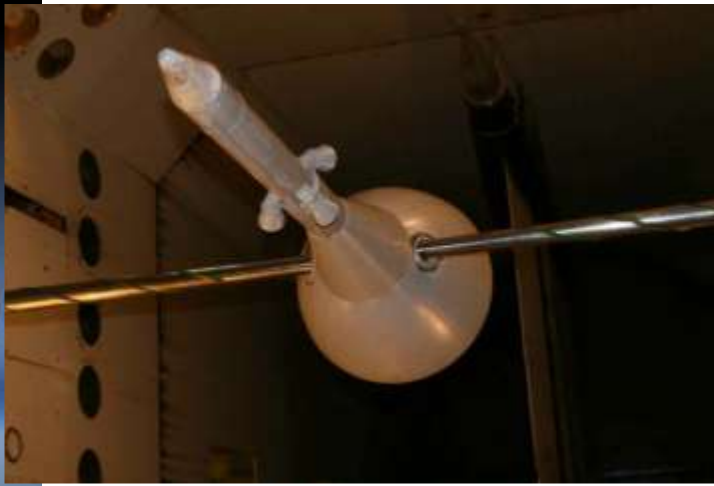
(b)



AIAA 2011-3504

Aerodynamics Challenge: Dynamic Stability

- Prediction of dynamic stability characteristics using CFD on a bluff body with jets in cross flow.



AIAA 2011-3504

Aerothermodynamics Discipline Overview

- Goal is to provide **heating environments to all external spacecraft components for all flight regimes**
  - Components: acreage, steps/gaps, seals, penetrations, protuberances, reaction control systems
  - Flight regimes: ascent, exo-atmospheric, entry

- Current customers include Orion, Commercial Crew, and technology development projects
  - Orion: Leads agency wide team that develops aerothermodynamic environment database, provides technical authority oversight, provides mission support (historically provided mission support and damage assessment for Orbiter)
  - Commercial Crew: Supports all commercial partners with both inline product development and technical authority oversight
  - Technology development: Leads development of high fidelity computational fluid dynamics (CFD) and ablator and thermal analysis (ATA) tools
  - Discipline level customers include thermal protection and guidance, navigation, and control communities: trajectory-based heating indicators, arcjet characterization and flight traceability assessment, coupled aerothermal-TPS simulations

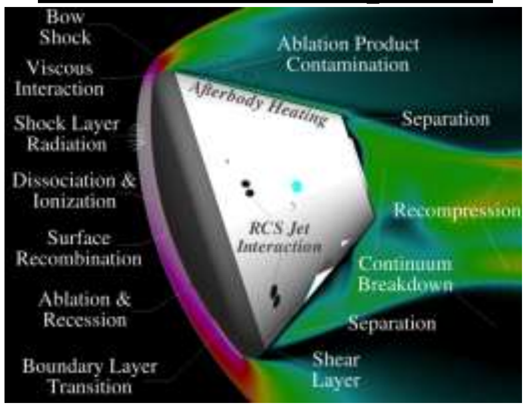
- Product development utilizes multi-faceted approach including ground and flight testing, computational methods, historical data, and engineering-level analysis
  - Ground testing: Experience testing in every high quality aerothermal facility in nation. Orion work has included ~30 ground tests in over 10 facilities
  - Flight testing: Orion PA-1 and EFT-1, Orbiter flight tests for boundary layer transition, catalysis, and protuberance heating
  - Computational methods: CFD is the workhorse for acreage heating database development (DPLR, Loci-CHEM, OVERFLOW, US3D, FIN-S, DAC). ATA is primarily used for wind tunnel and flight environment reconstruction (CHAR). Boundary layer transition (STABL)

- Emphasis is placed on overcoming technical challenges to improve product quality
  - Environments on geometrically complex components: ascent vehicles, cavities and protuberances, steps/gaps
  - Jet interaction environments: launch abort systems, RCS
  - Boundary layer transition: physics based and empirical methods
  - Fluid-surface interactions: ablation, shape change, catalysis

Aerothermodynamics Discipline Overview

Database Development

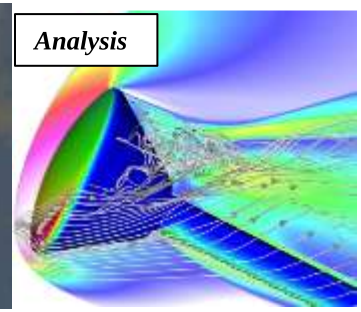
Technical Challenges:



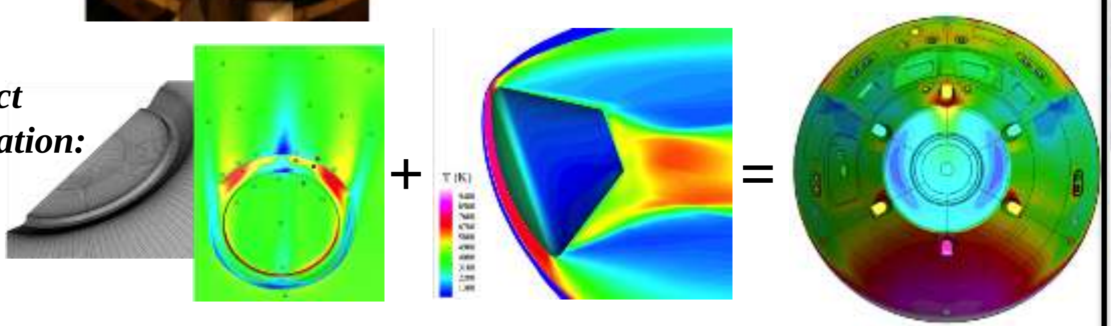
Inputs:

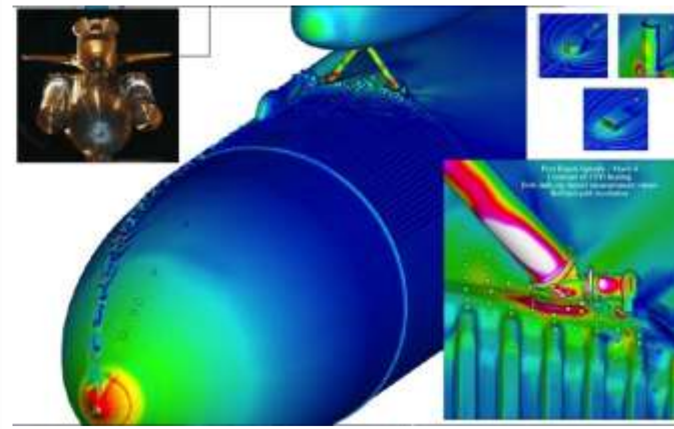

Ground Testing


Flight Testing


Analysis

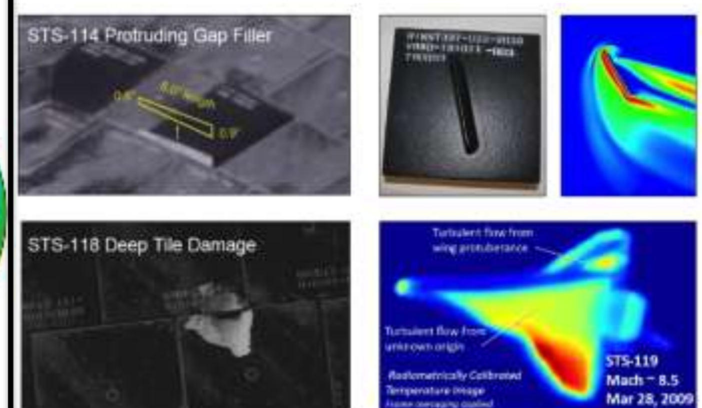
Product Integration:





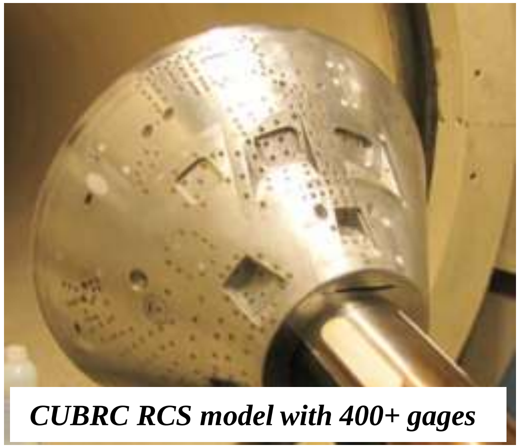
Ascent Environment Testing and CFD

Mission Support, Damage Assessment, and Flight Testing

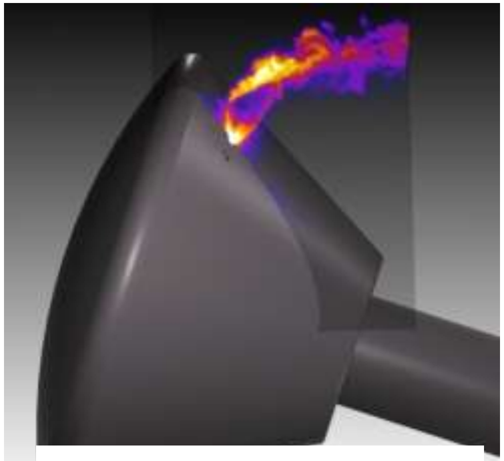


Aerothermodynamics Challenge: Orion RCS Jet Interaction Heating

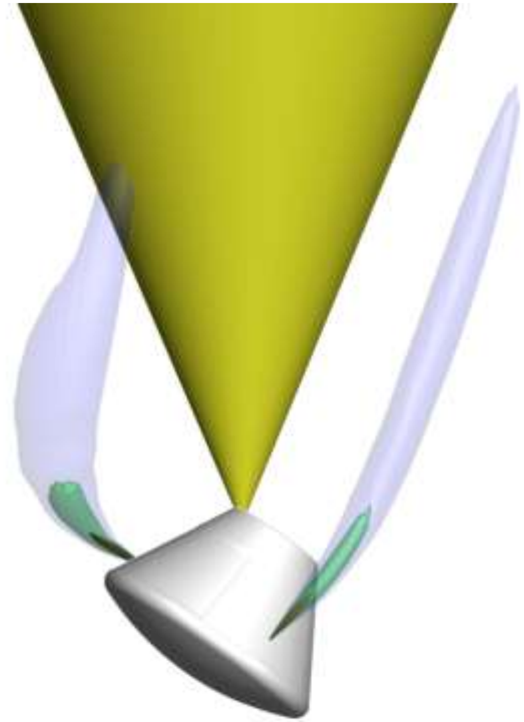
Predicting heating induced from 12 RCS jets on Orion Crew Module is a primary technical challenge due to unsteady flow interactions over a broad range of freestream conditions



CUBRC RCS model with 400+ gages

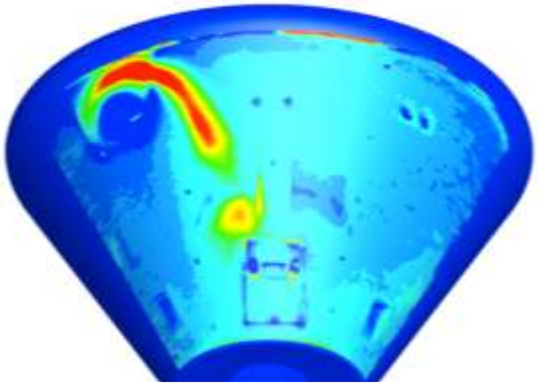


PLIF flow visualization of roll jet

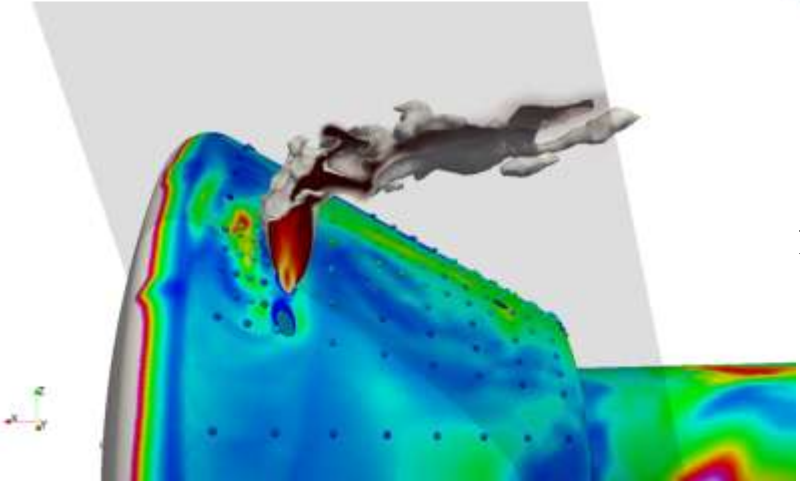


Investigation of RCS jet interaction with parachute riser lines

Orion has conducted 6 tests to develop RCS environments

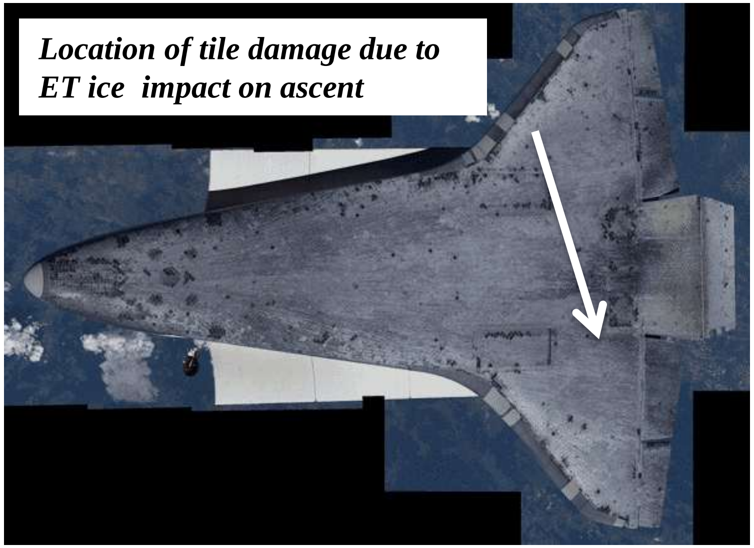


LaRC RCS model with TSP

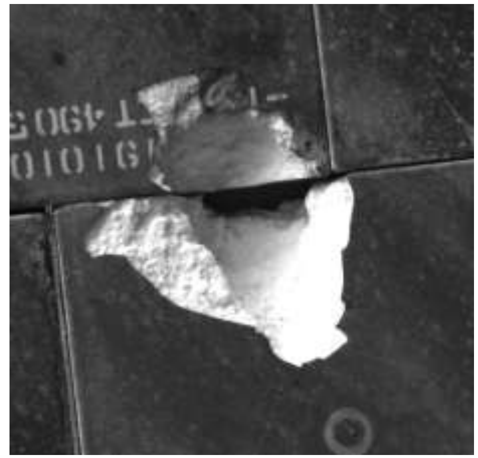


Initially reliant on empirical models alone, Orion team has been developing a validated CFD capability

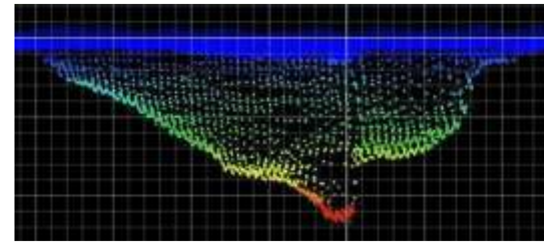
Aerothermodynamics Challenge: STS-118 Deep Tile Damage



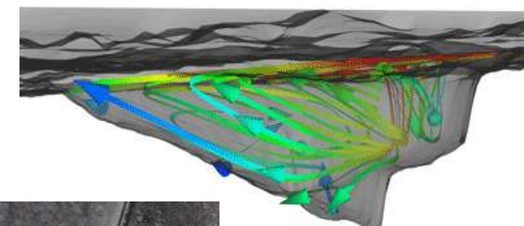
Photograph during focused inspection



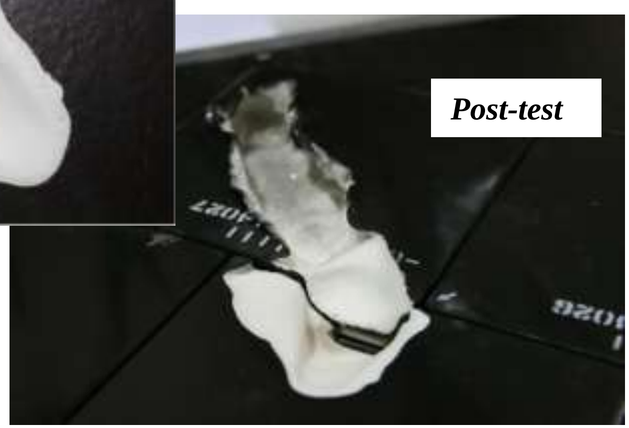
Laser Doppler Range Imaging used to get 3D details of damage geometry



In-mission CFD result



Assessment of ground-to-flight traceability effects indicated that damage would not propagate during re-entry



Arcjet test showed the potential for damage propagation

Post-flight photograph showed no damage propagation.

EG3 supported DAT with arcjet test support, aerothermal assessment of re-entering with damage, and explored environments on potential repair options.

Flight Vehicle Boundary Layer Transition Prediction

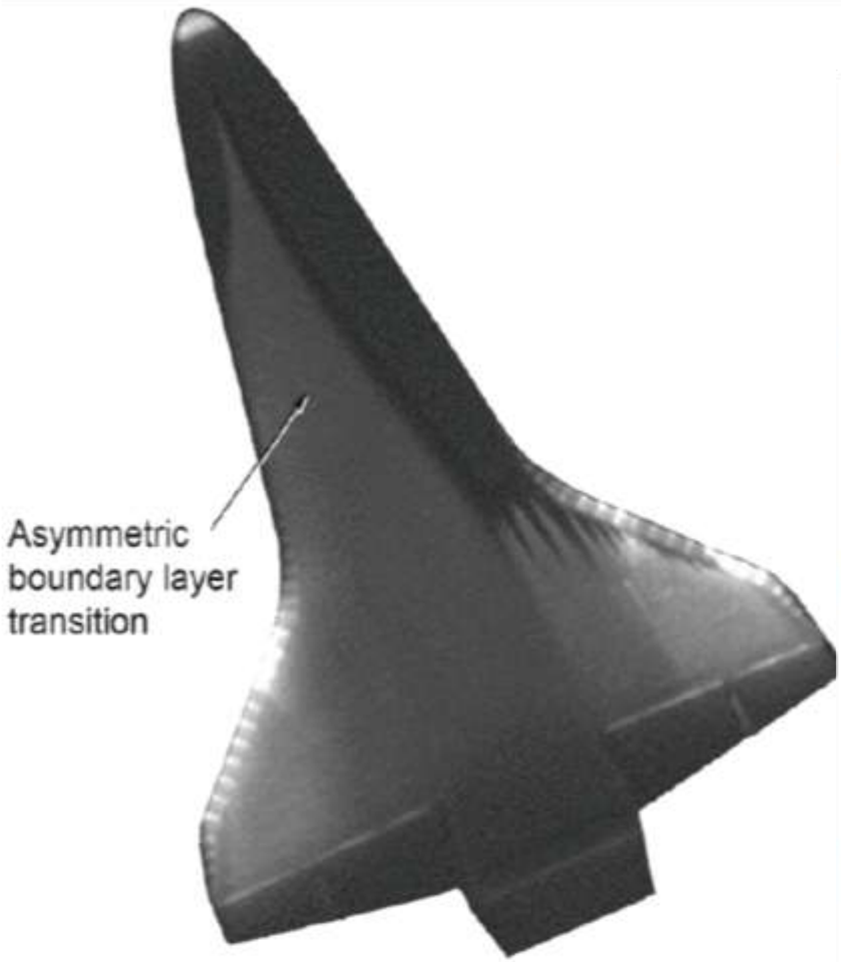


Figure 3: Thermal image of Endeavour during STS-134 re-entry near the point of closest approach, Mach 5.8, AOA = 28.8 deg, Slant Range ~32 nautical miles.

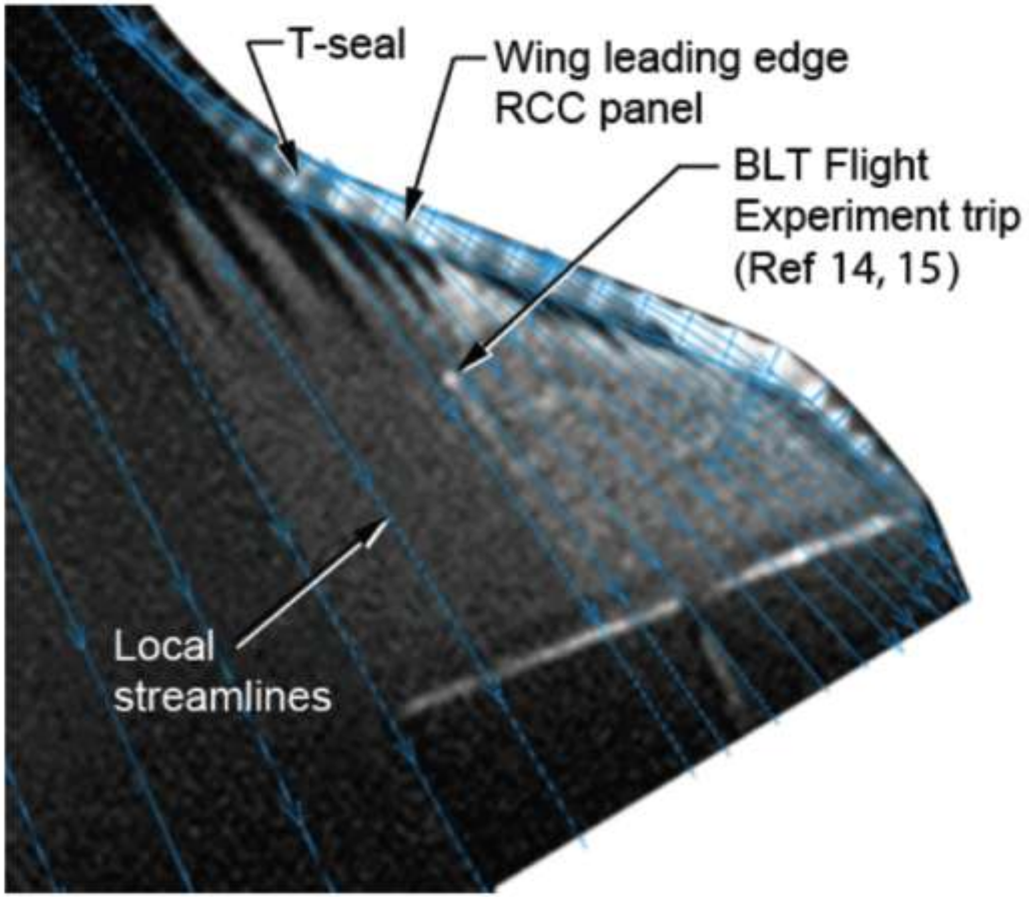
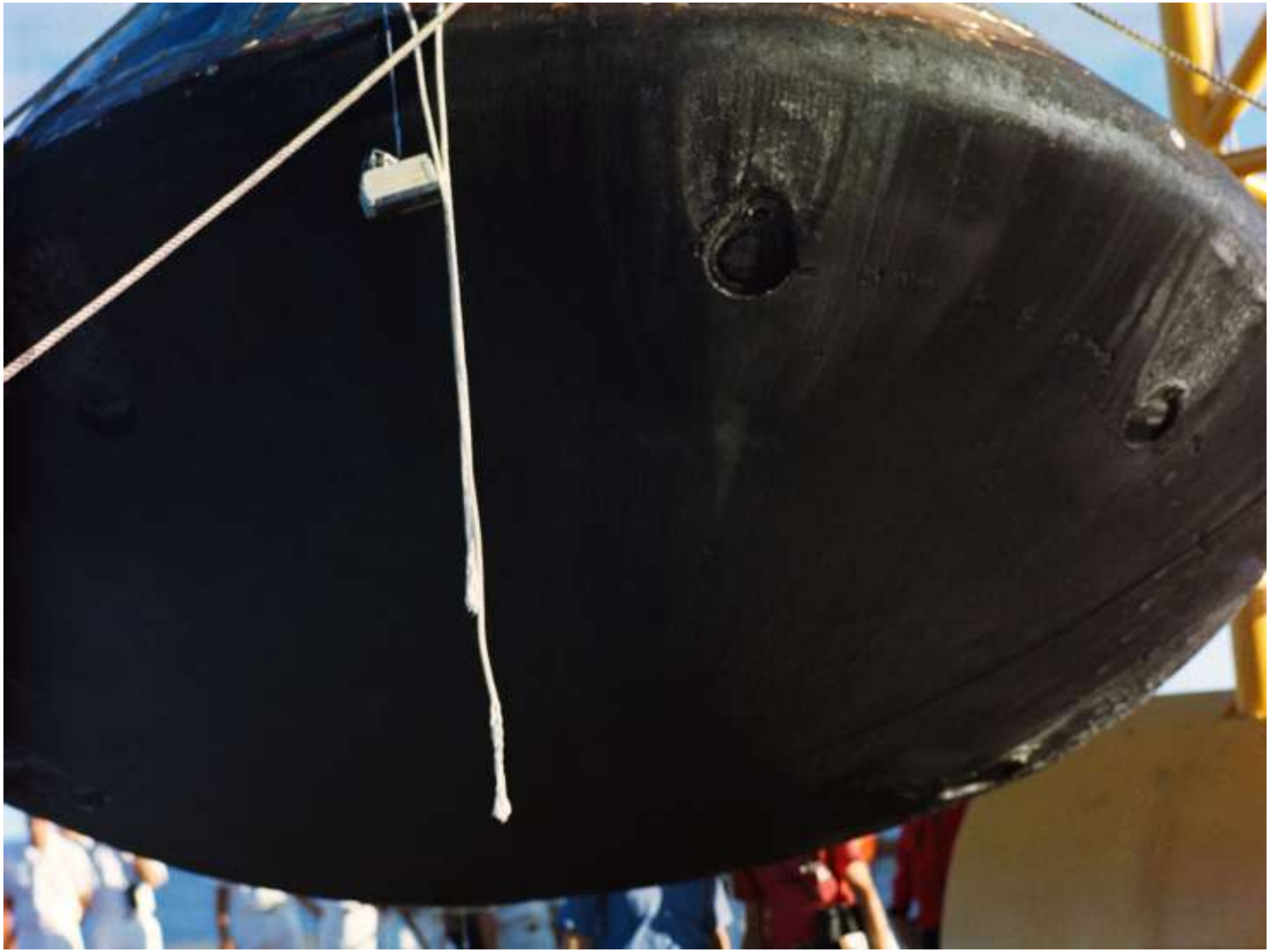


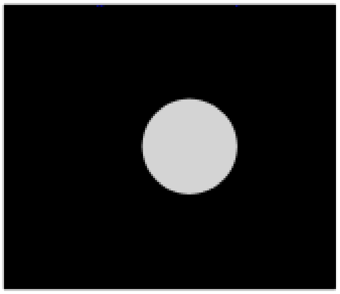
Figure 6: Transition patterns on Port wing. Turbulent wedges appear aligned with RCC panel T-seals. Mach = 5.8, AOA = 28.8 deg.

Flight Vehicle Boundary Layer Transition Prediction

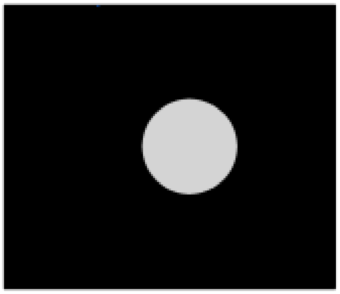


Rarefied Gas Dynamics Discipline Overview

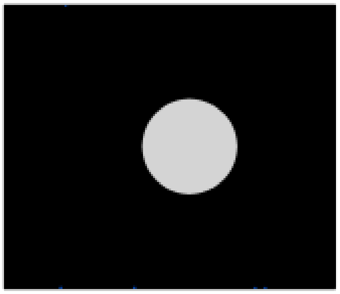
- Objective:
  - Provide state-of-the-art capabilities and tools for analysis of a variety of low density, non-continuum flows (from transitional to free molecular)
- Customers:
  - International Space Station
  - Orion
- Products:
  - **Thruster plume modeling** and plume impingement analyses
  - **Spacecraft aerodynamics and aeroheating** (reentry, aerocapture, aerobraking, orbital decay)
  - Application, development, maintenance of several computational tools (RPM3D and DAC (which is also distributed))
- Methods:
  - Mainly computational modeling
- Tools:
  - DAC (DSMC code)
  - RPM3D (Engineering tool for plume impingement analyses)
  - FREEMO (Free molecular code)
  - Other computational tools (RAMP, BLIMP, DPLR, …)



Continuum

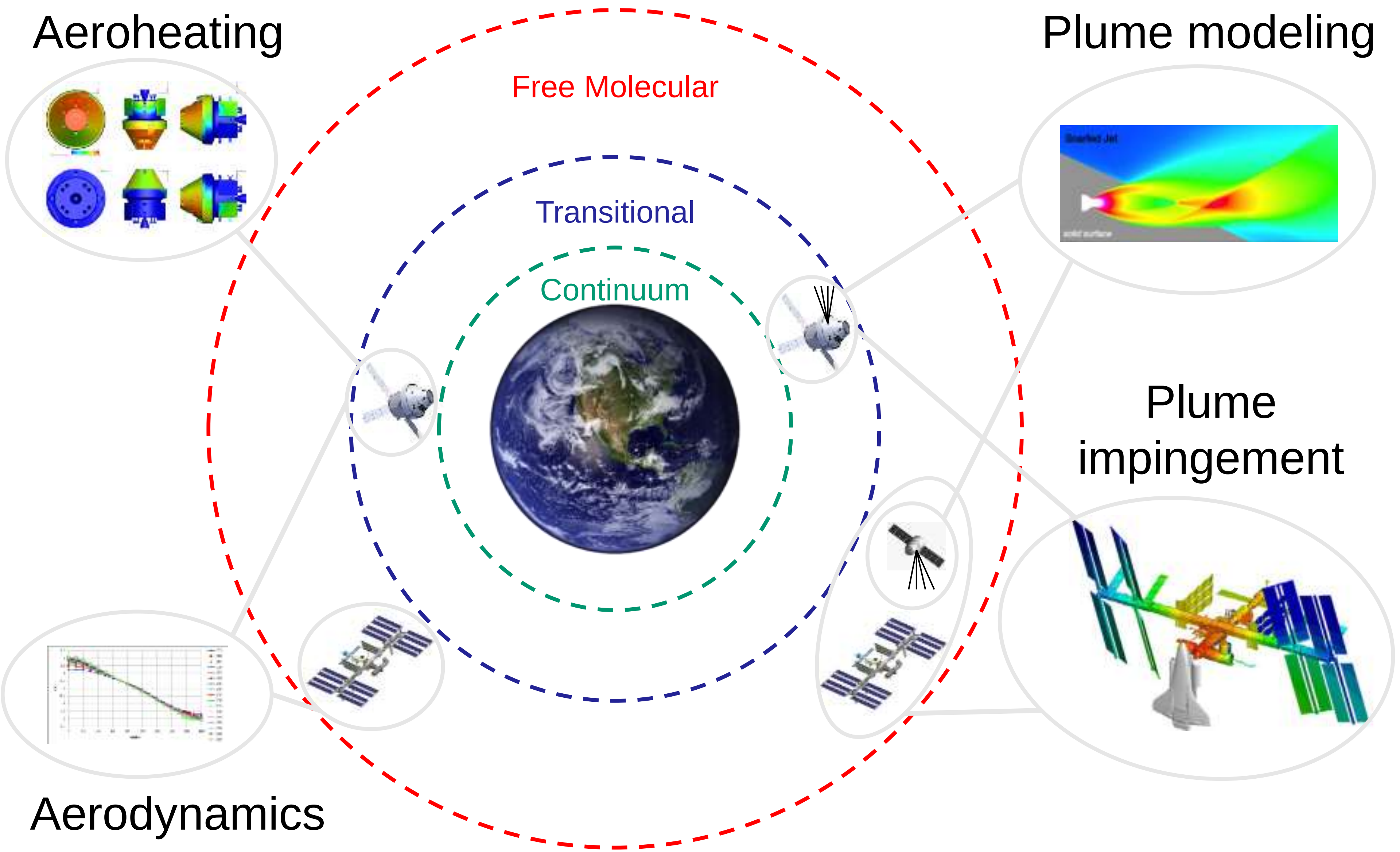


Transitional



Free molecular

Rarefied Gas Dynamics Discipline Overview

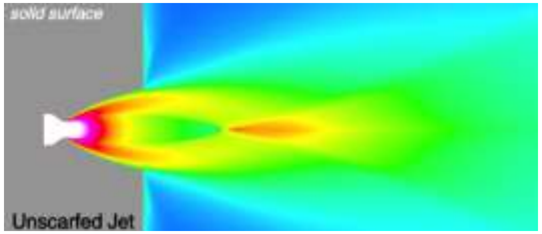


International Space Station Proximity Operations

ISS020E041290

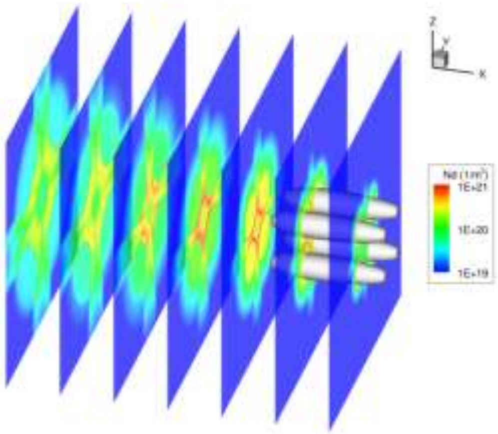
Rarefied Gas Dynamics Challenge: Plume impingement effect analyses

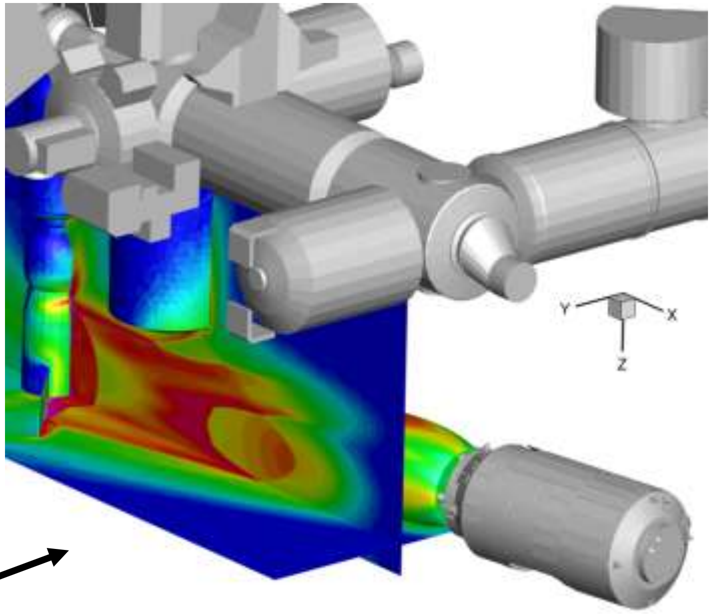
- HTV3 Main engine abort
  - Flow expands from continuum in the nozzle to free molecular in the far field
  - Complex flow fields must be properly modelled at each stage



Step 1:
Near field modeling
(Continuum -> CFD)

Step 2:
Far field modeling
(Transitional -> DSMC)





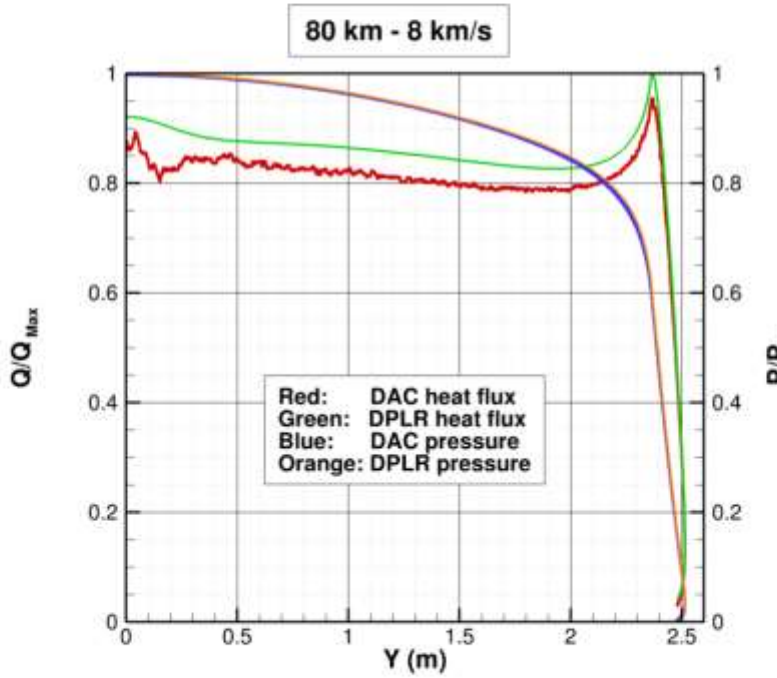
Step 3:
Surface interaction modeling
(Transitional -> DSMC or
Free molecular -> Engineering tool)

Rarefied Gas Dynamics Challenge: Bridging the gap between CFD and DSMC

- The DSMC method can be used to model continuum flows but is generally too expensive to use for real-life problems
- For re-entry databases, a bridging function is used between the highest CFD solution and the lowest DSMC solution ➔ not as accurate a model in that region as everywhere else

Challenges:

- Match gas parameters and chemistry models between codes
- Improve the DSMC code efficiency
- Incorporate advanced models in the CFD code to better model the rarefaction effects



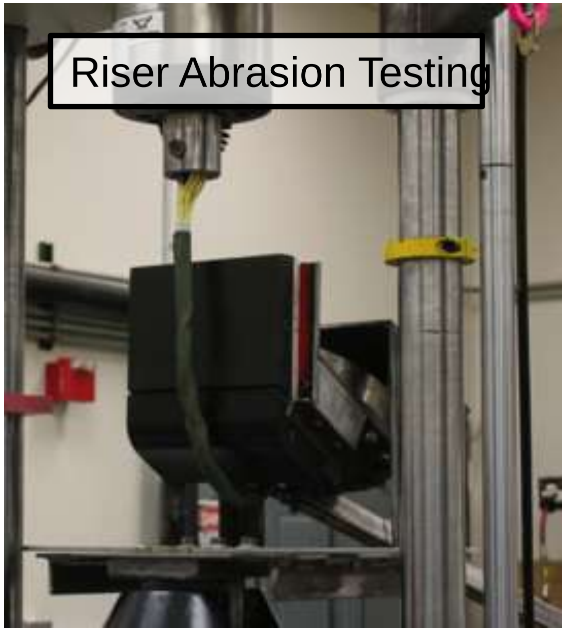
Surface properties on a capsule heat shield at 80 km and at zero angle of attack and sideslip angle with out-of-the-box codes

Decelerator Systems Discipline Overview

- The **Decelerator Systems** Discipline has significant experience in guided and ballistic parachute system development
  - **Design, development, performance evaluation, and certification**
- The team currently provides expertise to several high-visibility NASA projects & programs:
  - Orion capsule development (Chief Engineer and hardware design support)
  - Commercial Crew (Design reviews and expert consultation)
- Methods and tools include:
  - Testing: Air drop testing, ground testing
  - Analysis: State-of-the art parachute system modeling published at technical conferences
  - Measurements: Innovative instrumentation and avionics
  - Partnerships with academia to develop Fluid Structure Interaction models of parachutes

Decelerator Systems Team Overview


Sub-Scale Wind Tunnel Tests


Riser Abrasion Testing


Parachute Deployment Testing


Air Drop Testing

Wide Operation Space & Fault-Tolerance

- Parachute design is complicated due to a wide range of operating conditions
  1. Pad abort ➔ get the parachutes out fast
  2. Nominal reentry ➔ staged deployment to manage loads
  3. Final design is a compromise, which is the essence of engineering

- Fault tolerance is also a design requirement

Apollo 15 approaching splashdown

Decelerator Systems Challenge:
Pendulum Motion Under Two Main Parachutes

- Orion parachute development testing has included 4 tests with 2 main parachutes (nominally 3) to understand rate of descent characteristics with a failed main parachute
- During 2 of the 4 tests, the parachute & test vehicle system experienced an unexplained pendulum motion
  - Could effect touchdown incidence angle
- The main parachutes have a high drag coefficient and tend to "glide"
  - Both parachutes have glided together instead of exhibiting the somewhat random motion observed in most parachute cluster testing
- This phenomenon has not been reported previously and is currently under investigation
  - Complex interaction between the aerodynamics, system mass properties, and contact modeling
- Tools and methods being used to understand the complex phenomenon include:
  - Detailed trajectory reconstructions
  - Fluid Structure Interaction (FSI) modeling
  - Parachute aerodynamic sensitivity studies

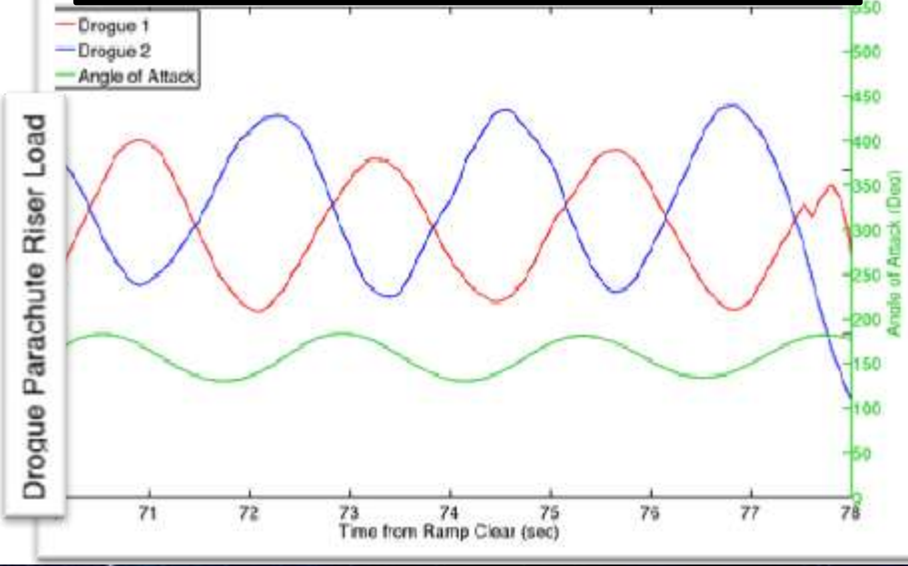
FSI of 2-cluster System at Non-zero Angle of Attack

Parachute Load Amplification Due to Riser Twist & Capsule Dynamics

- The Orion parachute team has observed large (~50%) variations in riser loads during drop testing when the risers twist up
  - This phenomenon has not previously been one of the design considerations for cluster parachute systems
  - Twist is induced by vehicle motion below the parachutes & random parachute motions
- The changes in load are in phase with vehicle dynamics once the risers are twisted
- Monte Carlo trajectory simulations are being used to understand the likelihood of this phenomenon taking place when the parachutes are highly loaded
- A detailed ground test program is underway to understand the potential magnitude of the variations

Main Parachutes Under Twist

Drogue Parachute Load Variations



Tools & Capabilities

Tools & Capabilities

Computational Tools

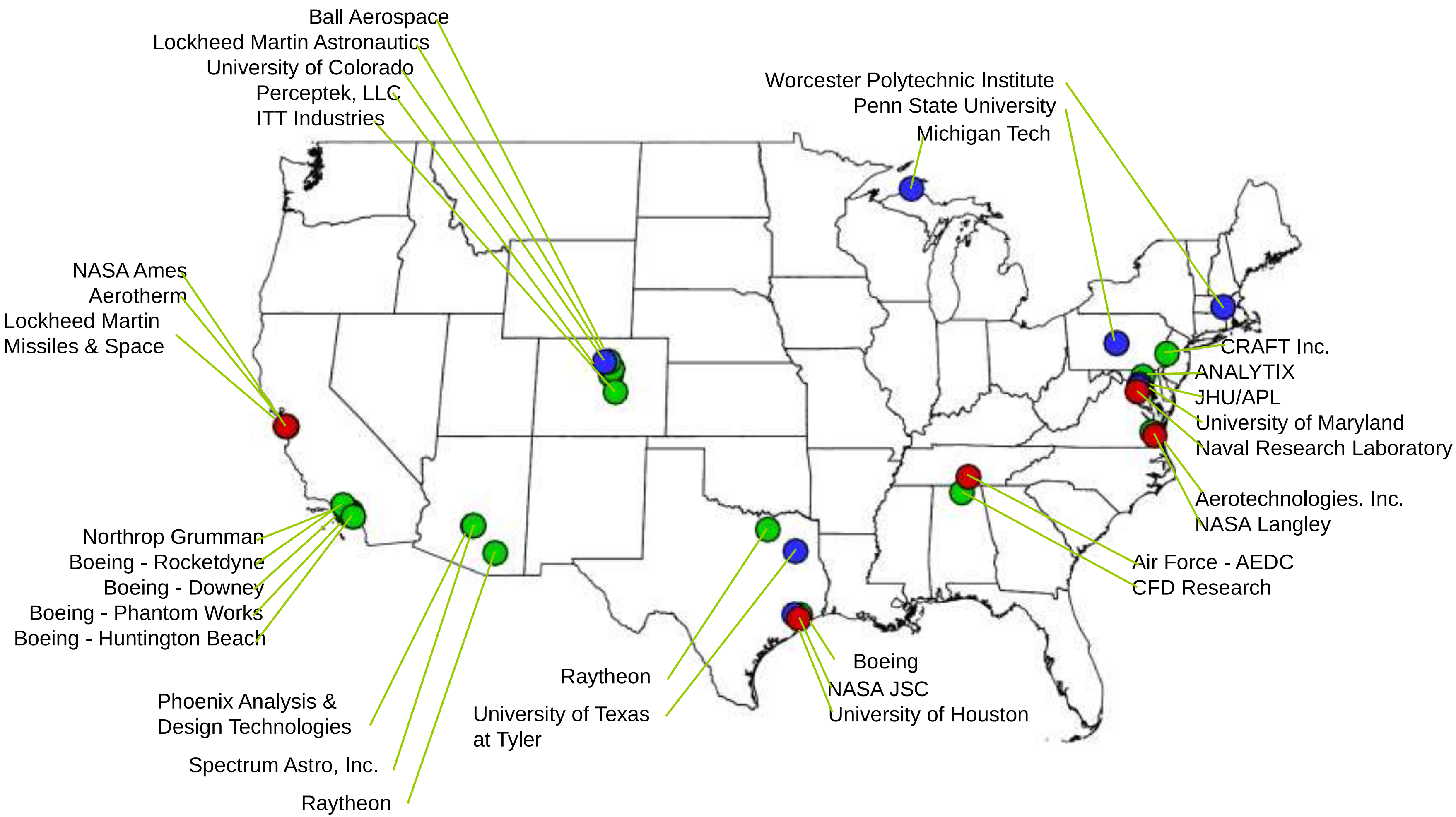
		Aerodynamics	Aerothermal
ARC	Cart3D	X	
ARC	Chimera Grid Tools	X	X
ARC	CBAero	X	X
ARC	DPLR	X	X
ARC	NEQAIR		X
ARC	Pegasus	X	X
JSC	CHAR		X
JSC	DAC	X	X
JSC	Debris	X	
JSC	Orion Aero API	X	
JSC	RPM 3D	X	X
JSC	SNEWT	X	
LaRC	OVERFLOW	X	X
MSFC	ARTIF		X
MSFC	Loci-CHEM	X	X
University of Minnesota	STABL	X	X
Sandia National Labs	DAKOTA		X

Test Facilities

		Aerodynamics	Aerothermal
ARC	9- by 7-Foot Supersonic Wind Tunnel	X	
ARC	11-Foot Transonic Unitary Plan Facility	X	
ARC	Electric Arc Shock Tube		X
ARC	Flight Mechanics Lab Test Cell 2	X	
ARC	Hypervelocity Free-Flight Ballistic Range	X	X
ARC	National Full-Scale Aerodynamics Complex	X	
LaRC	4-Foot Supersonic Unitary Plan Wind Tunnel	X	
LaRC	20-Foot Vertical Spin Tunnel	X	
LaRC	Aerothermodynamics Laboratory 31-Inch Mach 10 Air Facility	X	X
LaRC	Aerothermodynamics Laboratory 20-Inch Mach 6 Air Facility	X	X
LaRC	National Transonic Facility	X	
LaRC	Transonic Dynamics Tunnel	X	
AEDC	16-Foot Transonic Wind Tunnel (16T)	X	
AEDC	Aerodynamic 4-Foot Transonic Wind Tunnel (4T)	X	
AEDC	Hypervelocity Wind Tunnel 9 (T9)	X	X
Boeing	Polysonic Wind Tunnel (PSWT)	X	
Caltec	T5 Hypervelocity Shock Tunnel Facility		X
CUBRC	Cornell Aeronautical Laboratory (CAL) 48-Inch Shock Tunnel	X	X
CUBRC	Large Energy National Shock Tunnel (LENS I)	X	X
CUBRC	Large Energy National Shock Tunnel (LENS II)	X	X
CUBRC	Large Energy National Shock Tunnel (LENS XX)		X
Eglin AFB	ARF Ballistic Range	X	
Lockheed Martin	High Speed Wind Tunnel	X	
Texas A&M	Oran W. Nicks Low-Speed Wind Tunnel	X	
U. of Washington	Aeronautical Laboratory Kirsten Wind Tunnel	X	
U.S. Air Force Academy	Subsonic Wind Tunnel	X	

DAC's User Base

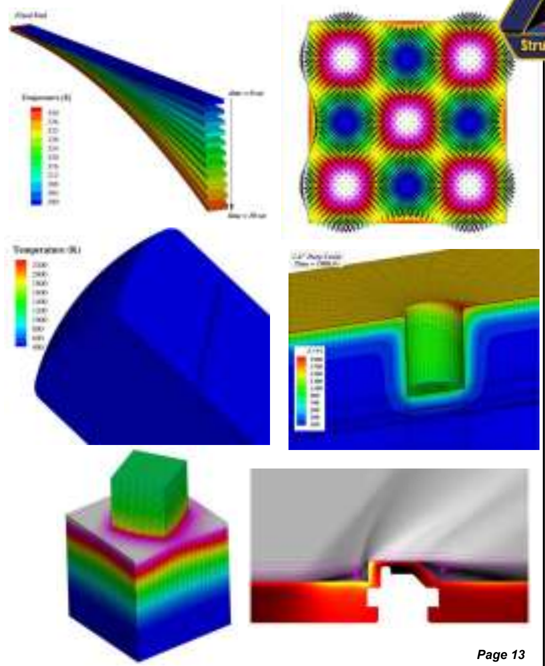
● NASA or DoD ● Industry ● University



CHAR - Capabilities & User Base

CHAR's Toolbox

	CHAR	STAB	TD
Charring Ablation	X	X	
1D	X	X	X
2D	X		X
3D	X		X
Porous Flow	X		
Enclosure Radiation	X	X	X
Inverse	X		
Generalized mesh	X		
Contact conduction	X		X
Adaptive Mesh	X		
Thermal Stress	X		
Parallel	X		X
Rigorous Verification	X		
Fluid/Thermal Coupling	X		



CHAR: New EA Ablation Tool!
STAB: Legacy EA Ablation Tool!
TD (Thermal Desktop/Sinda): EA Thermal Analysis Tool!

JSC
ARC
LaRC
JPL

Aerolab – High Performance Computing Facility