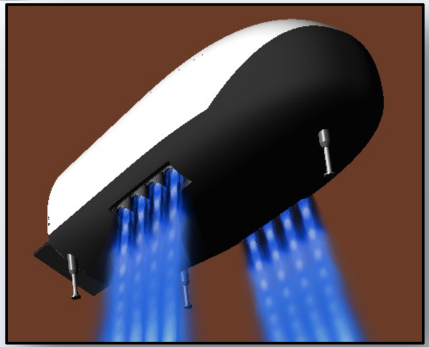
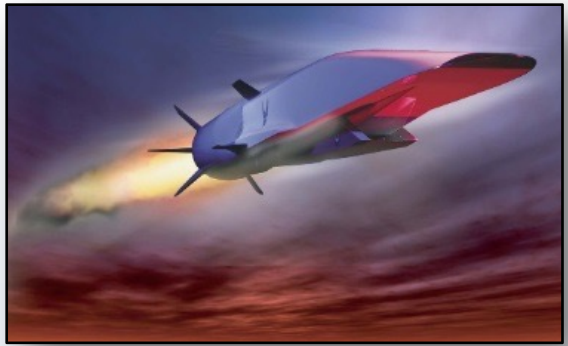
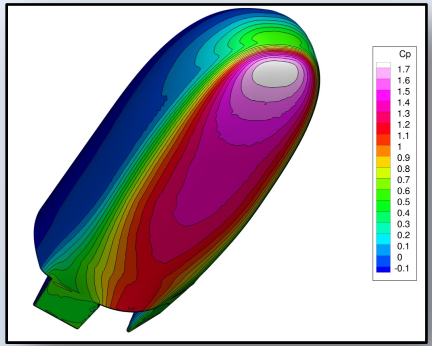
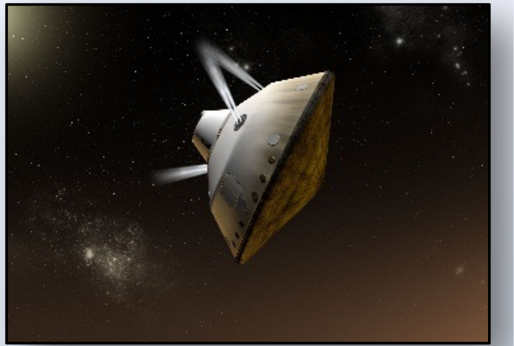




Evaluation of CFD as a Surrogate for Mach 2.4 to 4.6 Wind-Tunnel Testing Project Overview



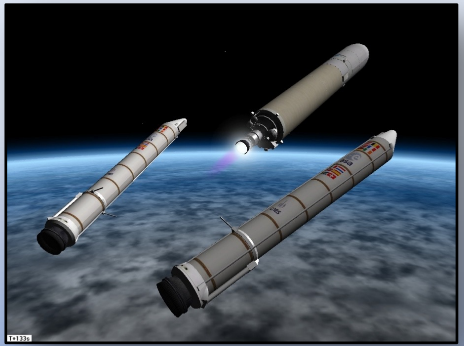


Jim Ross

NASA Ames Research Center, Moffett Field, California

Matthew Rhode, Bryan Falman, Karl Edquist, Mark Schoenenberger, Gregory Brauckmann, Bil Kleb, Thomas West, Stephen Alter, David Witte

NASA Langley Research Center, Hampton, Virginia



Outline

- Background – why we're doing this
- Project structure and ground rules for evaluations
- Evaluation Teams description

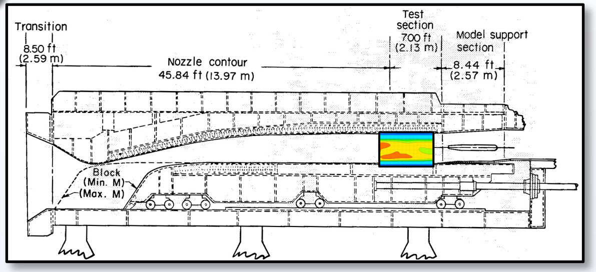
Langley Unitary Plan Wind Tunnel

- Finished in 1955
  - Test Section 1 – Mach 1.5 to 2.9, Re 0.5 to 11×10^6 per foot
  - Test Section 2 – Mach 2.4 to 4.6, Re 0.5 to 8.25×10^6 per foot
- Heavily used for NASA, DoD, and industry projects for decades
- Early 2000's, NASA policy changed - charged all customers full cost
  - Interest in high-supersonic flight regime also dwindled
- In 2012 facility was mothballed and put on the demolition list for 2022
- For next 5+ years facility was mothballed, operated by Jacobs at full cost recovery, mothballed again
- In 2016 decision to recertify and reactivate based on need for testing of Space Launch System
- Facility has been active since then but **remains** on the demolition list for 2022

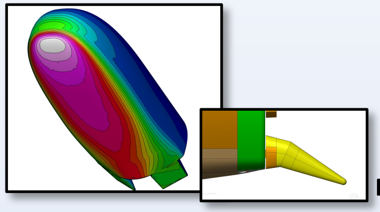
Evaluation of CFD as a Surrogate for Testing at High Supersonic Speeds
Aerosciences Evaluation and Test Capabilities (AETC) Challenge

- **Description:** Assess ability of CFD to address NASA (and National) Aerosciences prediction requirements in the Mach 2.4 – 4.6 range at conditions achievable in LaRC UPWT
  - Evaluate accuracy, efficiency, and resources needed, for CFD compared to wind tunnel testing for past, present, ***and future*** problems of interest
    - Engineering Perspective - vehicle aero database development
    - Flow physics discovery perspective - research tool to develop a better understanding of fluid dynamic phenomena and CFD evaluation
- **Objective:** Inform Agency of risk incurred by divesting of the LUPWT by performing a series of wind tunnel tests and associated CFD analyses for test cases deemed critical, specifically areas where flow physics understanding and prediction capability are weak
- **Impact:**
  - Provides critical information required to evaluate a decision concerning closure of the LaRC Unitary Plan Wind Tunnel
  - Develop a methodology that may be applied to other ground-test capabilities
    - Tightly integrated CFD/Experimental teams
    - Assessment of other potential facility and/or capacity level reductions in the NASA aeroscience ground test portfolio

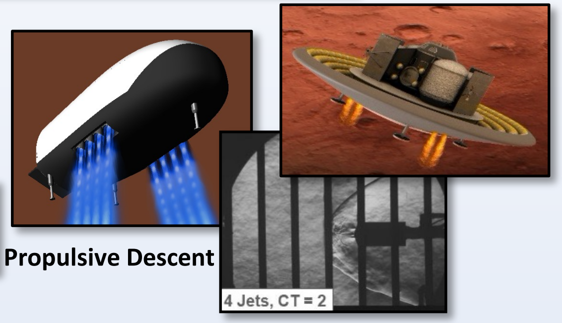
Aerodynamic Challenges Adopted to Study



Test Section Flow Characterization

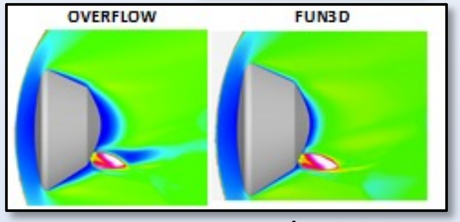


Control Surface Effectiveness

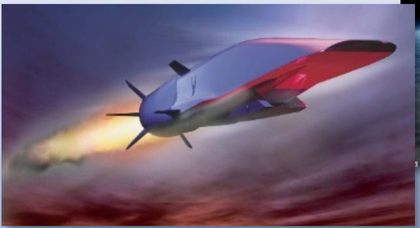


Propulsive Descent

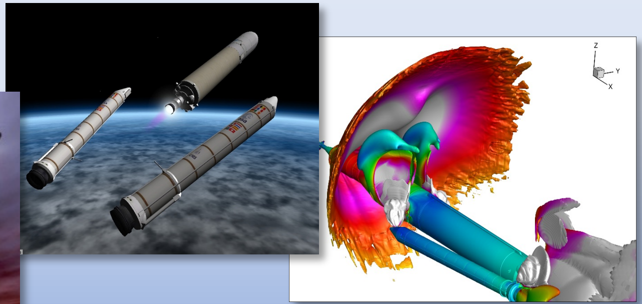
Check Standard Model Aerodynamics



RCS/Backshell Jet Interaction



Hypersonic Vehicle Inlet Integration



Multi-Body Separation

- Propulsion/Aero Interaction for Supersonic Retro-Propulsion (Propulsive Descent)
- Control Surface Effectiveness for Hypersonic and Entry/Descent Vehicles
- Reaction Control System Aerodynamic Jet Interaction for Entry Vehicles
- Multi-Body Aerodynamics for High-Speed Separation Events
- Hypersonic Vehicle Inlet/Isolator Performance
- Simple wing/body aerodynamics*
- ***Test section flow characterization is required to perform other evaluations****

* Added later to fill in missing information

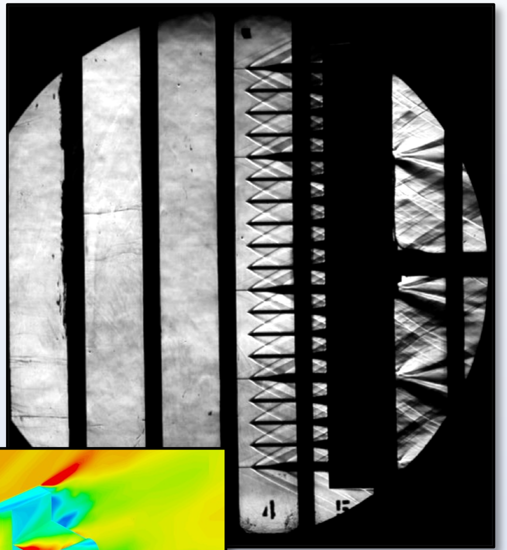
Common Ground Rules

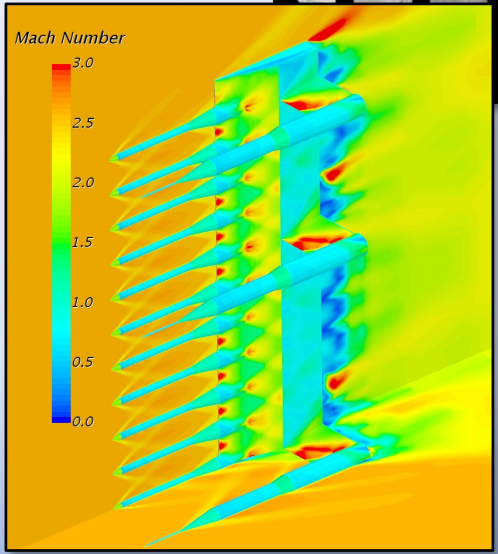
- Each team must have a NASA partner project to cost share
- Formal uncertainty analyses are required
  - CFD
  - Wind tunnel data
- Reasonable quantity of comparison data and sufficient test variables included – e.g., model geometry variation, free-stream conditions, angles of attack and/or sideslip
- Pre-test CFD predictions must be complete before data is distributed
- Comparisons may lead to second round of CFD to determine source of any inaccuracies found in the CFD that may be found

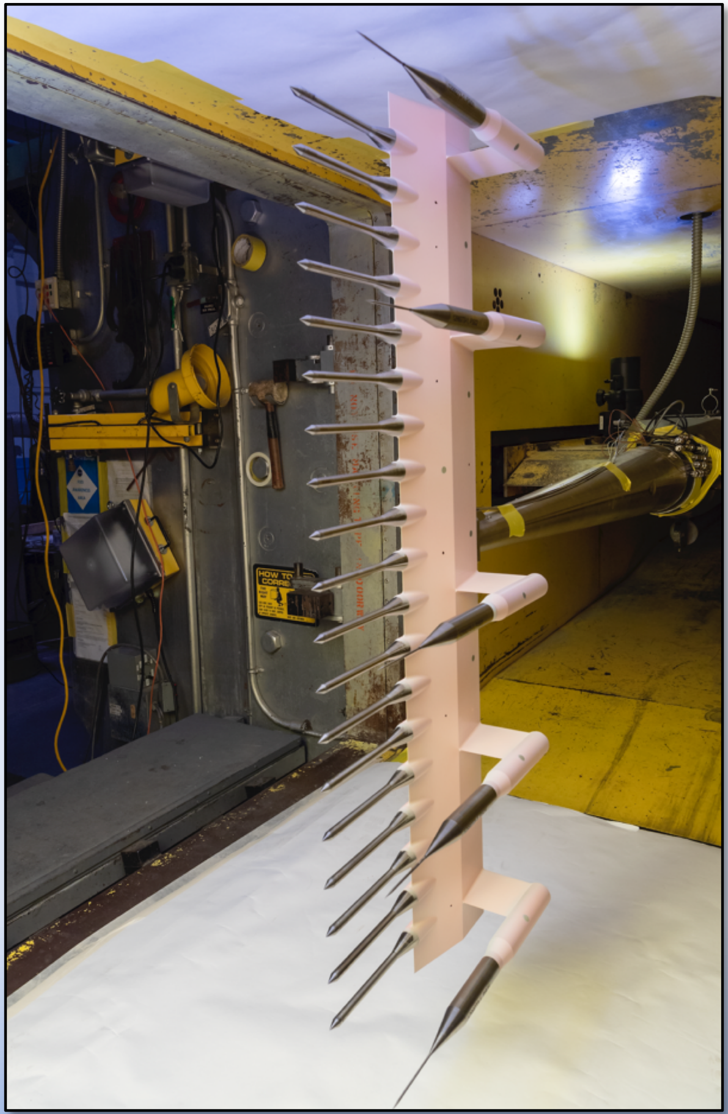
Flow Characterization Evaluation

PI: Matthew Rhode, LaRC

- M_∞: 2.30 to 4.63
- Re : 1 to $5x10^6$/ft
- Measurements covered entire test section
- 19 5-hole probes on a traversing rake (x-y traverse)
  - Pitot pressure
  - Upwash & sidewash angles
  - Subset of conditions with 19 total temperature probes
  - 5 static pressure probes
- 127 static pressure on ceiling from nozzle through the test-section
- CFD codes included:
  - FUN3D
  - OVERFLOW
  - USM3D
  - STAR-CCM+



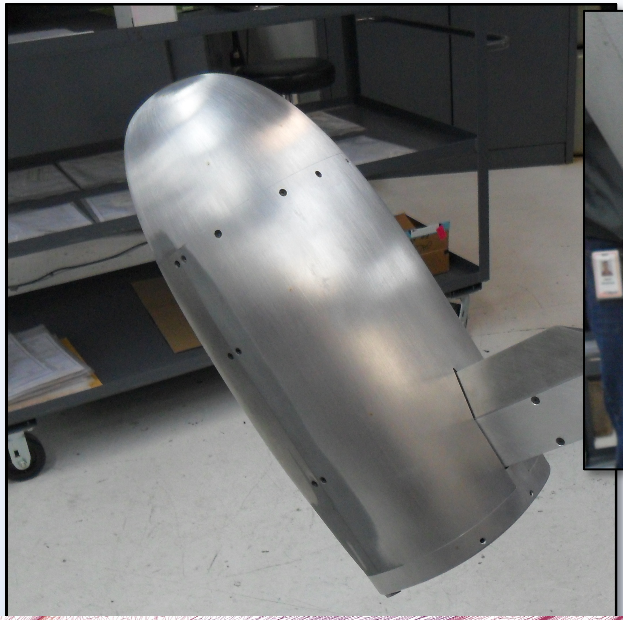


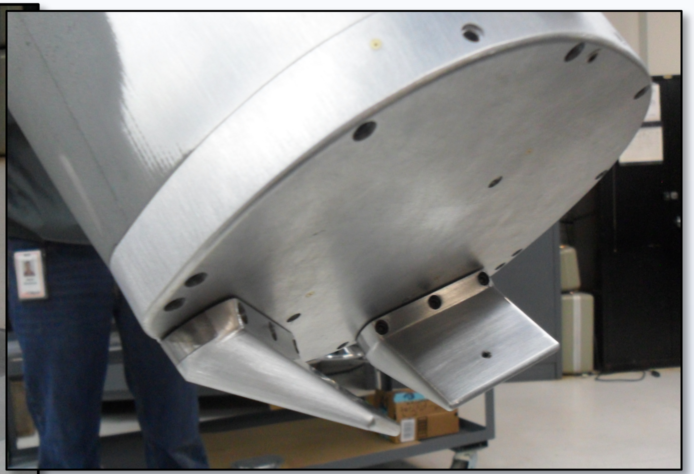


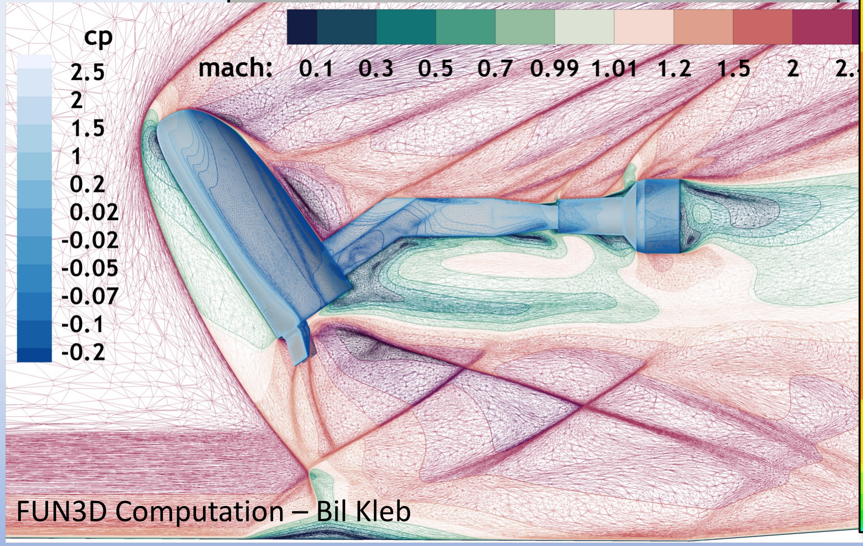
Control-Surface Effectiveness Evaluation

PI: Jim Ross, ARC

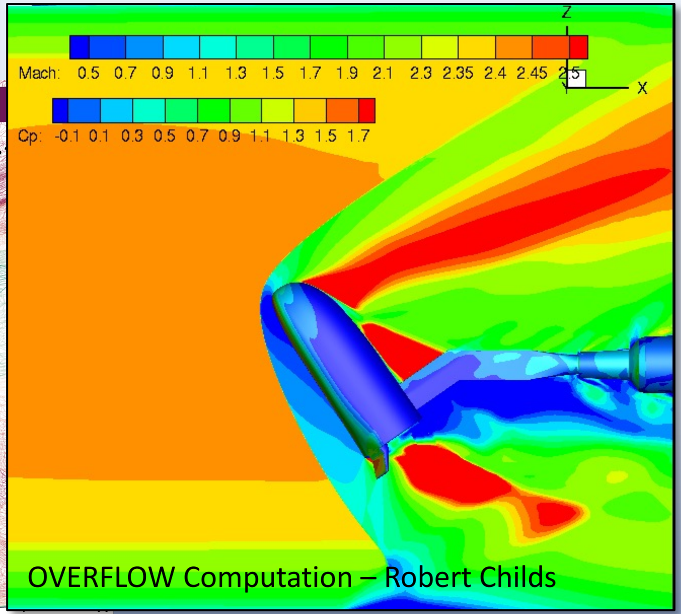
- Supported by Game Changing Development Program
- Two CFD codes used
  - OVERFLOW
  - FUN3D with adaptive mesh
- Data comparisons
  - Overall forces and moments
  - Flap hinge moments
  - Surface pressures - Pressure Sensitive Paint (PSP) in the experiment
  - Doppler Global Velocimetry (DGV) measurements in shock/floor-boundary layer







FUN3D Computation – Bil Kleb



OVERFLOW Computation – Robert Childs

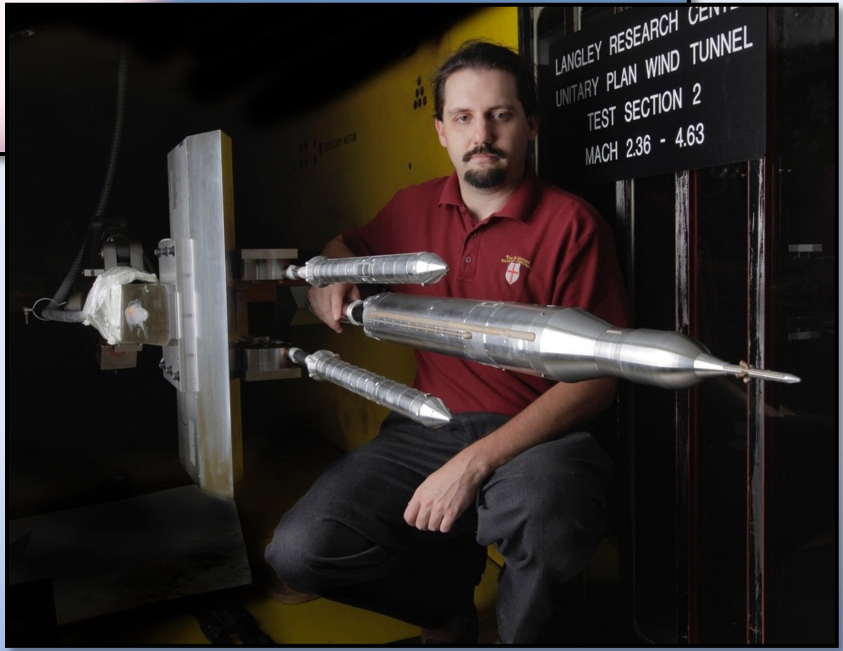
Cobra – Named for the **Co**-**O**ptimization **B**lunt-body **R**e-entry **A**nalysis tool used to develop it

MRV – **M**id-L/D **R**igid **V**ehicle

Booster Separation Evaluation

PI: Greg Brauckmann, LaRC

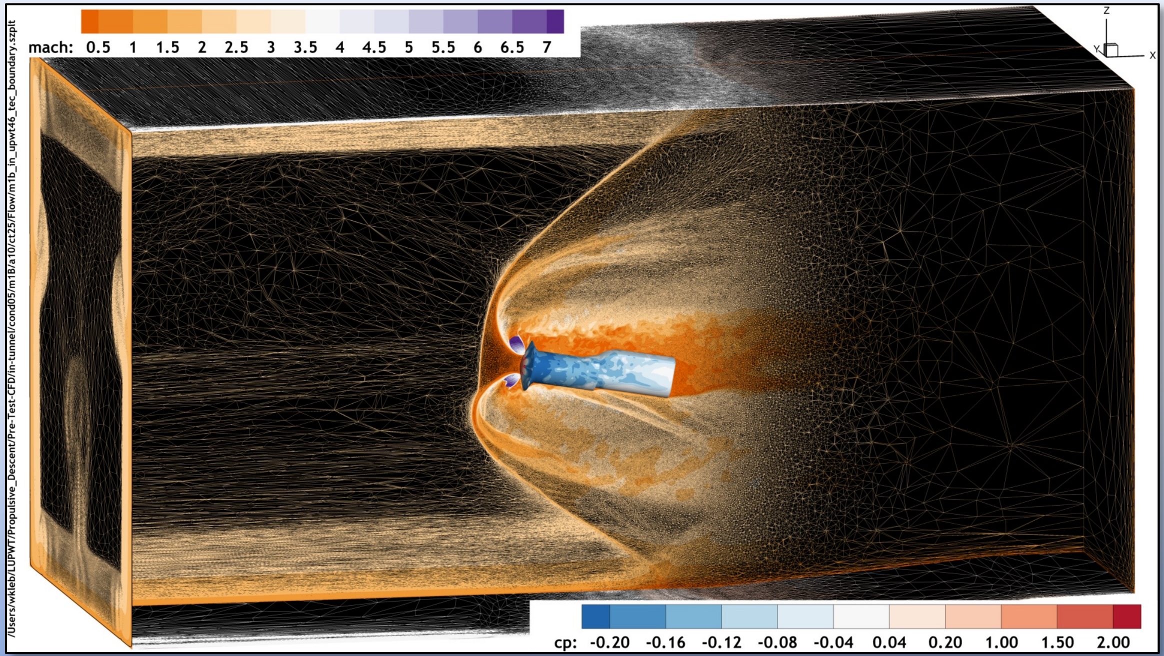
- Exception to the rule – AETC supplies new CFD comparing with existing SLS WT data
  - ❖ New CFD staff with no previous experience with booster separation analysis
  - ❖ Two CFD codes
    - ➢ FUN3D with adaptive mesh
    - ➢ LAVA
- Quantities of interest are forces and moments acting on
  - ❖ Core
  - ❖ Port and starboard boosters



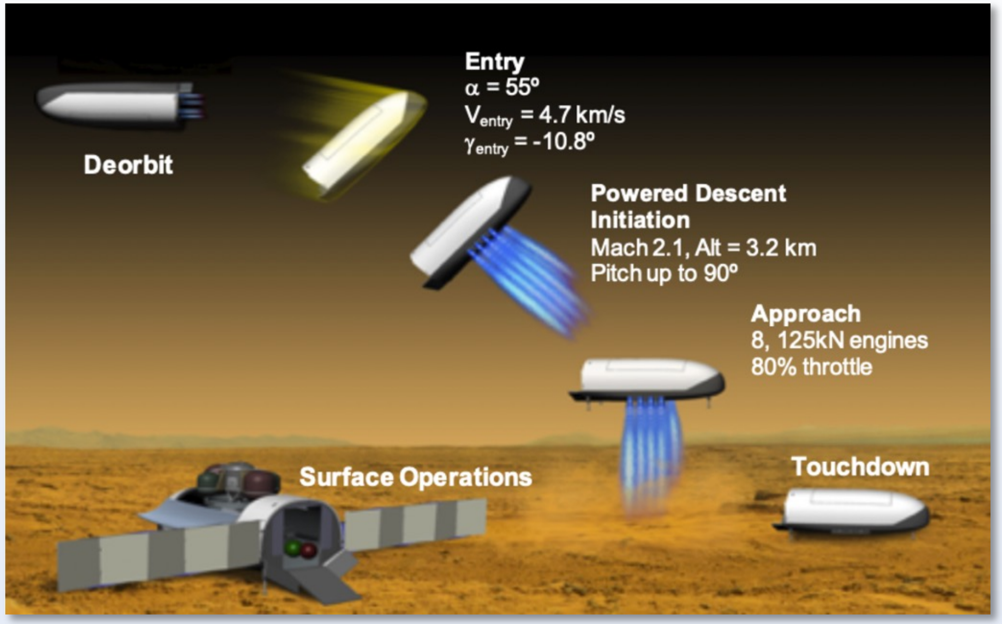
Propulsive Descent Evaluation

PI: Karl Edquist, LaRC

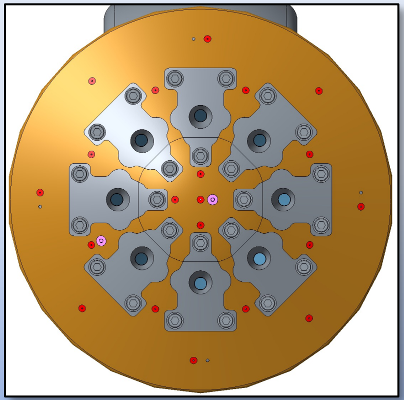
- Supported by NASA's Game Changing Development Program – Descent System Studies
- Retro-propulsion goal is achieving required delta-V for landing heavy payloads on Mars
  - Requires aerodynamic drag on heat shield in addition to direct thrust
- Three CFD codes: Overflow, Fun3D, and Loci-Chem
- Measurements include pressure distributions using PSP and unsteady pressures



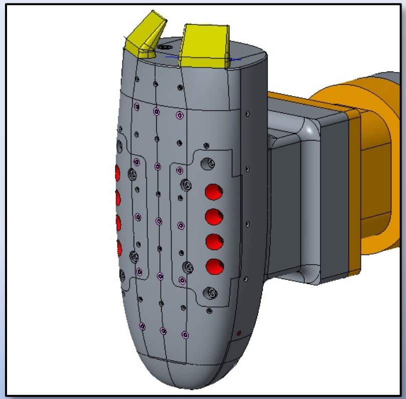
Mid-L/D Entry Concept



HIAD WT model design



CobraMRV WT model design

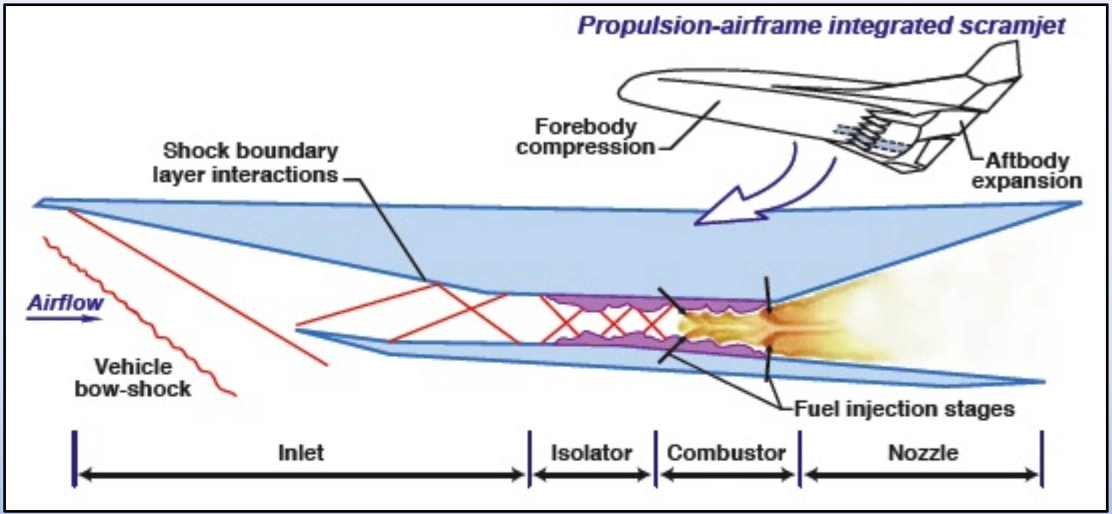


Hypersonic Vehicle Inlet Performance

PI: David Witte, LaRC

- NASA Hypersonic Technology Project is our partner
  - Interest is inlet/isolator performance
- Accurate CFD prediction of the operating boundaries for these inlet/isolators has been elusive
- Measurements include pressure distributions throughout the flow path
- Five CFD codes: VULCAN, LOCI-CHEM, FUN3D, Wind-US, and Kestrel
- Test scheduled for ~October 2021

Scramjet Engine Flow Features

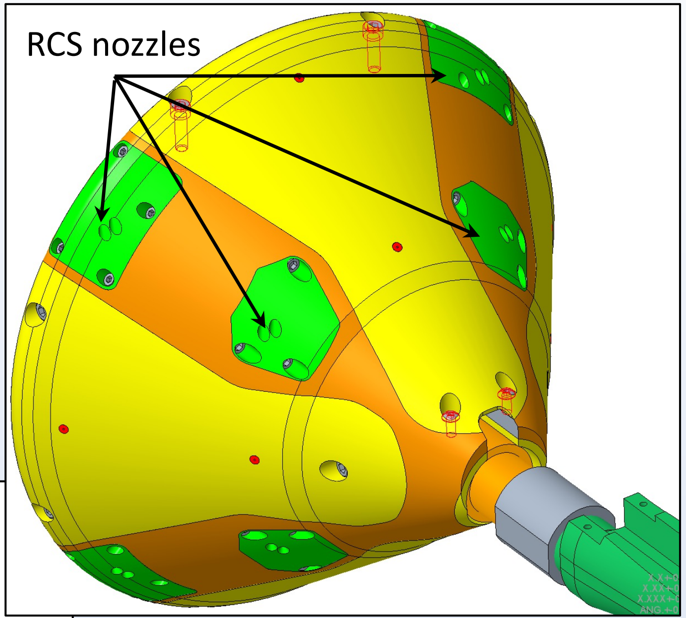


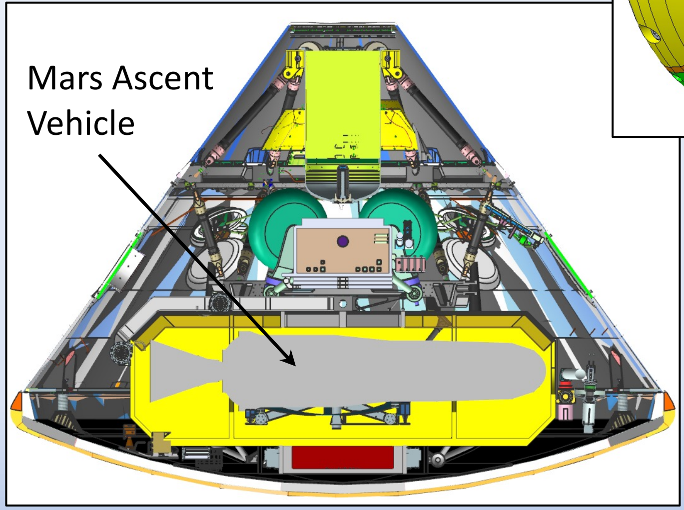
Reaction Control System Jet Interactions

PI: Mark Schoenenberger, LaRC

- Partner project is Mars Sample Retrieval Lander
- CFD aided design process for internal flow and RCS nozzle locations
- Comparison data includes:
  - Forces and moments (flow-through balance)
  - PSP
  - Schlieren
  - DGV as available
- Two CFD codes:
  - OVERFLOW
  - FUN3D with adaptive mesh

MSRL entry vehicle

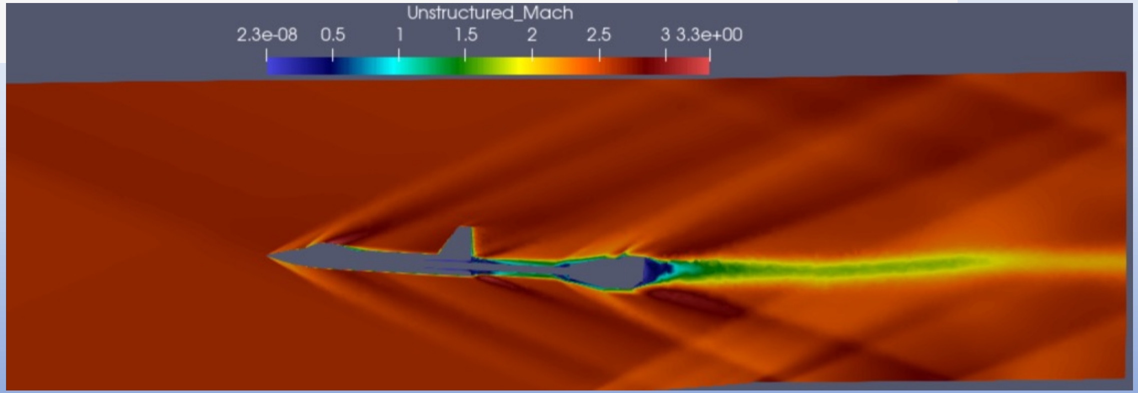




Check Standard Model Aerodynamics

PI: Jim Ross, ARC

- Relatively simple wing-body configuration
  - Attached flow conditions should be well handled by CFD
  - Using wealth of previously acquired data
- CAD model generated from 1982 blueprints and recent laser scan
- Two CFD codes:
  - LAVA
  - Kestrel
- Simple instrumentation, comparisons will be
  - Forces and moment coefficients - internal balance
  - Base and cavity pressures



Summary

- These CFD evaluations is establishing the ability of CFD to predict important (and complex) flows in the Langley Unitary Plan Wind Tunnel
- Will provide important input to a decision on closing and demolishing the wind tunnel
    - ❖ Specifically, the technical risks and costs of relying solely on CFD to predict vehicle aerodynamics in the high-supersonic flight regime

Questions?