Aerodynamic Forces and Moments of the Morpheus Lander Using OVERFLOW

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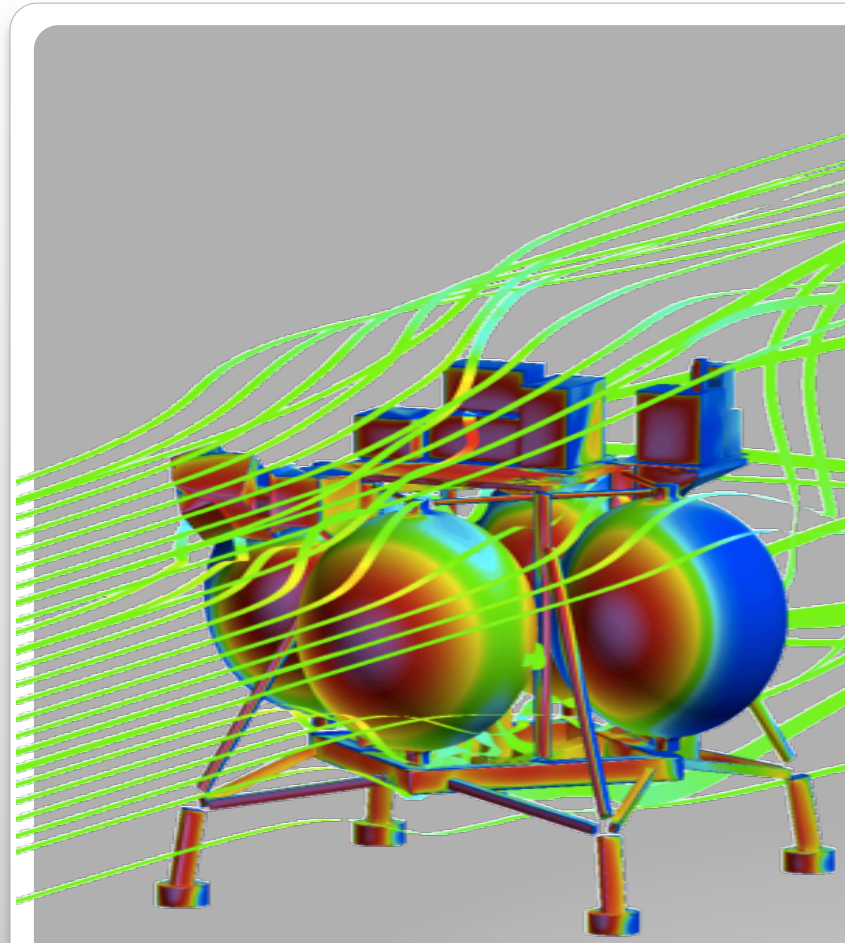
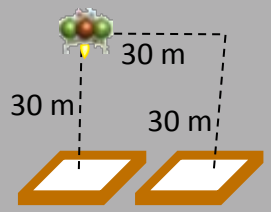
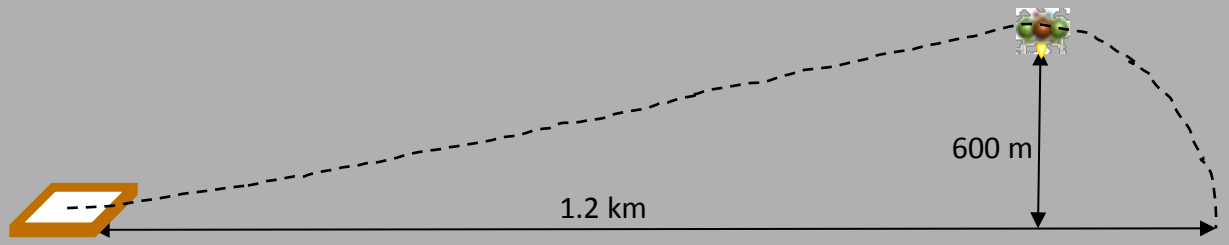


- Project Overview
- Geometry
- Aerodynamic Responsibilities
- Wind Tunnel Test
- Overset Grids
- OVERFLOW Results
- Comparison
- Conclusions & Future

Overview



Free Flight



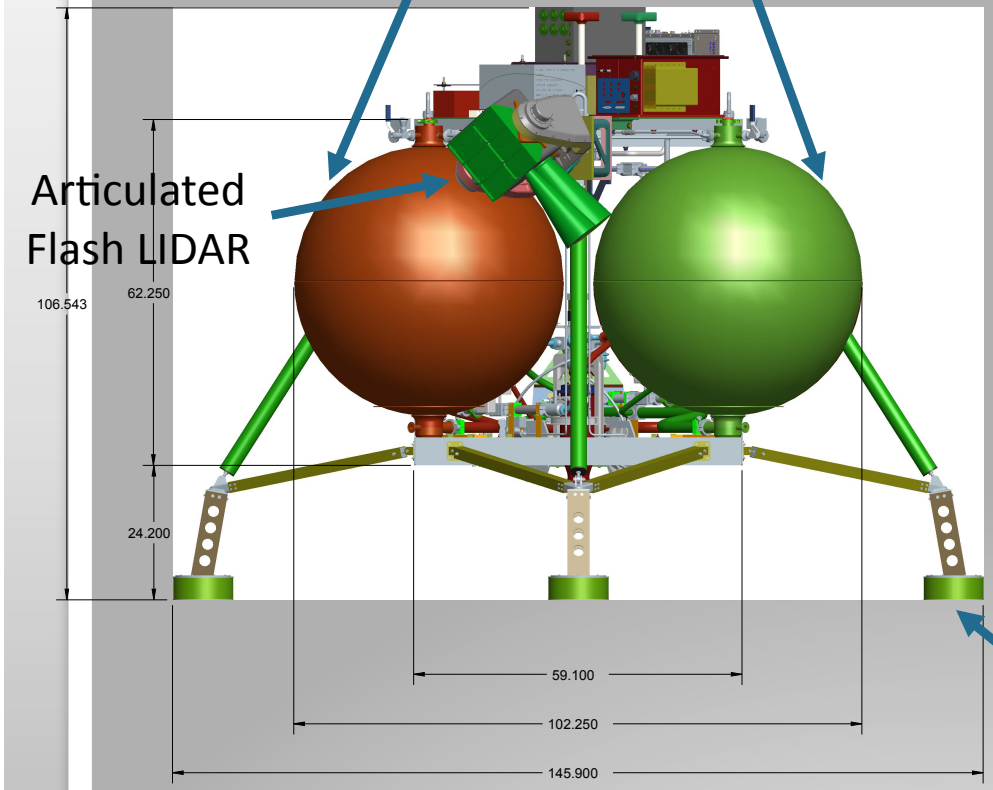
ALHAT Hazard Detection Phase (HDP) Trajectory

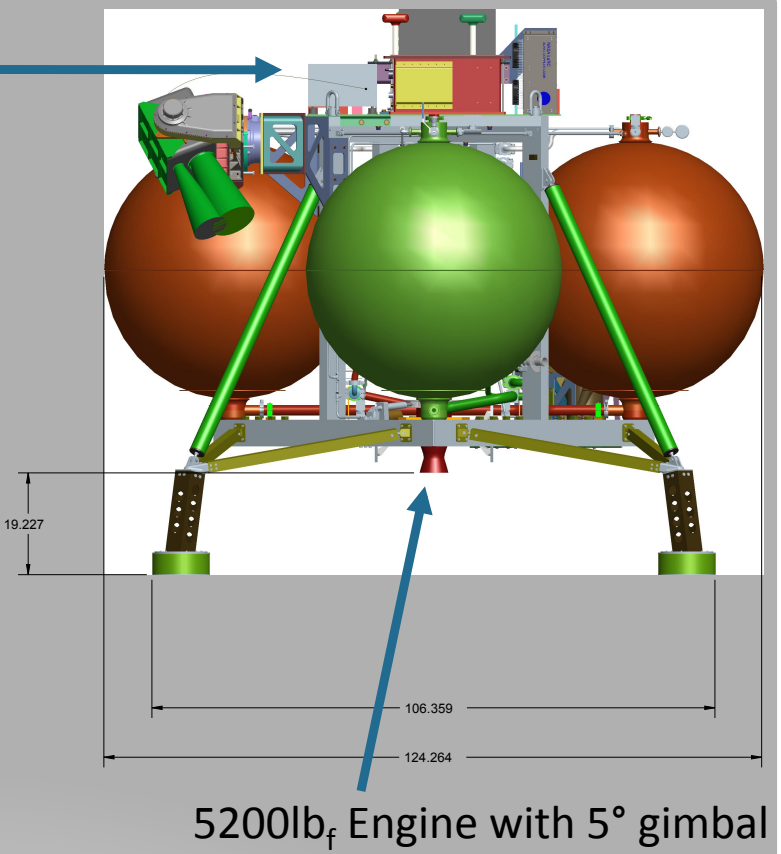
- Lunar Lander prototype vehicle developed as a terrestrial vertical testbed
  - Test precision landing and hazard detection
  - Improve liquid oxygen and methane rocket engine
- Flight testing occurs at JSC and KSC with a hazard field
- To date, completed 5 engine hot fire tests, 20 tethered tests, and 2 attempted free flights
  - Second free flight attempt ended catastrophically on August 9, 2012
  - Plan to return to flight testing by end of 2012
- Vertical take off and landing flight tests will include a parabolic trajectory reaching 1640 ft in altitude at 70 mph (Mach 0.1)

Project Morpheus

MORPHEUS

Geometry


LOX & Methane Fuel Tanks
Articulated
Flash LIDAR
106.543
62.250
24.200
59.100
102.250
145.900
Landing Pads


Avionics Pallet
19.227
106.359
124.264
5200lb$_f$ Engine with 5° gimbal

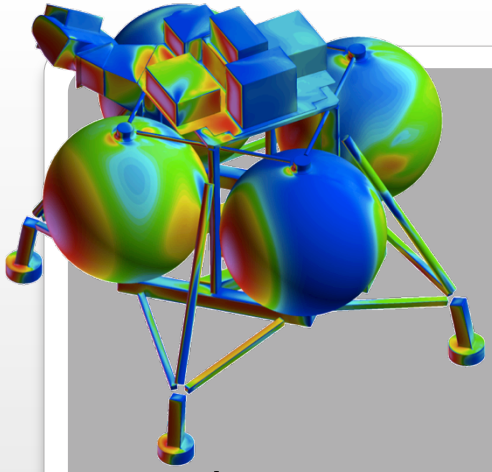
Aerodynamics

- Vehicle has no aero control surfaces
  - Understand the natural aerodynamic characteristics of the vehicle
  - Implications to terrestrial free flight and testing
  - Take vehicle level corrective action if necessary
    - RCS included for roll control
- Develop database to account for aerodynamic forces & moments in control and performance simulations
  - Wind tunnel test data
  - CFD results
    - Simulated using structured Overset grids and the OVERFLOW CFD solver
- Assess ground effects

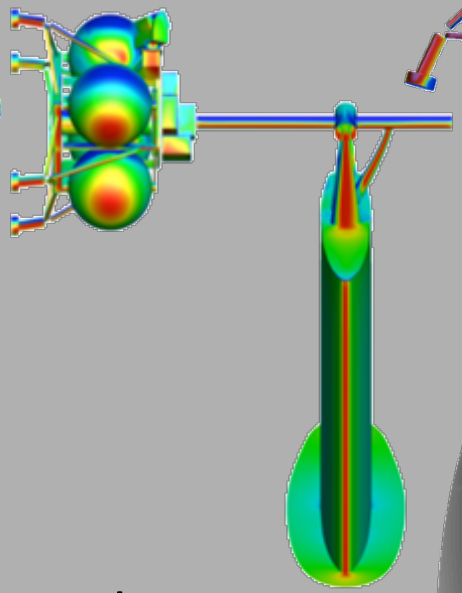
MORPHEUS

Wind Tunnel Test

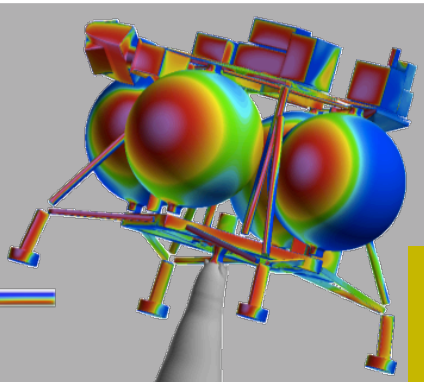
- Wind tunnel testing conducted at the University of Washington Aeronautical Laboratory 8’ x 12’ wind tunnel to anchor CFD results
- Full envelope of vehicle orientations covered: 360° of roll and angle of attack
  - Low speed of vehicle increases the effects of winds
- Reynolds number sensitivity to correlate with vehicle flight envelope
- Vehicle shape and flight conditions present a challenge in scale testing



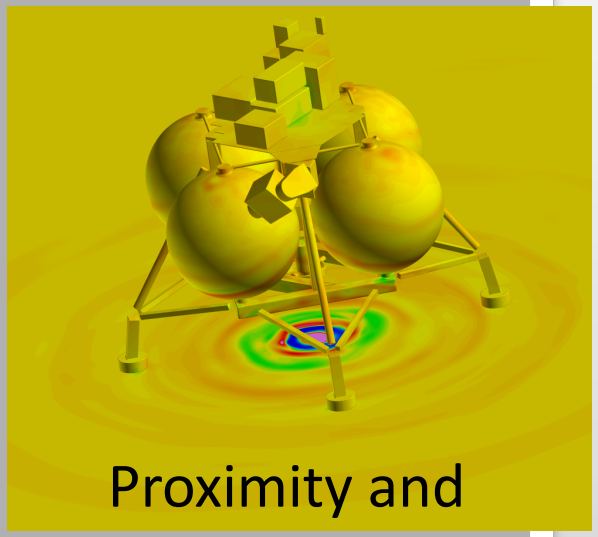
Morpheus 1.5



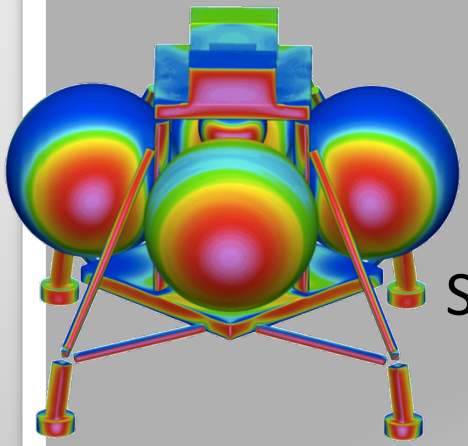
WTT Tare



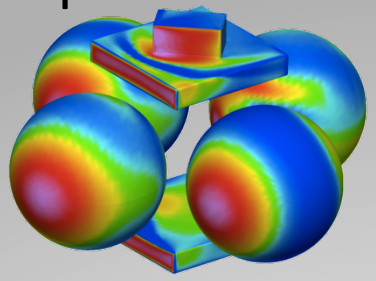
Morpheus 1.5+



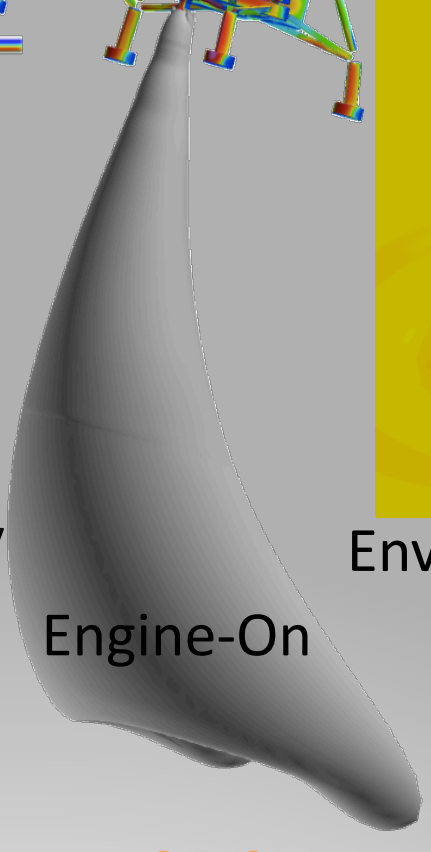
Proximity and Environment Mitigation



Morpheus 1.0



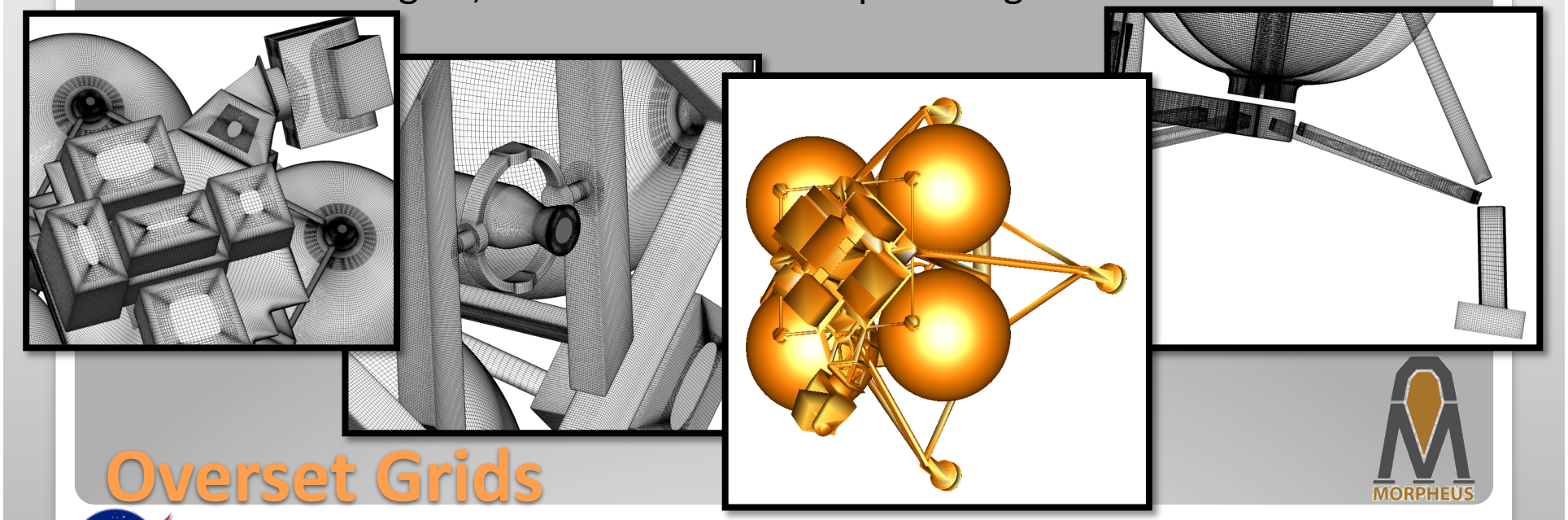
Simple Geometry



Engine-On

Configurations of Morpheus Vehicle Assessed

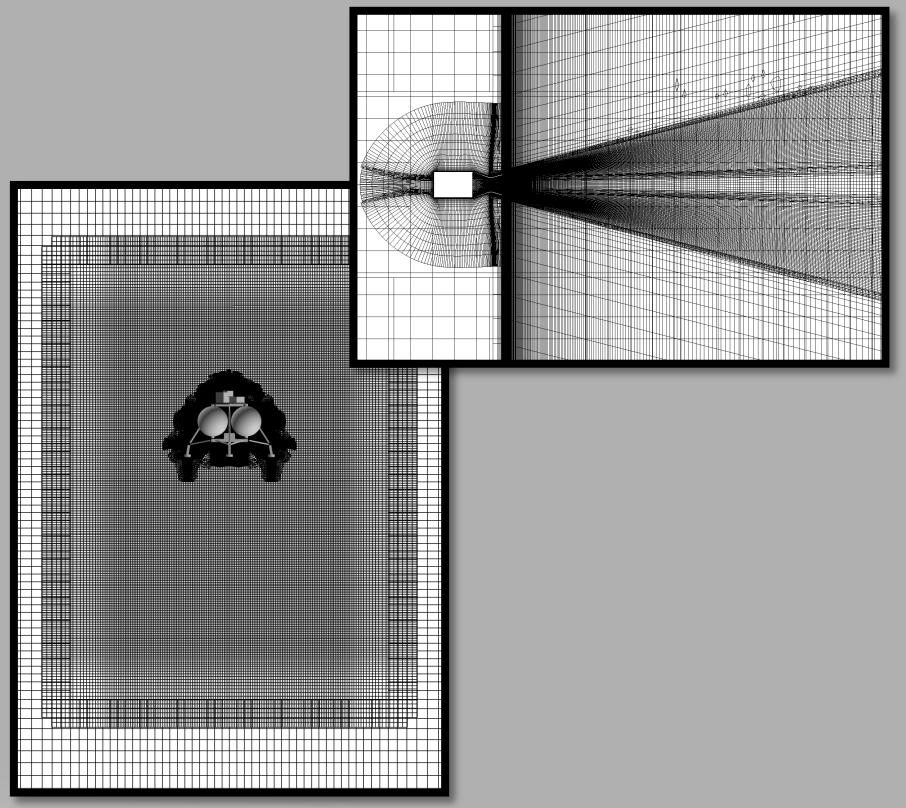
- Grids generated with Chimera Grid Tool 2.1+
- PEGASUS5 used for domain connectivity
- 184+ grids defined with 90 million+ grid points
  - Features include: LIDAR transmitter/receiver, engine, fuel lines, avionics plate, wake box for subsonic flow
  - Approximated features: avionics “boxes,” junction of leg struts, stationary LIDAR & engine, thicknesses of some plumbing features



Overset Grids

OVERFLOW Setup

- Steady State
  - Constant CFL
- SST turbulence model
  - No compressibility correction
- Numerical Methods
  - RHS: HLLC
  - LHS: SSOR
- Used Full Multi-Grid

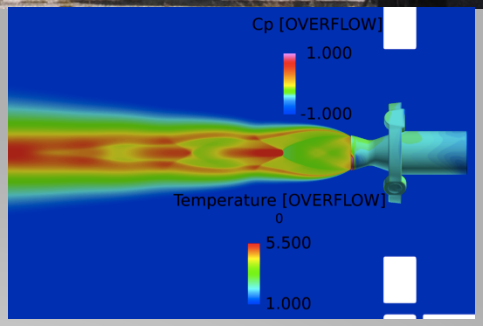


- Plume and environment cases run time accurate
- Desired drop of 3 orders of magnitude for convergence
  - All cases are unsteady

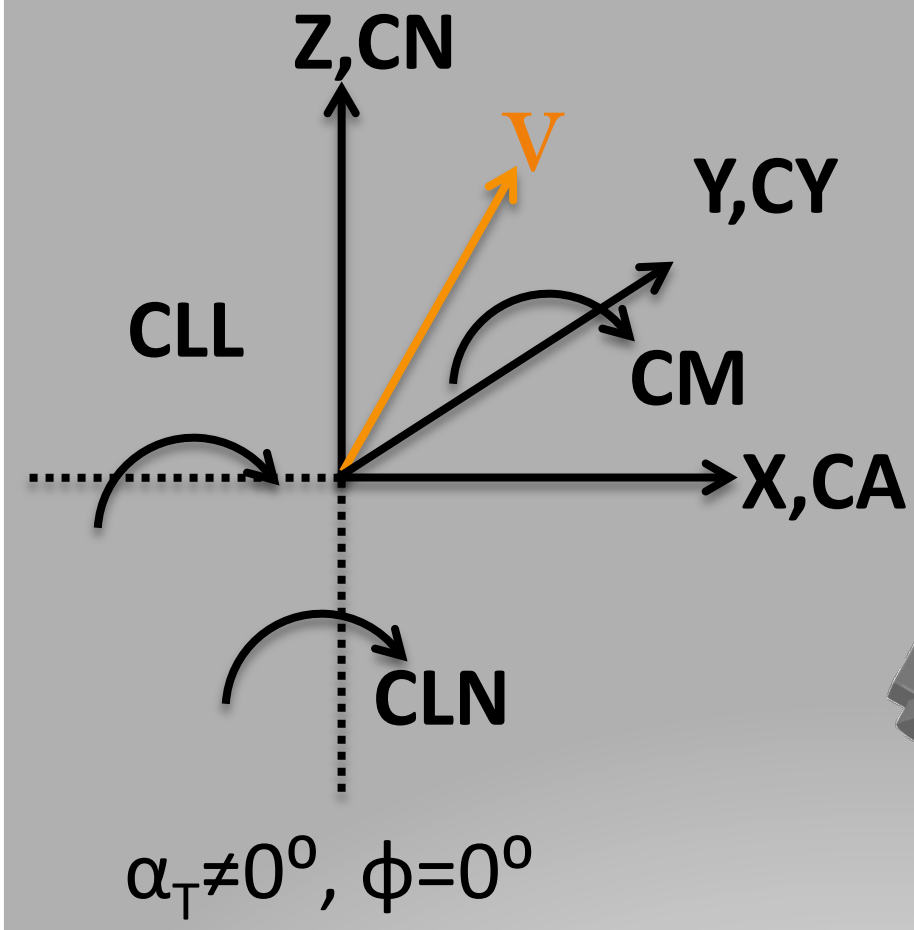
- Runs performed at NASA JSC on L1 cluster

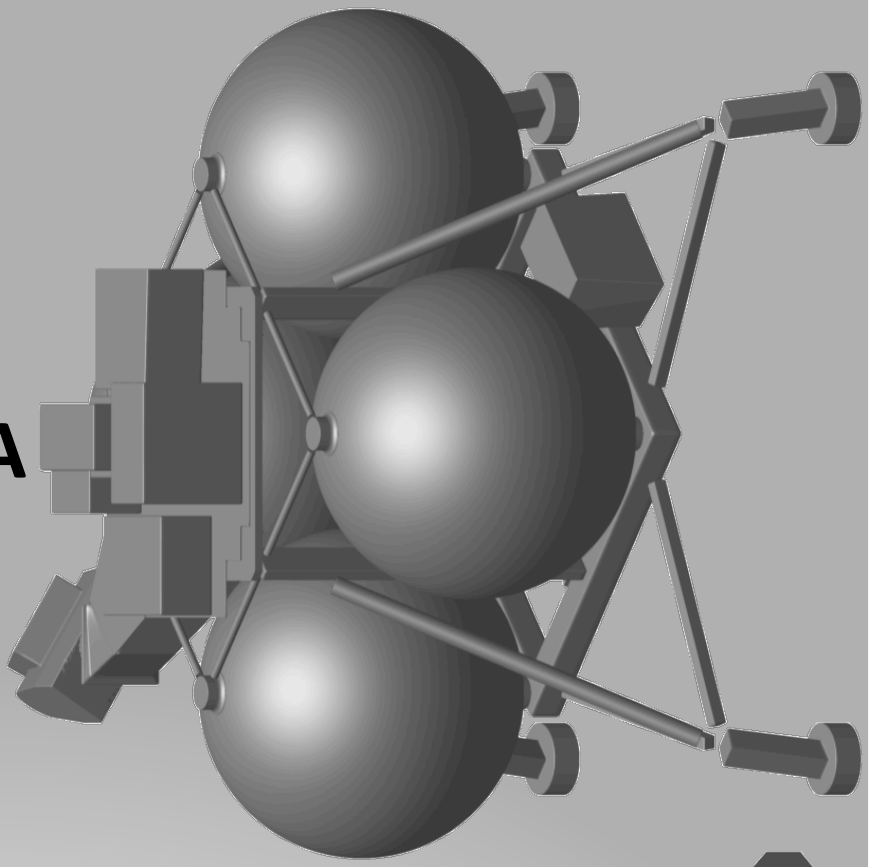
Config	Cases	CPU Hours
Simple	11	7000
Morpheus 1.0	62	64000
Morpheus 1.5	138	380000
WTT Conditions	64	170000
WTT Tare	10	64000
Morpheus 1.5+	23	84000
Plume On	15	57000
Engine Only	3	14000
Ground Proximity	2	94000*
Flame Trench		
Total	328	840000

*Not included in Total CPU Hour

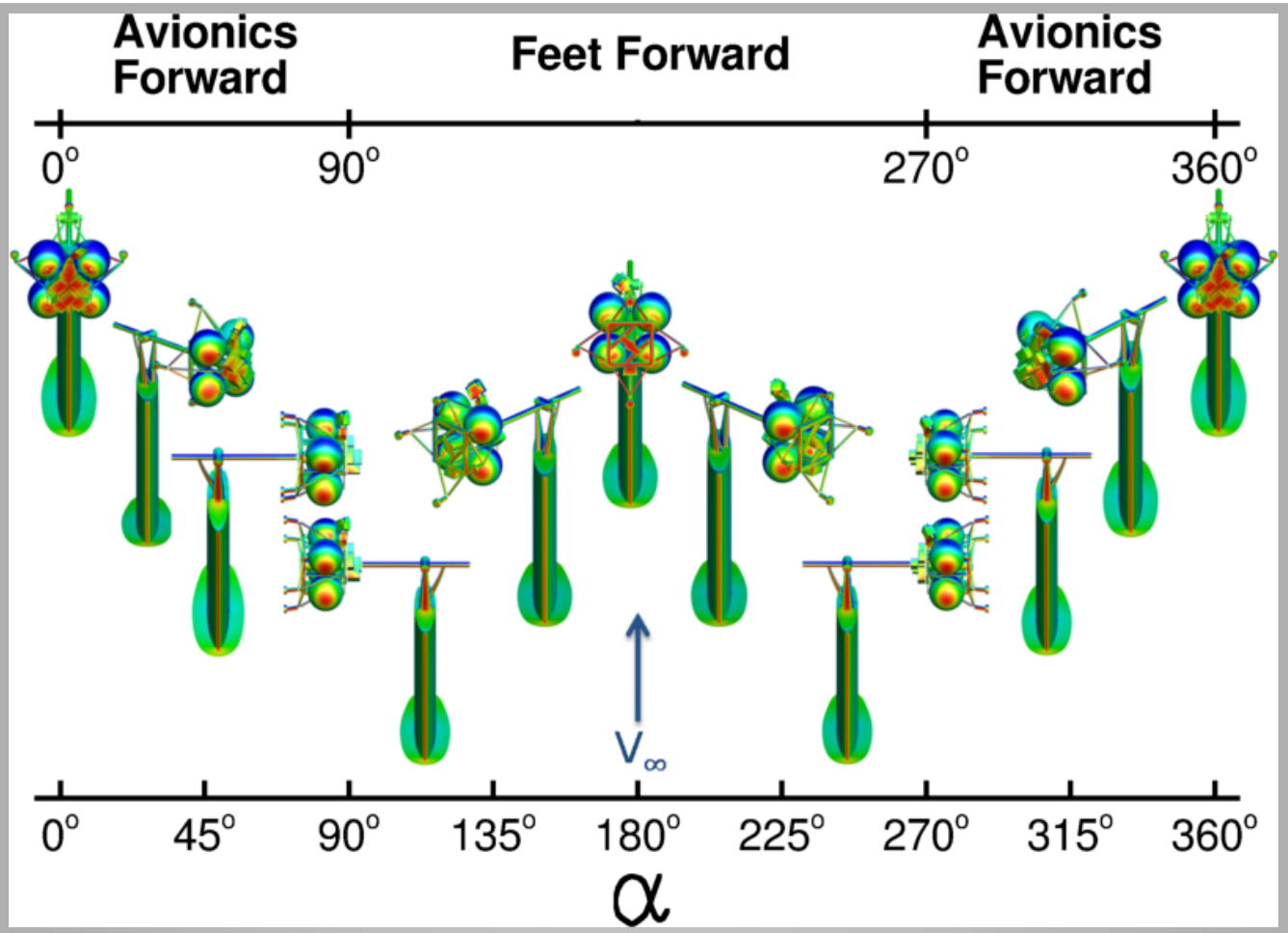


Computational Metrics

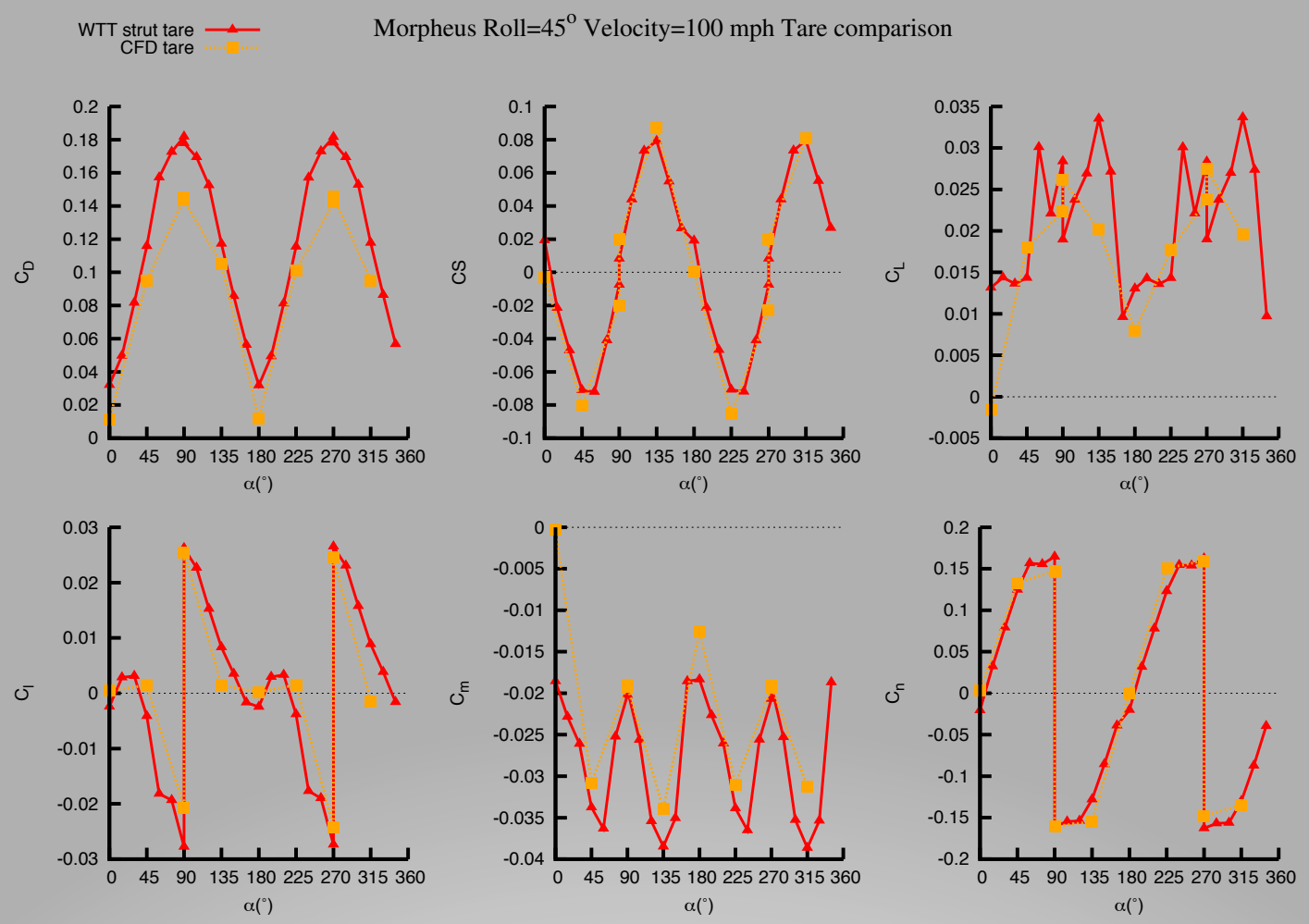




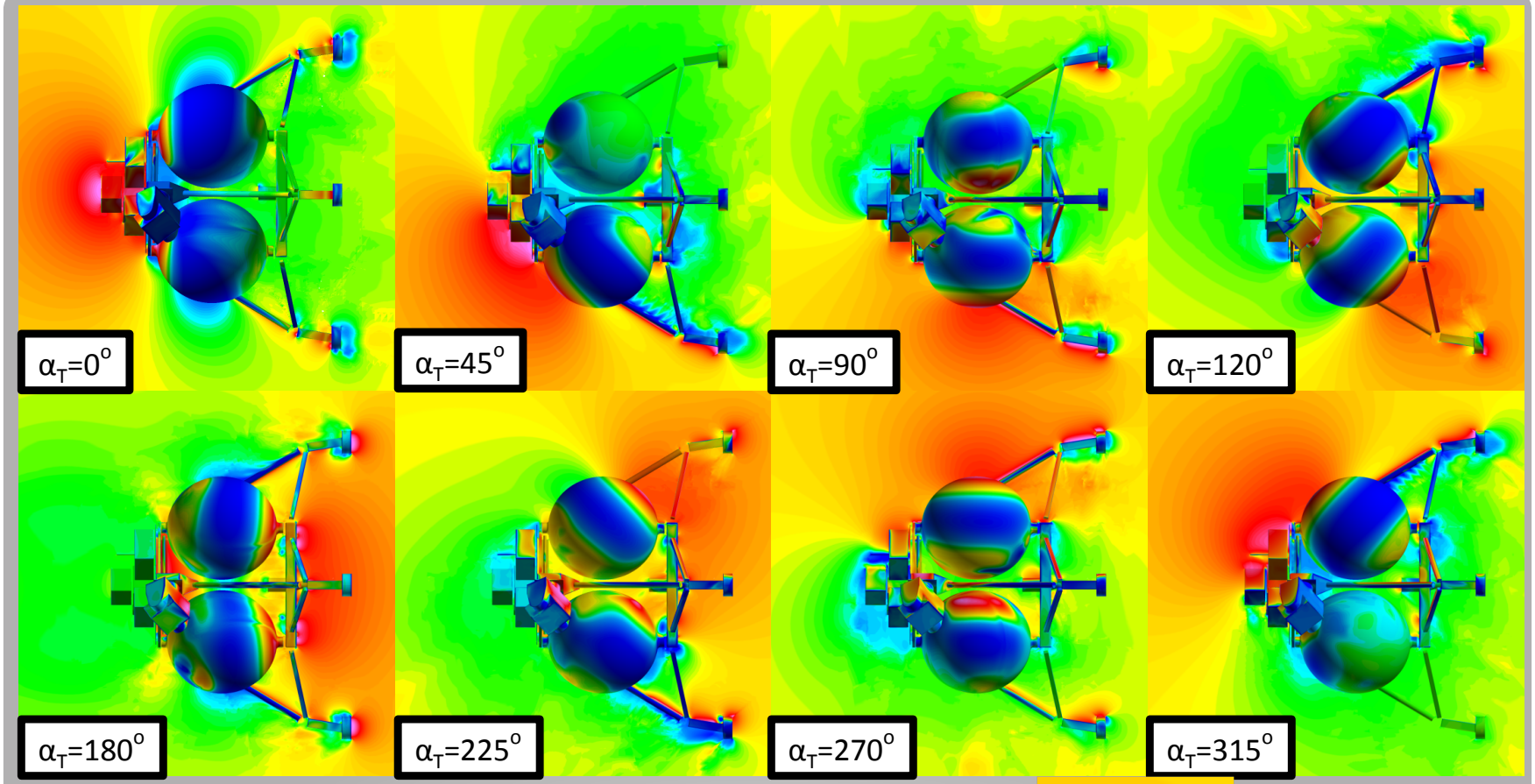
Morpheus Body Axes



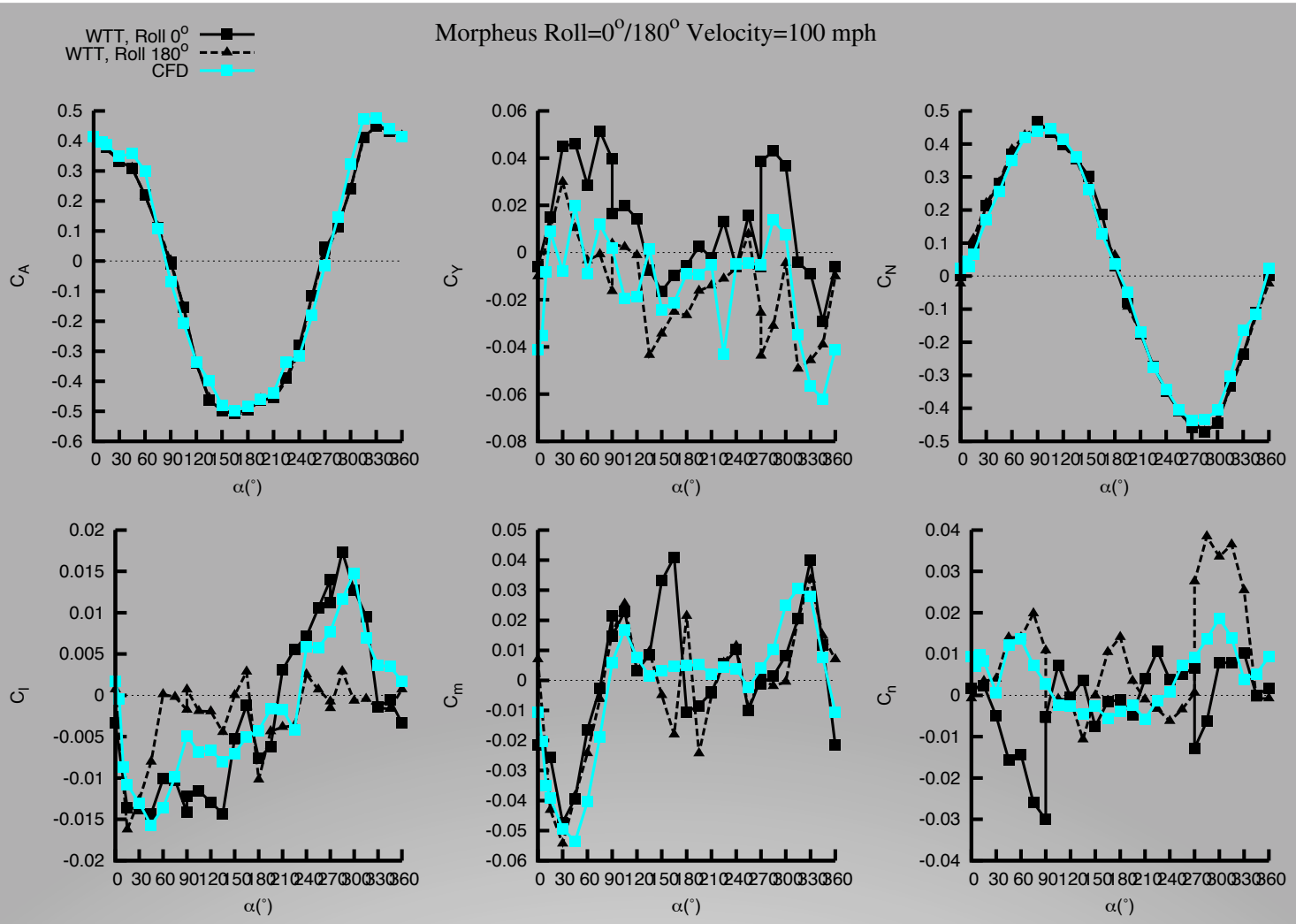
Sampling of CFD Results: Wind Tunnel Tare Assessment



WTT Tare Comparison

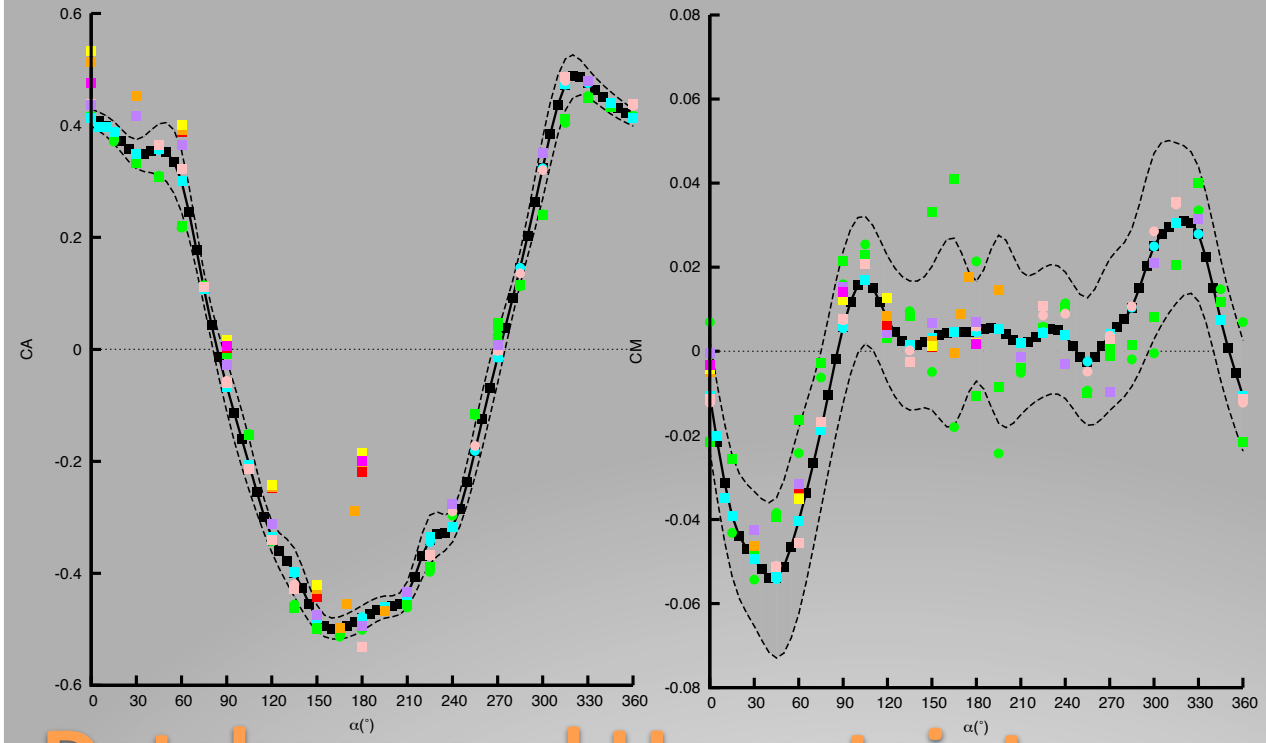


Sampling of CFD Results: Free Flight, Roll 225°



CFD to WTT Comparison

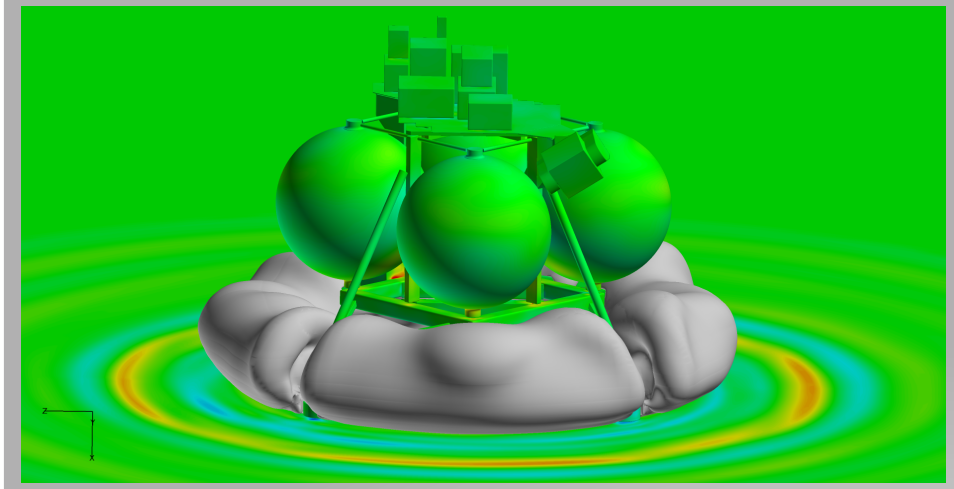
- Database developed from WTT data and CFD Flight & WTT Conditions results
- Uncertainty for each coefficient built from three components:
  - WTT Repeatability
  - Reynolds number variation experienced in WTT
  - CFD to WTT correction

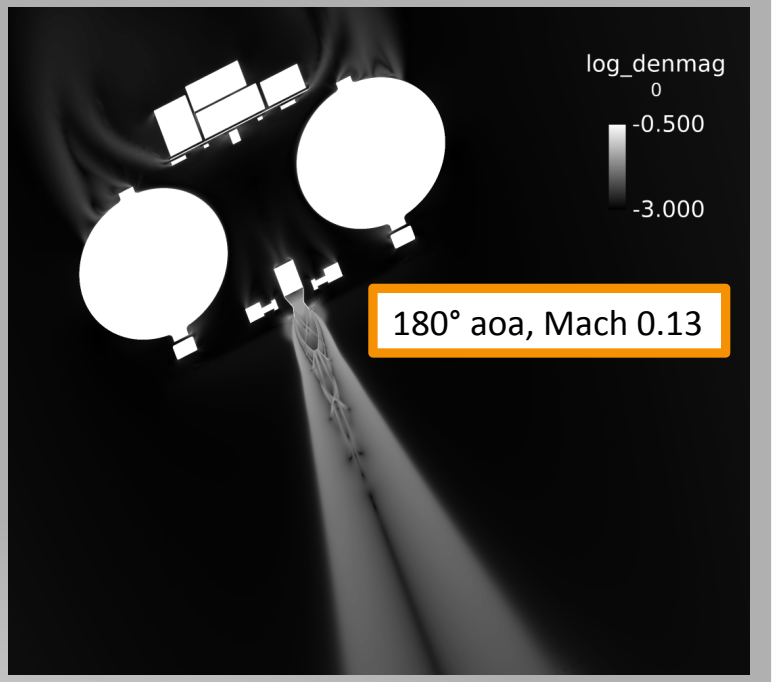


Roll 0°, Mach 0.13

Database and Uncertainty

- Engine-On increment added to database from plume modeling CFD results
- CFD results and flight testing show strong plume structure to be ~5 ft in length
- IOP waves captured by CFD





Sampling of CFD Results: Plume & Ground Effects

Conclusions & Future

- CFD is able to match trends seen in wind tunnel testing and flight testing
  - Used to build a database for simulation and stability analyses
- Continuing to assess environment mitigations with flame trench design
- Morpheus 2.0 vehicle will be a completely new body shape with two vertically stacked tanks