

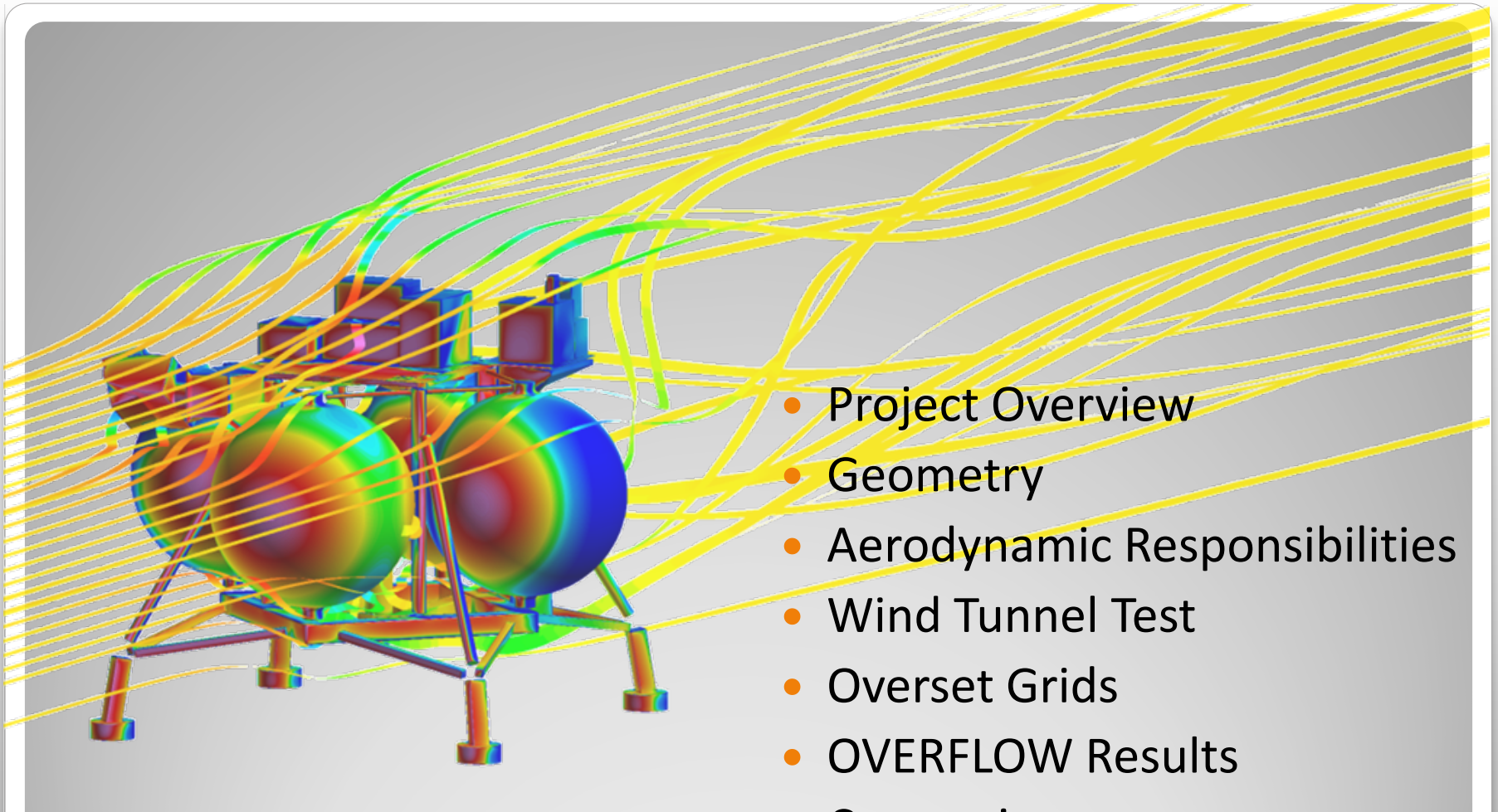
# Aerodynamic Forces and Moments of the Morpheus Lander Using OVERFLOW



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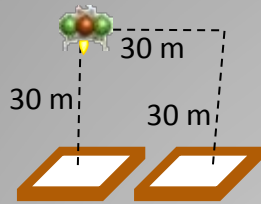




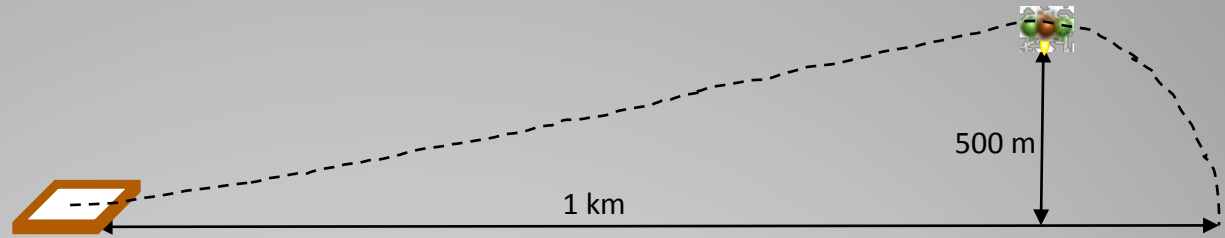
- Project Overview
- Geometry
- Aerodynamic Responsibilities
- Wind Tunnel Test
- Overset Grids
- OVERFLOW Results
- Comparison
- Conclusions & Future

## Overview





## Free Flight

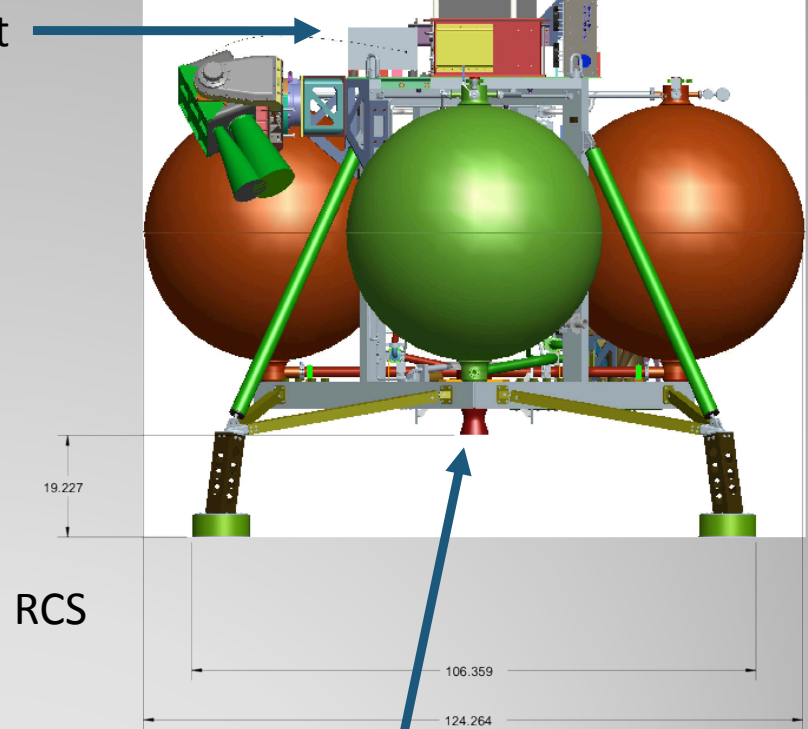
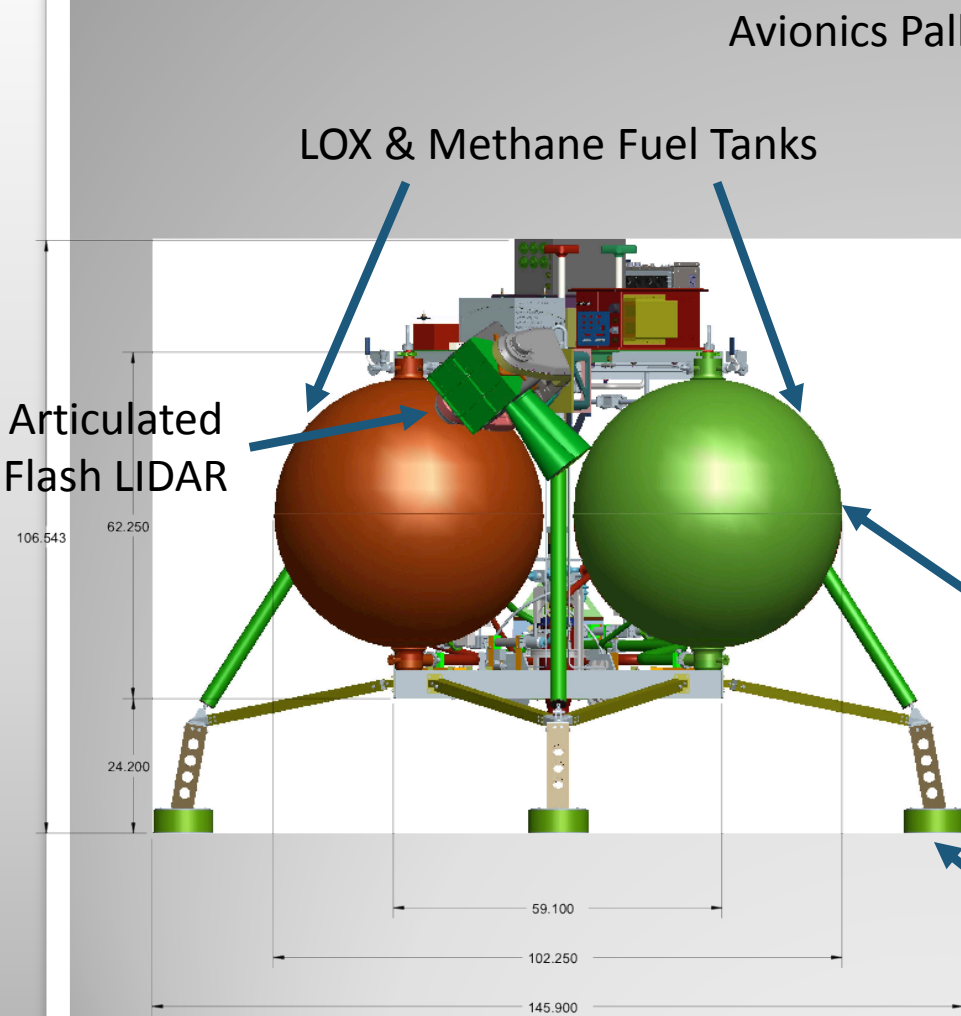


## ALHAT Hazard Detection Phase (HDP) Trajectory

- 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 1600 ft in altitude at 70 mph (Mach 0.1)

# Project Morpheus





RCS

5200lb<sub>f</sub> Engine with 5° gimbal

Landing Pads

# Geometry

\*All units in inches

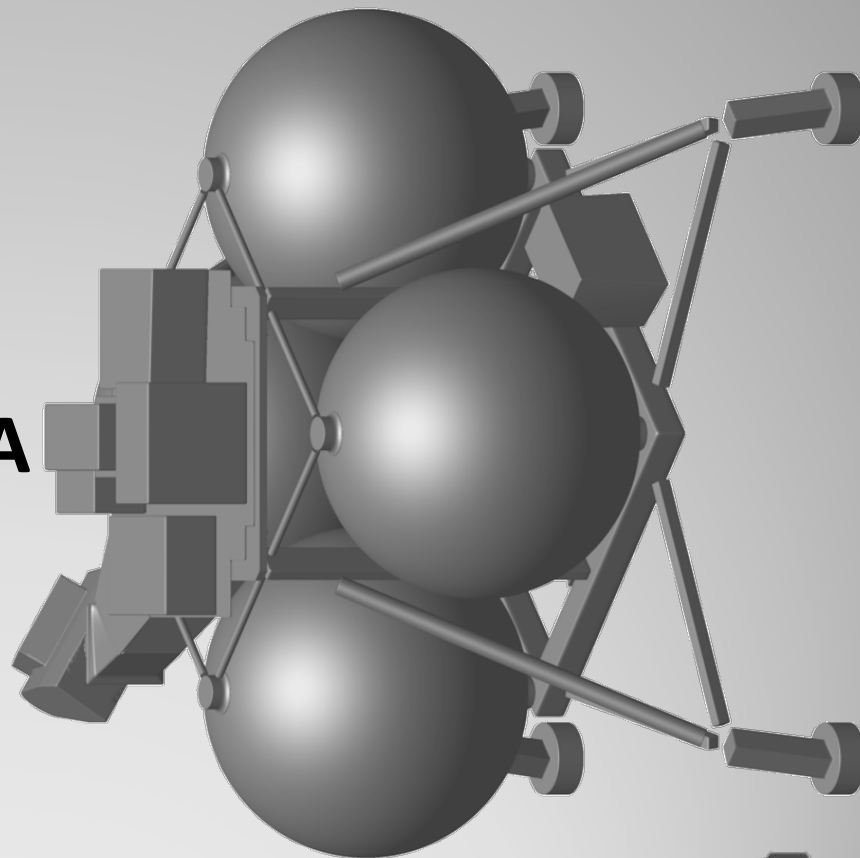
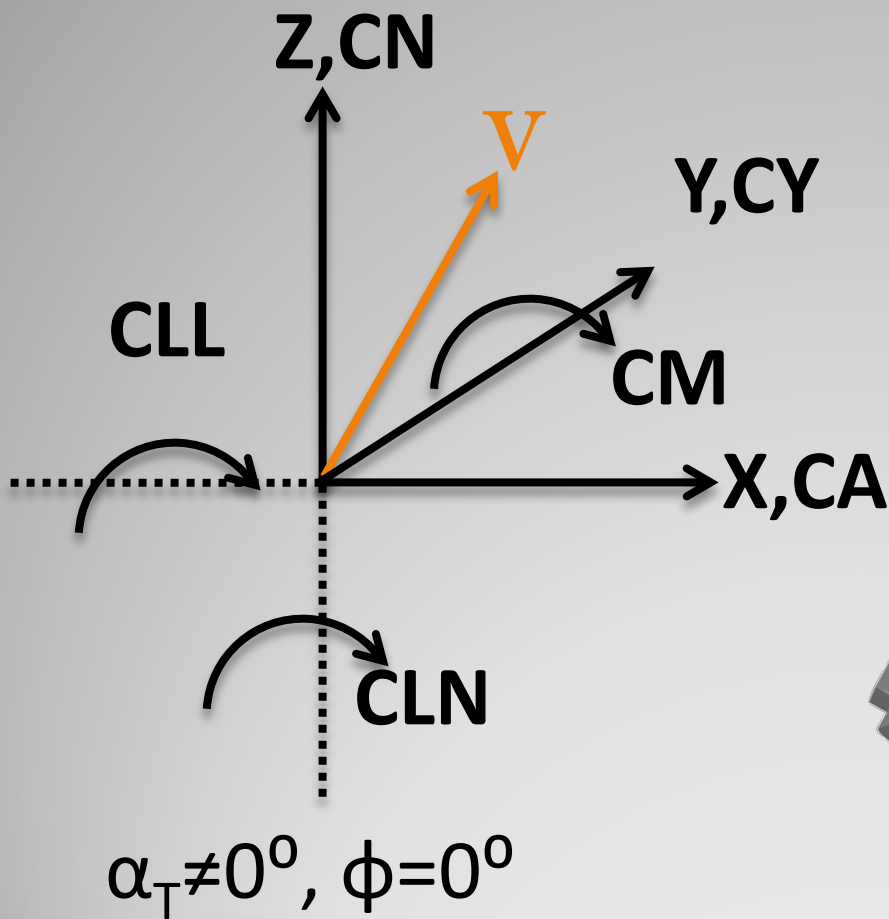




# Aerodynamics

- 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 Body Axes



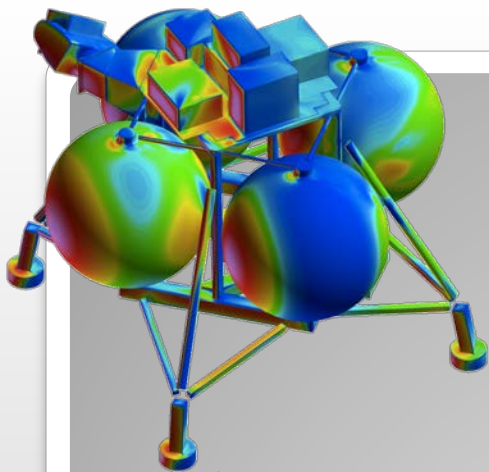


- Wind tunnel testing conducted at the University of Washington Aeronautical Laboratory 8' x 12' wind tunnel to anchor CFD results
- Full envelope of vehicle orientations covered: 360° of roll and angle of attack
  - Low speed of vehicle increases the effects of winds
- Reynolds number sensitivity to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



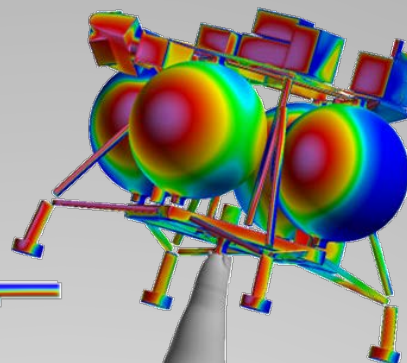
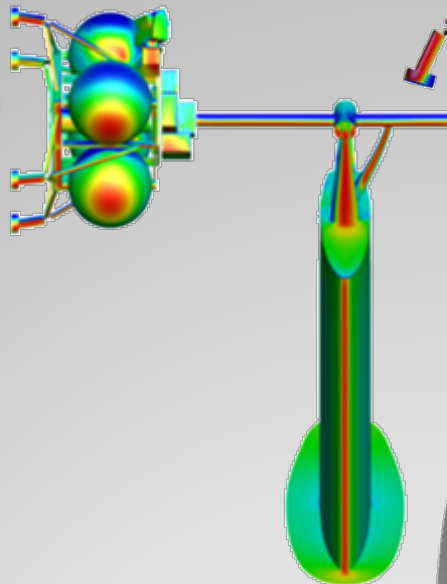
## Wind Tunnel Test



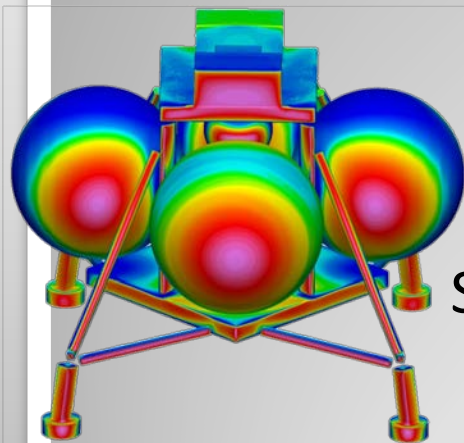


Morpheus 1.5

WTT Tare

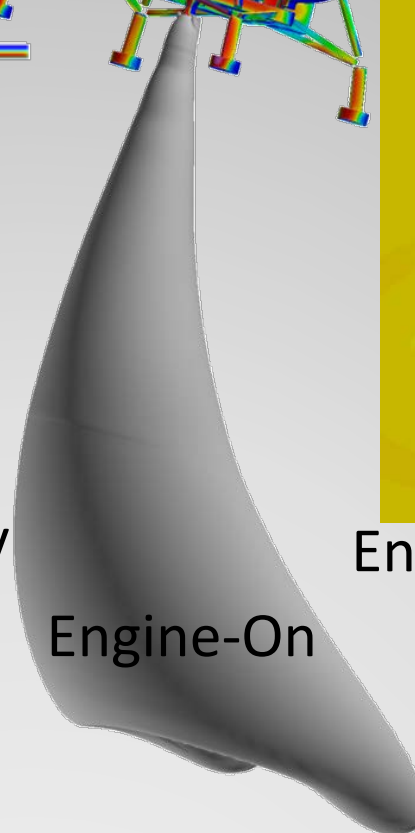
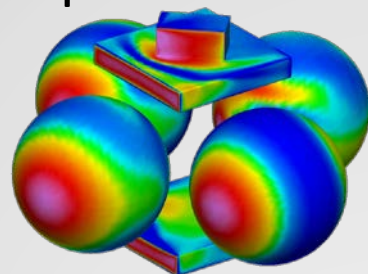


Morpheus 1.5+



Morpheus 1.0

Simple Geometry



Engine-On



Proximity and  
Environment Mitigation

## Configurations of Morpheus Vehicle Assessed



11/1/201

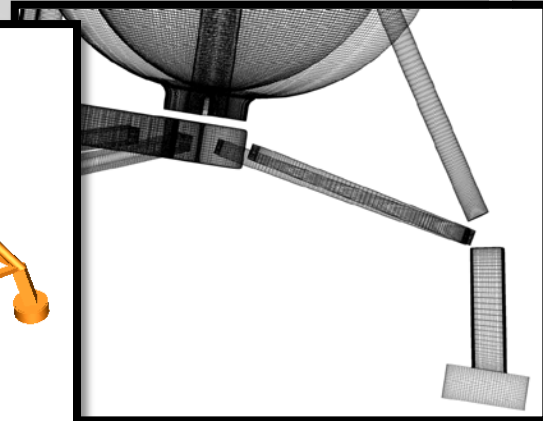
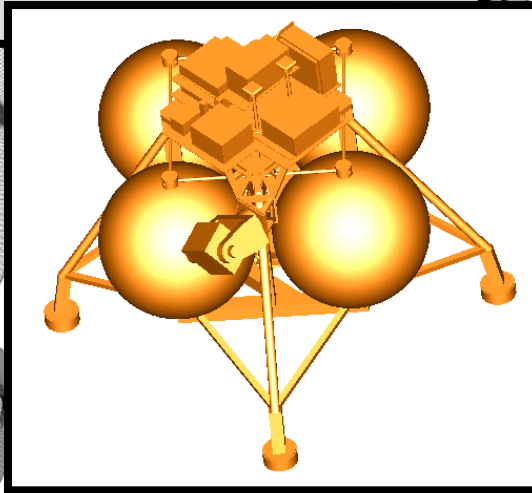
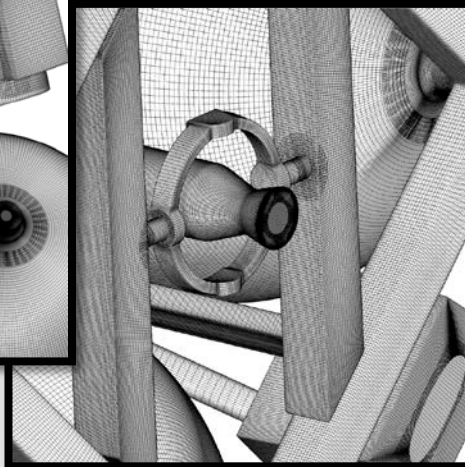
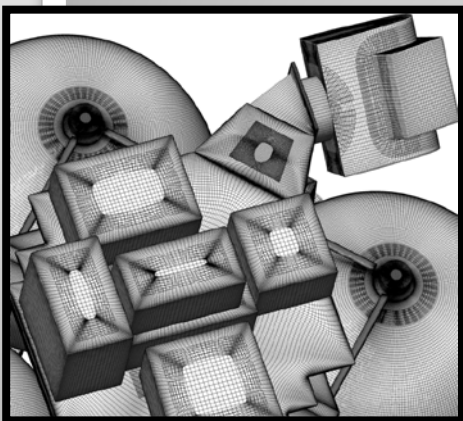
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Project Morpheus, 11th Symposium on Overset Composite  
Grids and Solution Technology

8



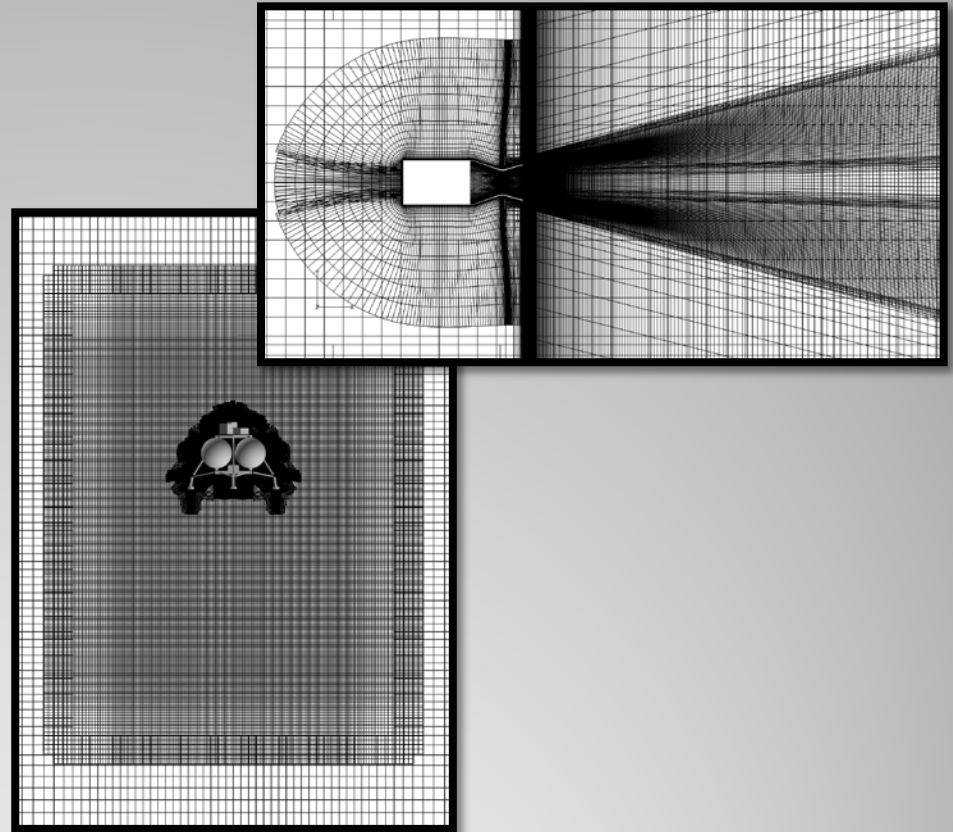
- Grids generated with Chimera Grid Tool 2.1+
- PEGASUS 5.1n used for domain connectivity
- 184+ grids defined with 90 million+ grid points
  - Features include: LIDAR transmitter/receiver, engine, fuel lines, avionics plate, wake box for subsonic flow
  - Approximated features: avionics “boxes,” junction of leg struts, stationary LIDAR & engine, thicknesses of some plumbing features



## Overset Grids



- Steady State
  - Constant CFL
- SST turbulence model
  - No compressibility correction
- Numerical Methods
  - Initial Results:
    - RHS: Central Differencing
    - LHS: Beam-Warming Scalar
  - Later Results:
    - 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



## OVERFLOW Setup

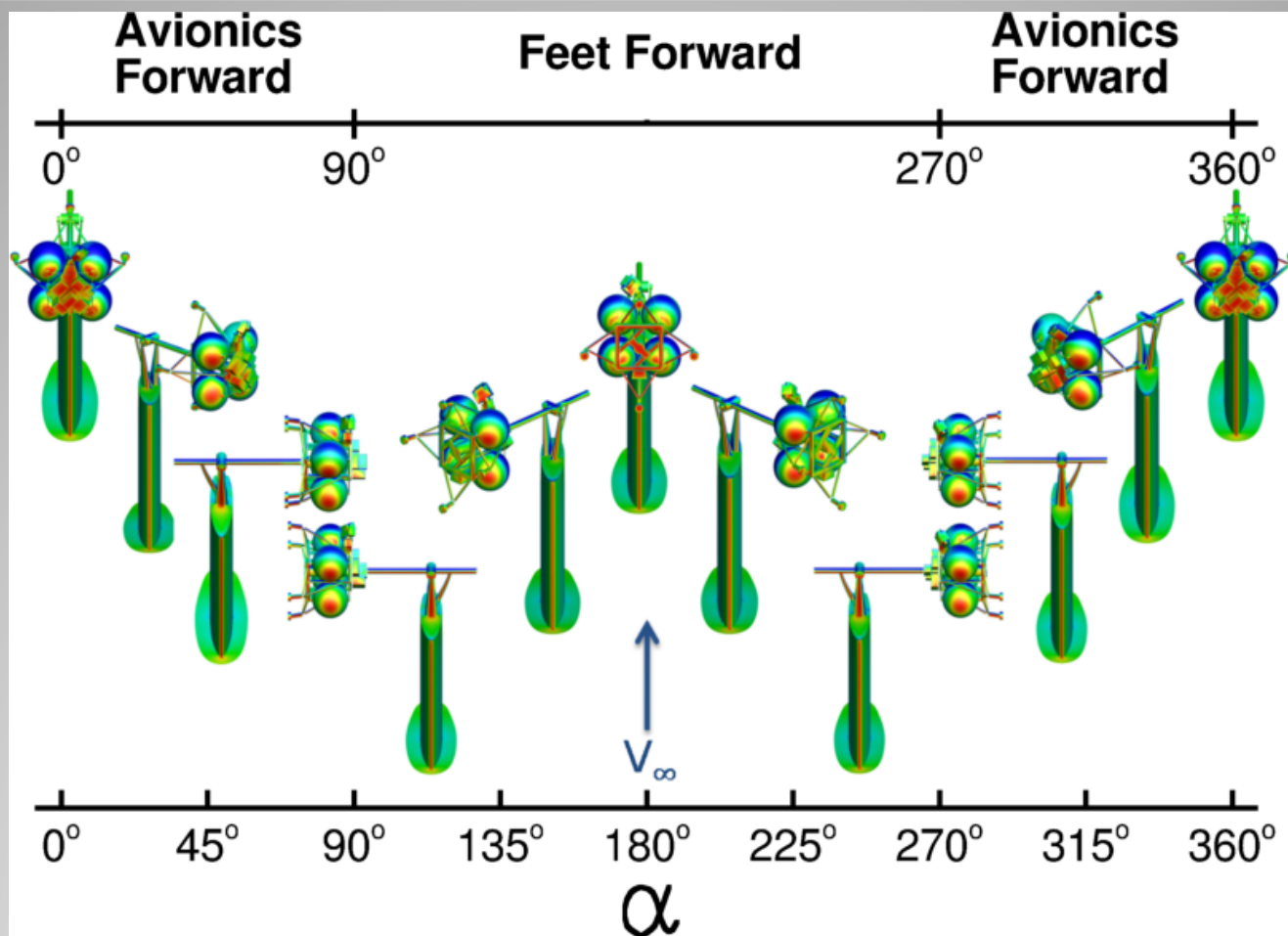


- Runs performed at NASA JSC on L1 cluster
  - SGI Altix ICE

Config	Cases	CPU Hours
Simple	11	7000
Morpheus 1.0	62	64,000
Morpheus 1.5	138	380,000
WTT Conditions	64	170,000
WTT Tare	10	64,000 <sup>+</sup>
Morpheus 1.5 <sup>+</sup>	23	84,000
Plume On	15	57,000
Engine Only	3	14,000 <sup>*</sup>
Ground Proximity	2	94,000 <sup>*</sup>
Flame Trench	13	170,000 <sup>*</sup>
<b>Total</b>	<b>341</b>	<b>826,000</b>
*Not included in Total CPU Hours		
<sup>+</sup> Run on Pleiades		

## Computational Metrics



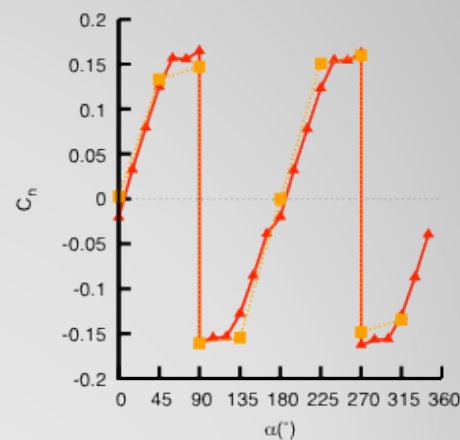
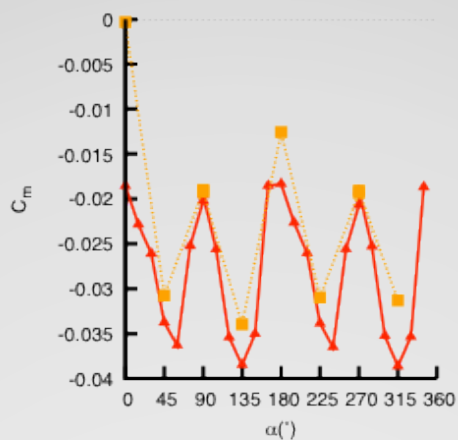
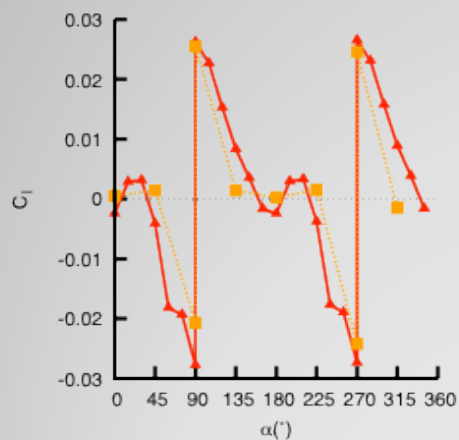
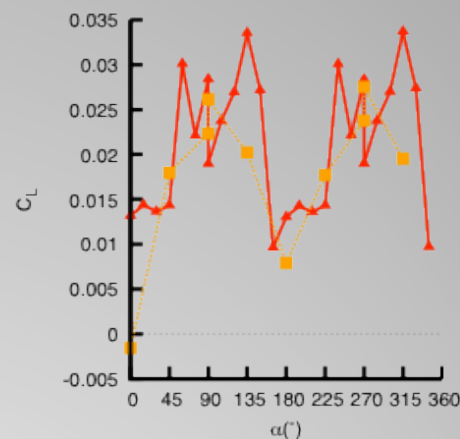
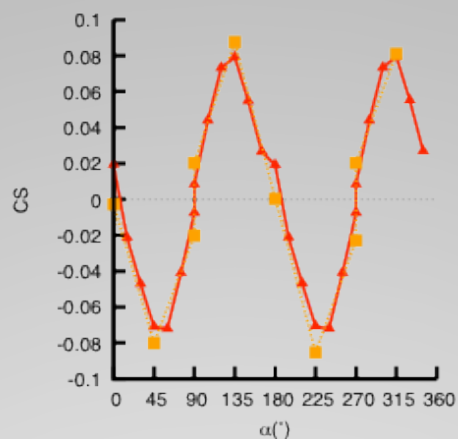
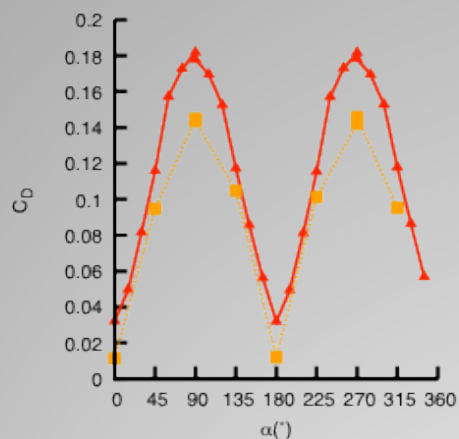


## Sampling of CFD Results: Wind Tunnel Tare Assessment



WTT strut tare —▲—  
CFD tare —■—

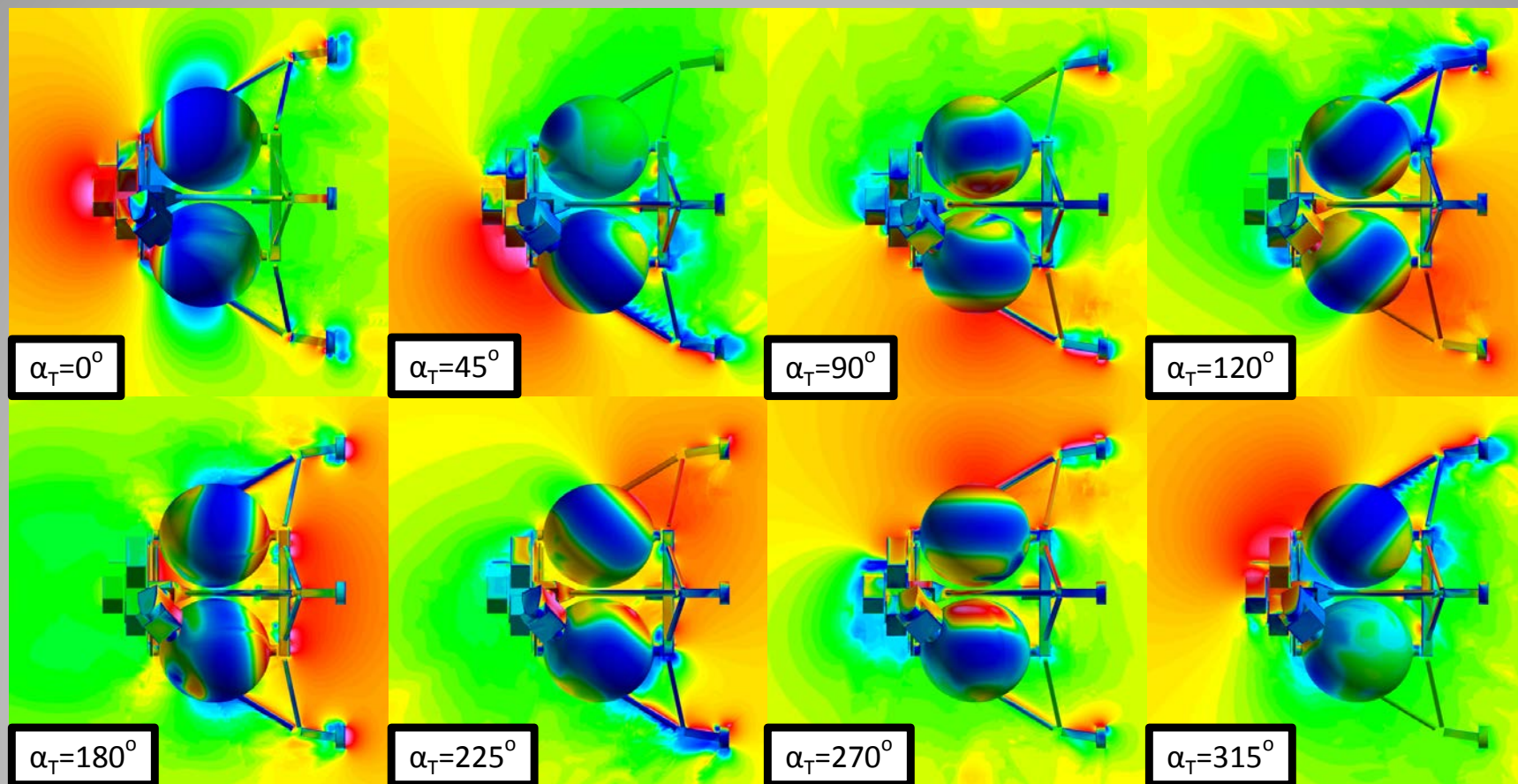
Morpheus Roll=45° Velocity=100 mph Tare comparison



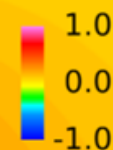
# WTT Tare Comparison







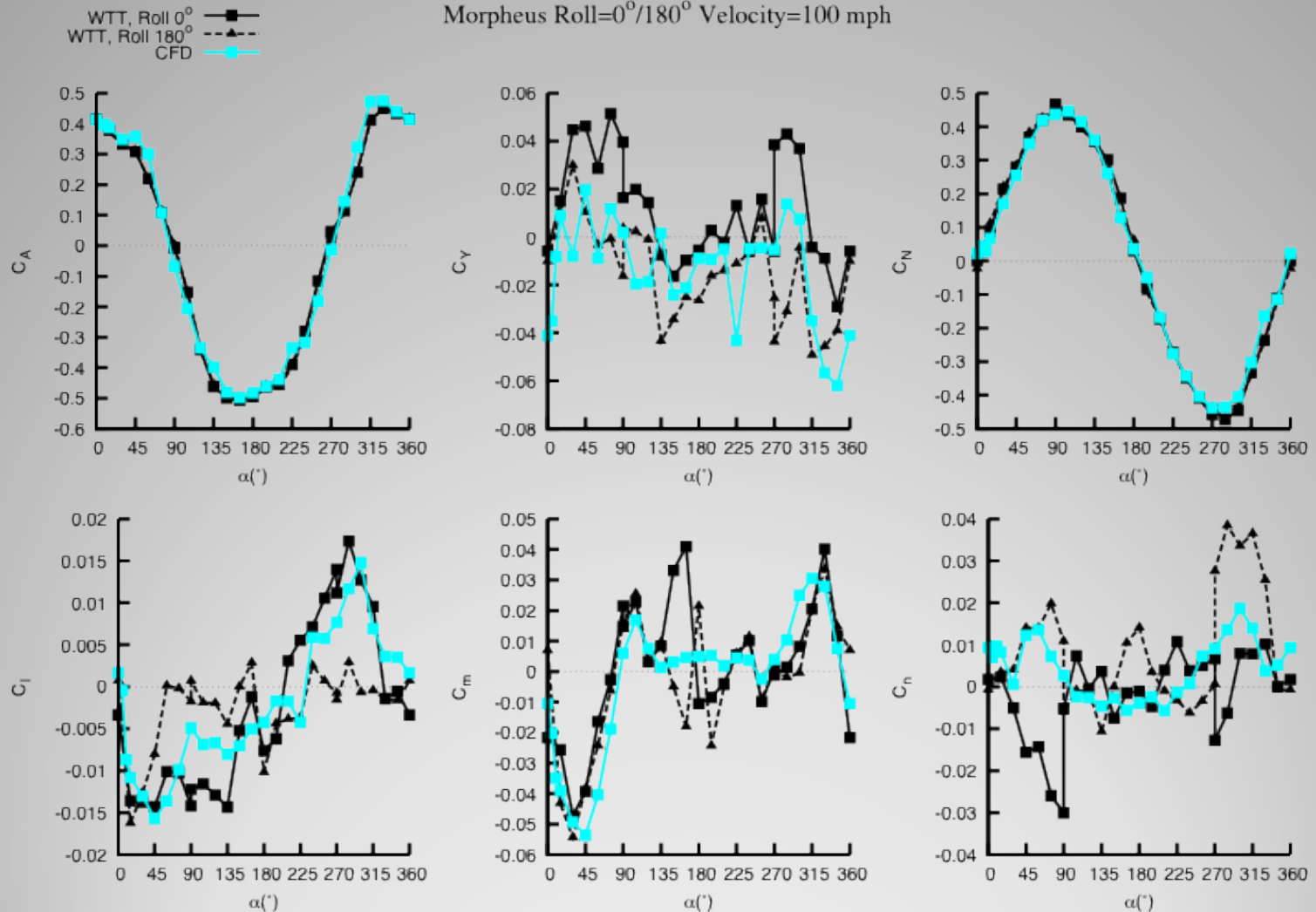
Cp [PLOT3D]



# Sampling of CFD Results: Free Flight, Roll $225^\circ$ @ Mach 0.13



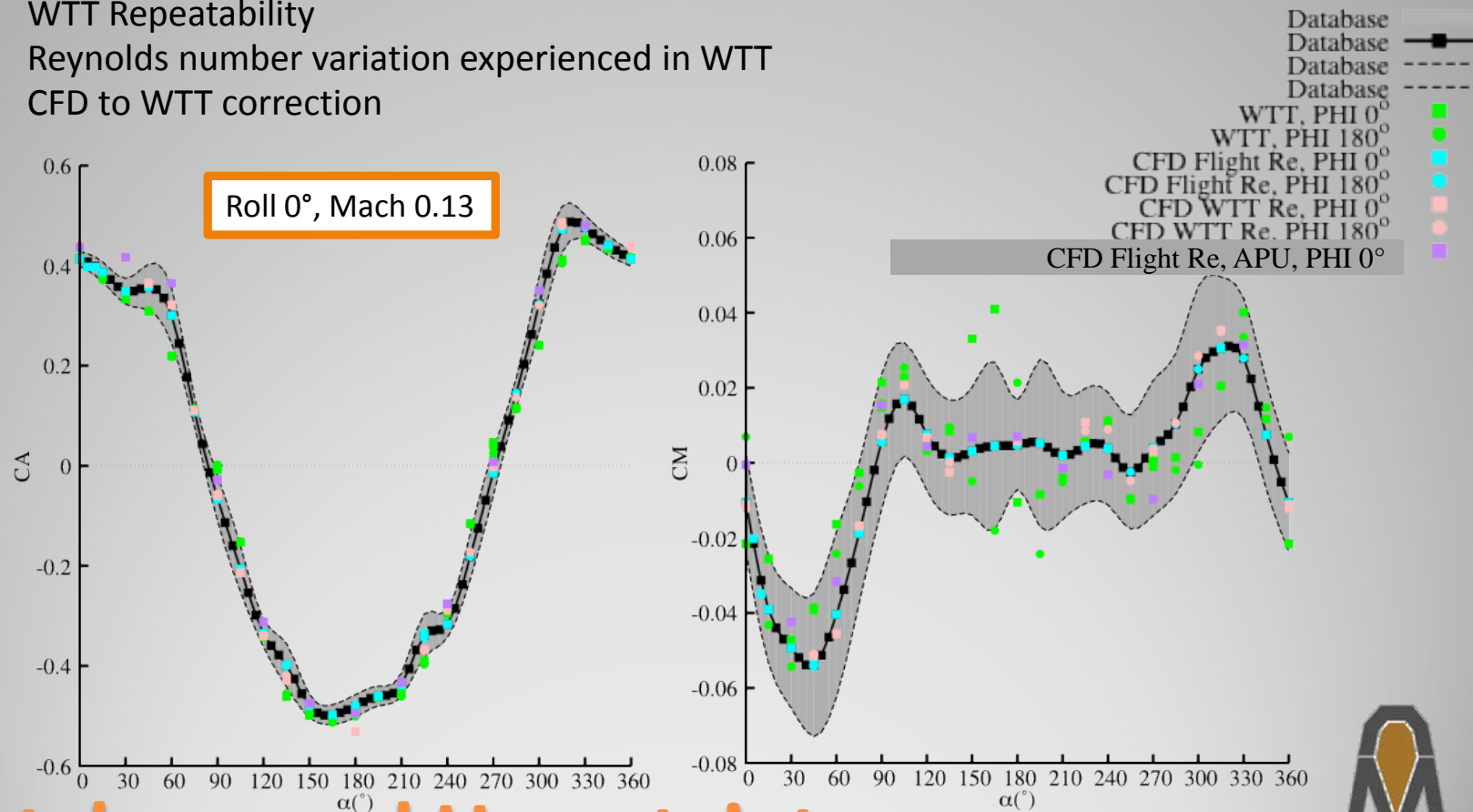
Morpheus Roll=0°/180° Velocity=100 mph



# CFD to WTT Comparison



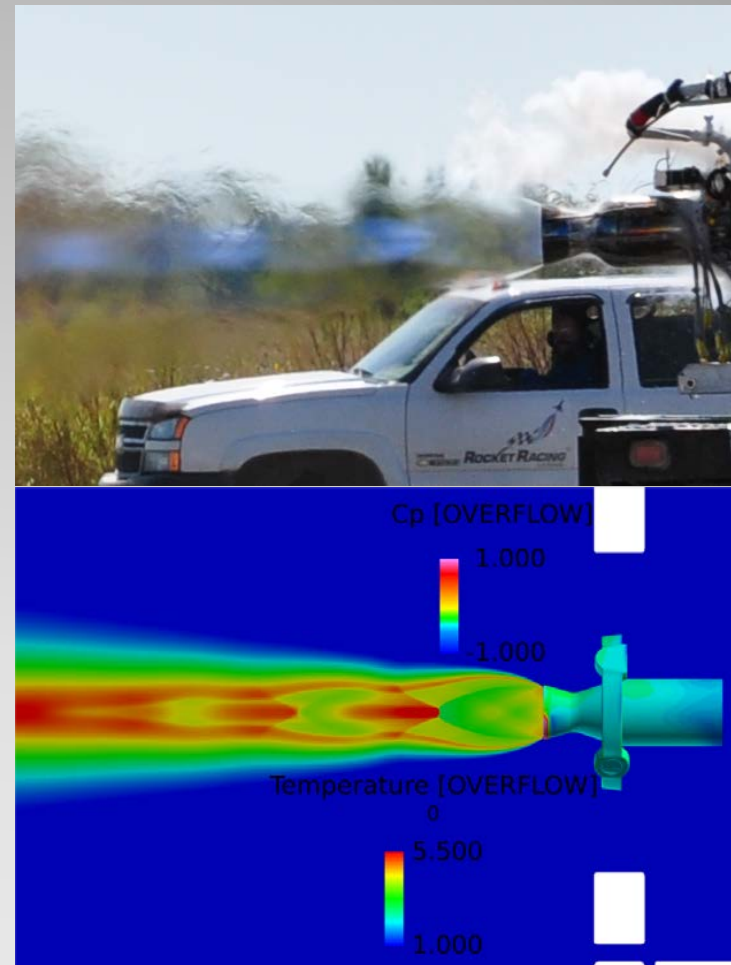
- Database developed from WTT data and CFD Flight & WTT Conditions results
- Nominal data based on CFD at Flight Conditions
- Uncertainty for each coefficient built from three components:
  - WTT Repeatability
  - Reynolds number variation experienced in WTT
  - CFD to WTT correction



## Database and Uncertainty



- Initial plume simulated with air
  - Later results created from approximated LOX-Methane conditions at nozzle exit
- Inflow boundary surface specified at the plenum exit
- ~Mach 4.2 flow at nozzle exit

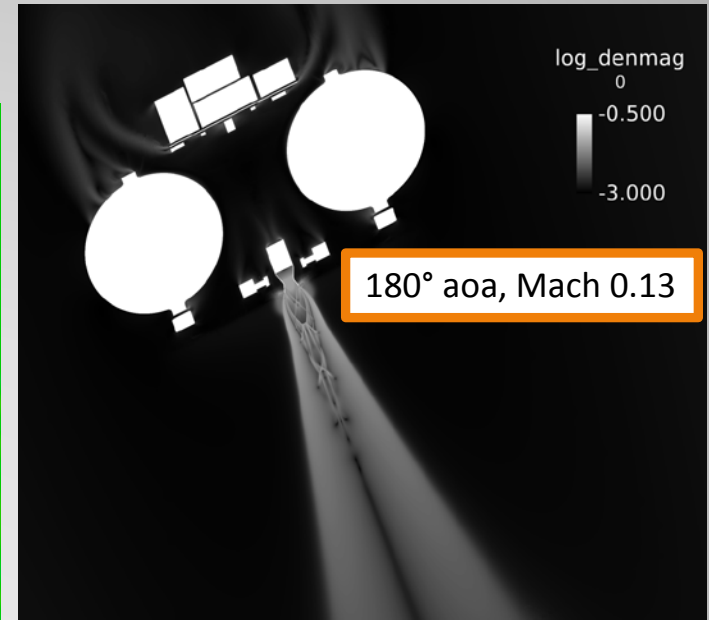
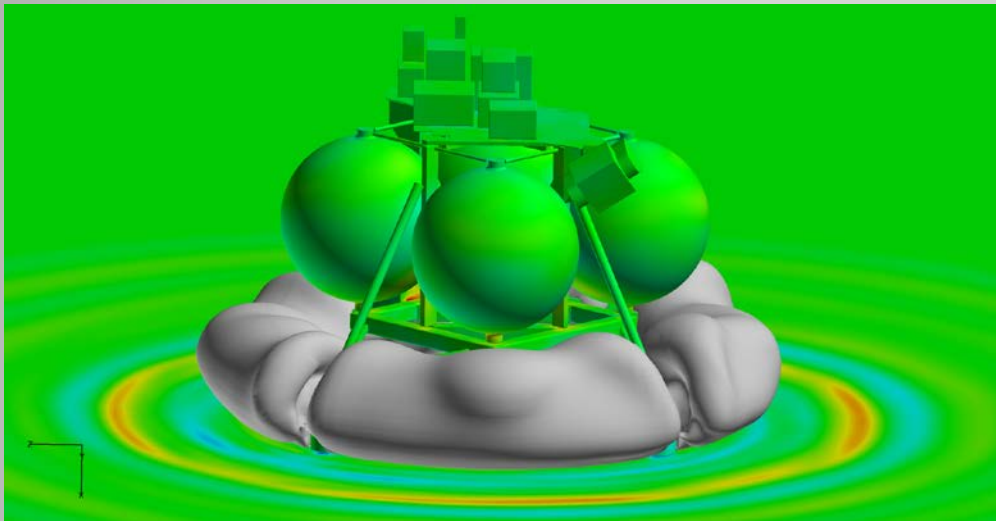


## Sampling of CFD Results: Engine-On





- Engine-On increment added to database from plume modeling CFD results
  - Most influence on axial force  $\pm 10^\circ$  around  $180^\circ$  total angle of attack
- Flight testing shows strong plume structure  $\sim 5$  ft in length
- IOP waves captured by CFD

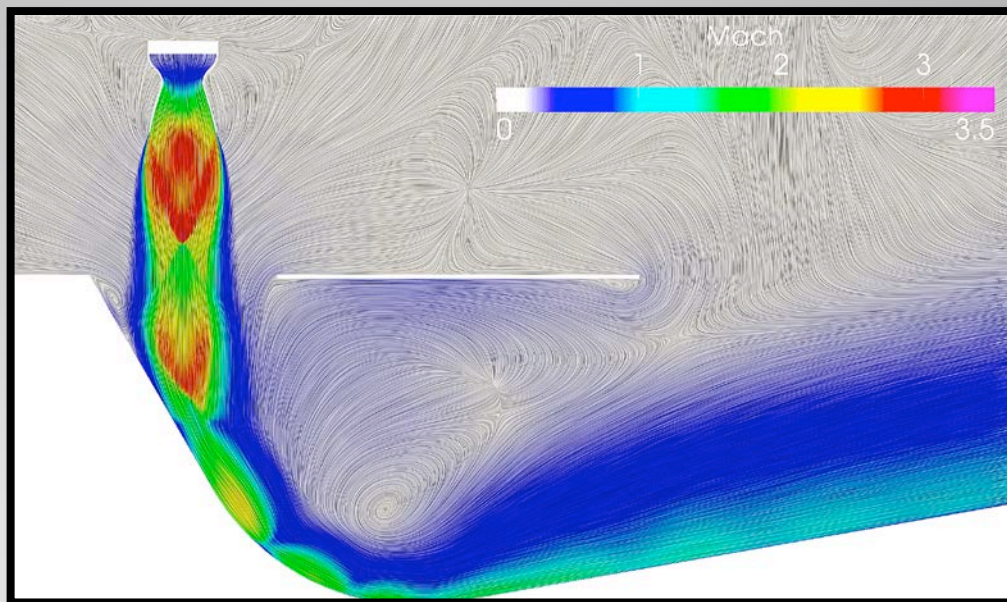


## Sampling of CFD Results: Plume & Ground Effects





- CFD matches trends seen in wind tunnel 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

## Conclusions & Future



# Questions?

Thanks to contributors: Ray Gomez, Phil Stuart, Phil Robinson, Jim Greathouse and Tuan Truong at NASA JSC.