
# Towards the Prediction of Entry Capsule Dynamic Stability Characteristics with Reduced Free Flight Motion in FUN3D

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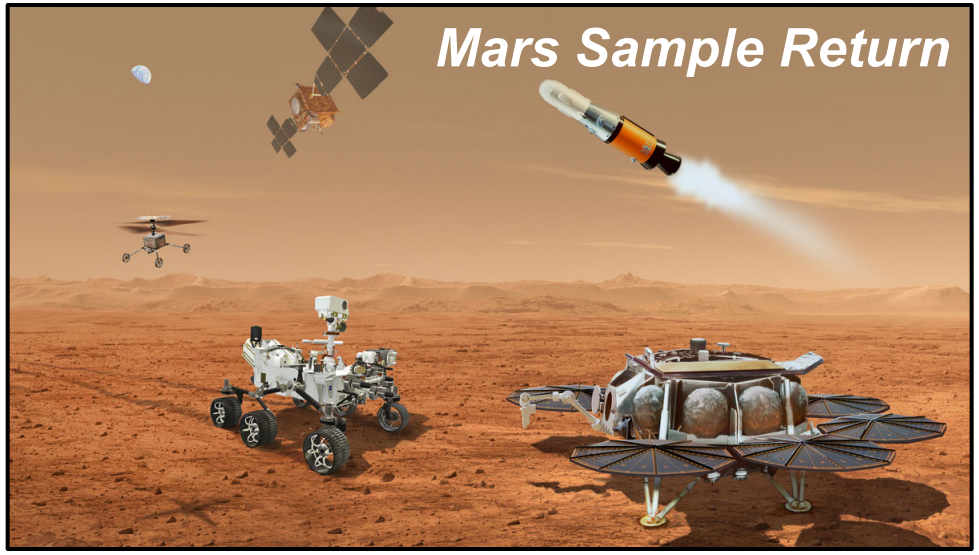
# Motivation

- Multiple entry, descent, and landing (EDL) flight projects are actively working to characterize entry capsule dynamic stability in the subsonic, transonic, supersonic flight regimes
- Limited access to in-demand ground test facilities
- Expand / enhance available test data with free-flight computational fluid dynamics (CFD)
  - Provide greater insight to ground test cases
  - Simulate cases not possible in ground testing
  - Isolate component effects and flowfield physics
- Constraining degrees-of-freedom (DOF) reduces model complexity and isolates DOF contributions

**Objective:** Verify FUN3D's 6-DOF path and begin active application to flight projects. Work towards a computational predictive capability for entry capsule dynamic stability such that data from concurrent ground testing will enable validation efforts of this solver and its continued use on EDL vehicles.


Image credits: NASA



# Outline

- Motivation
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- Background
- Solver
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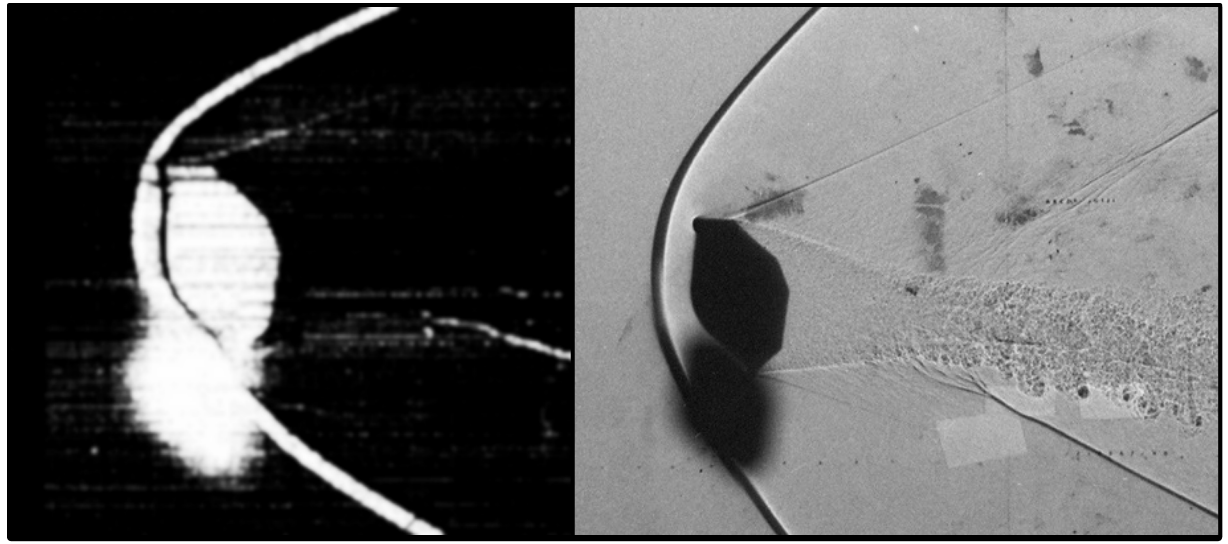
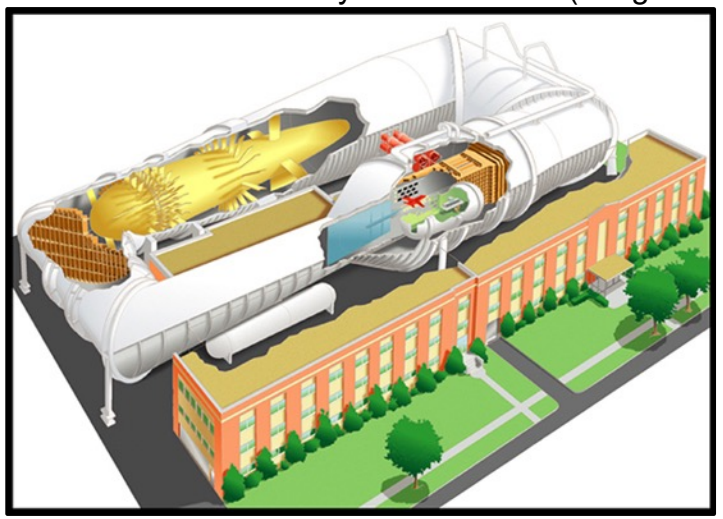
# Background

- Historical Approach
  - Historical EDL flight and test data
    - Degradation of data poses concerns
  - Ground testing
    - Wind Tunnel (VST, TDT)
    - Ballistic Range
  - Limitations
- Other Current Computational Approaches to Capsule Stability
  - ARC/ESM Free-Flight CFD (US3D) [2,3,4]
  - POST2/FUN3D Coupling [5]
  - OVERFLOW 6-DOF [6]

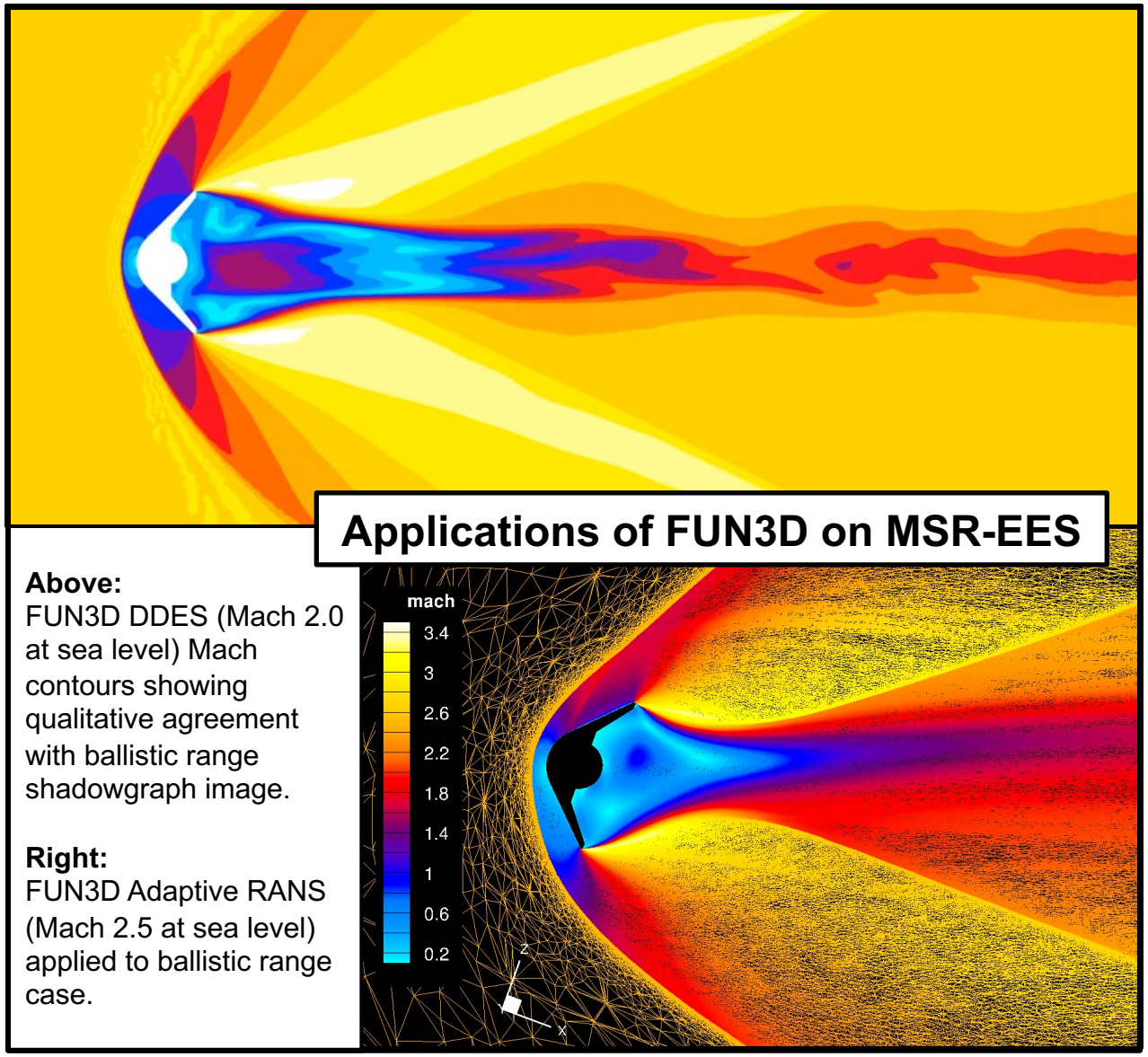


**Above:** Genesis ballistic range test report [1] image (left) compared to a rescanned image at similar orientation and unknown condition (right)
**Below:** NASA LaRC's Transonic Dynamics Tunnel (Image Credit: NASA)



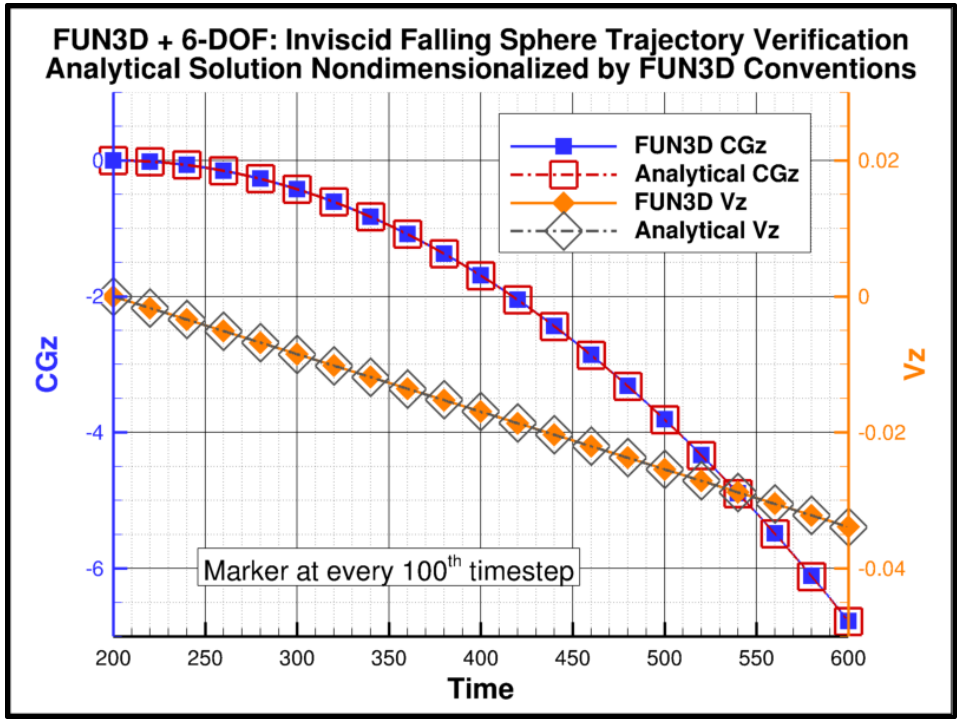
# Solver

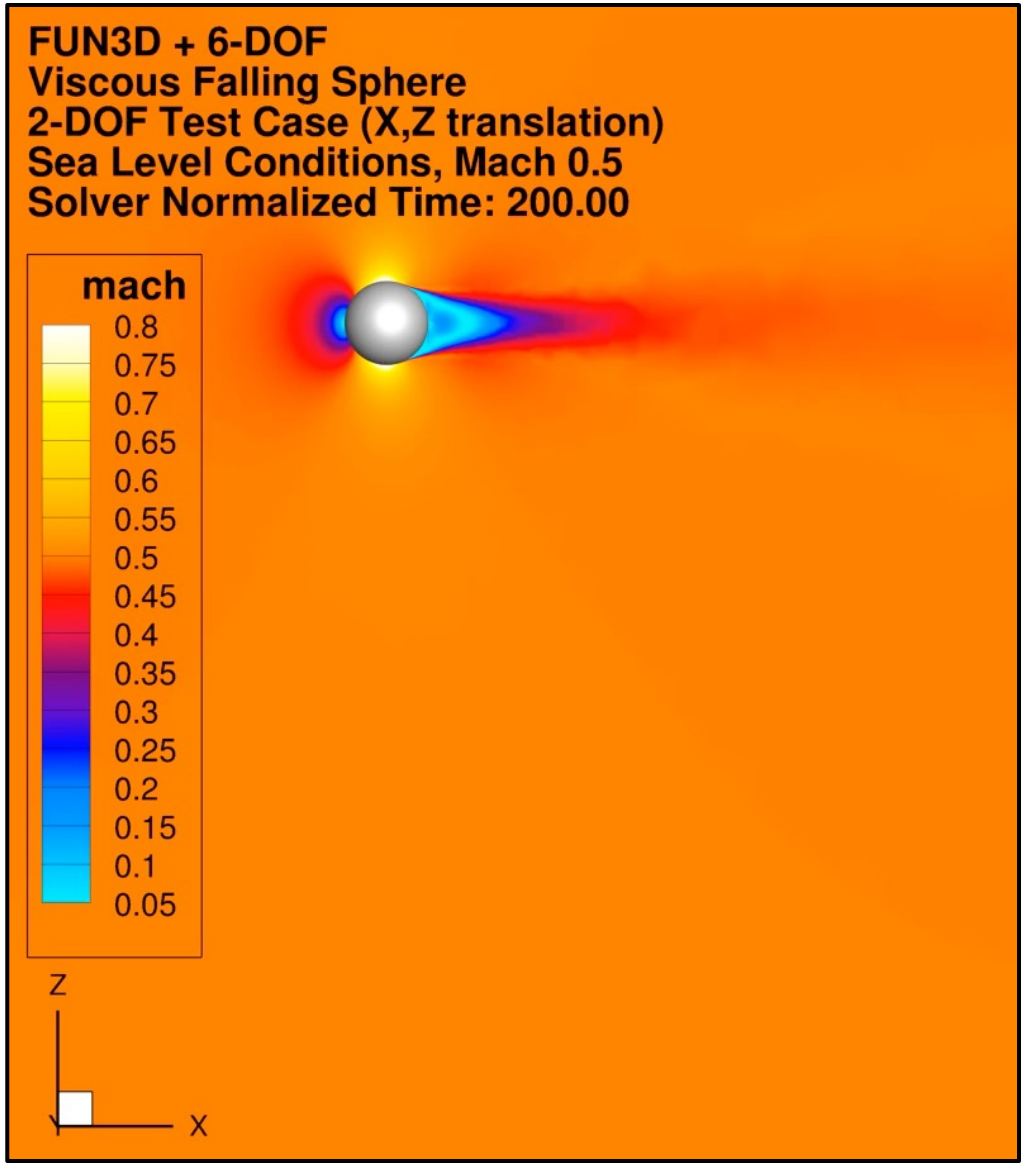
- FUN3D
  - Circa late 1980s
  - Unstructured solver
  - NASA LaRC developed
  - Widely used by government, academia, and industry
  - Active use for capsule aerodynamics, EDL technologies
  - Offers multiple approaches
- 6-DOF Library
  - Developed by Koomullil et al. [7]
  - Coupled to FUN3D in late 2000s [8]
  - Little documented use in FUN3D
  - Required rediscovery



# Verification: Falling Sphere

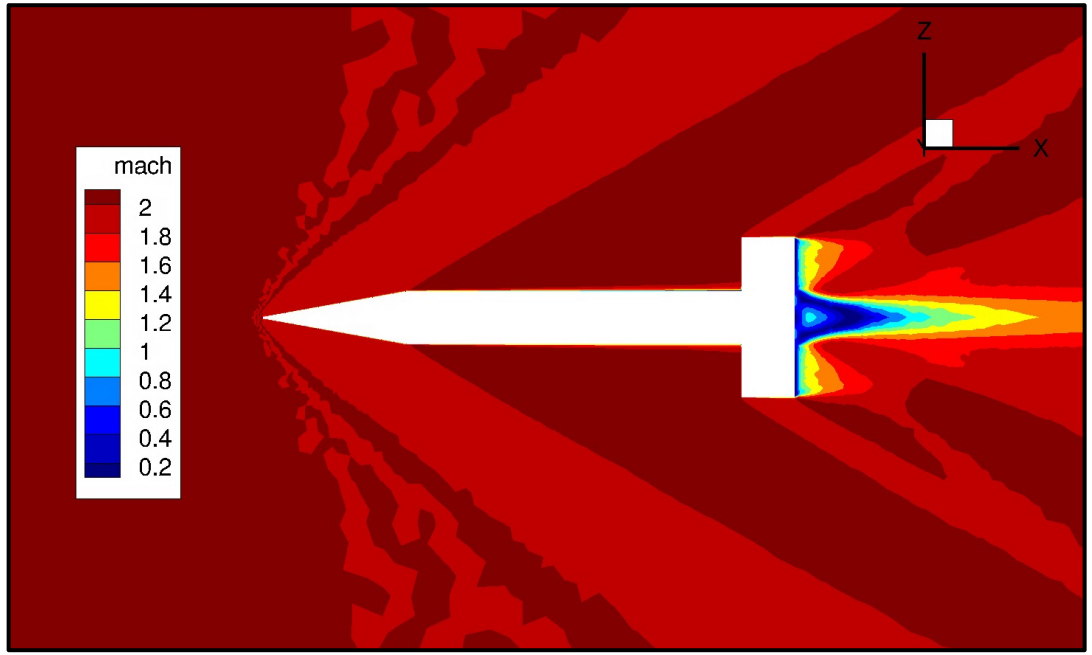
- Inviscid Case
  - Analytical solution → $z_t = z_0 + v_{z,0}t + \frac{1}{2}gt^2$, $v_{z,t} = gt$
  - Verify body movement
- Viscous Case
  - Step towards application



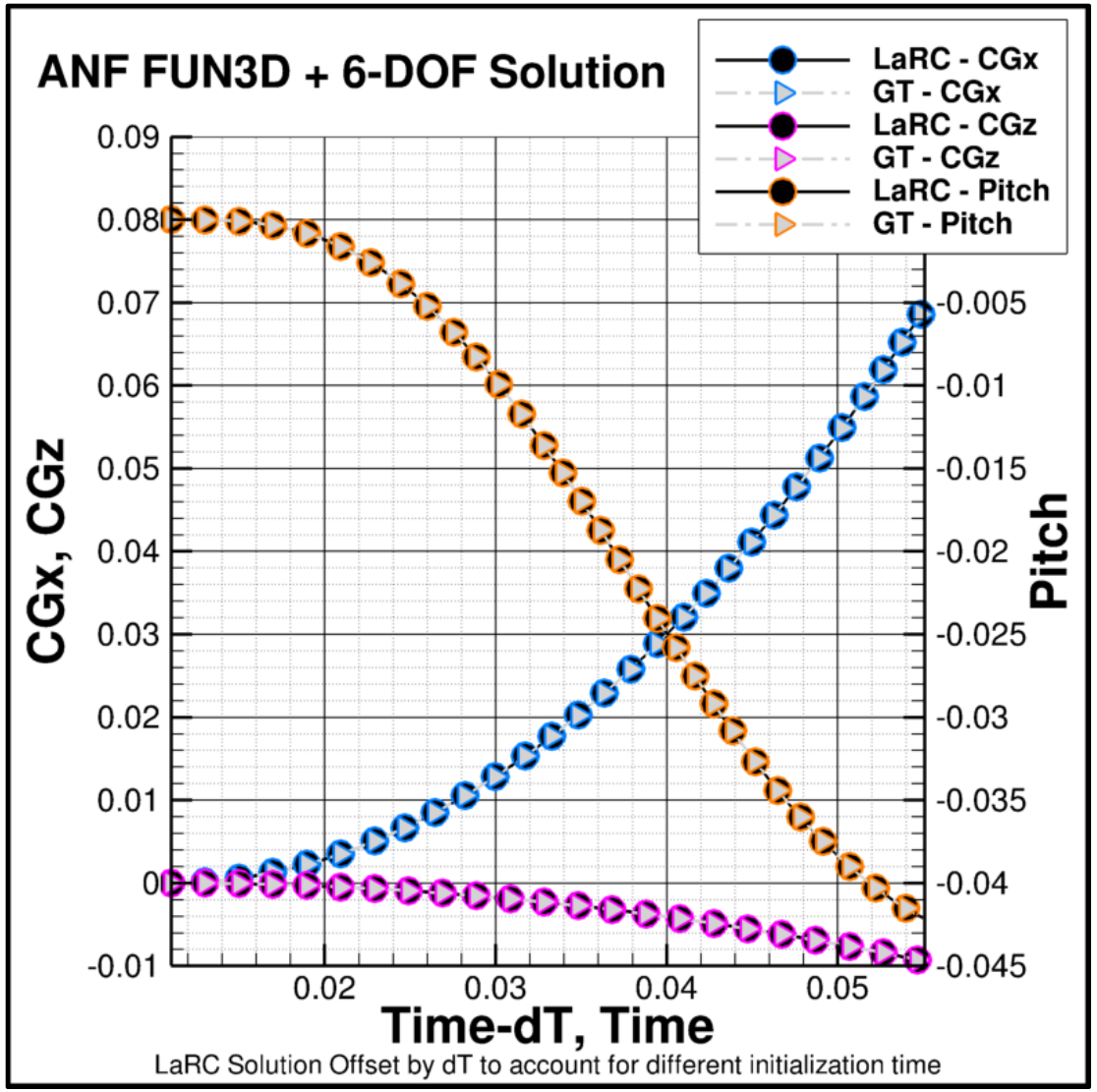



# Verification: Army-Navy Finner

- Provided by GT POST2/FUN3D team
  - Case uses FUN3D's 6-DOF path
- Used in GT framework verification [9]
- Verify LaRC solver build



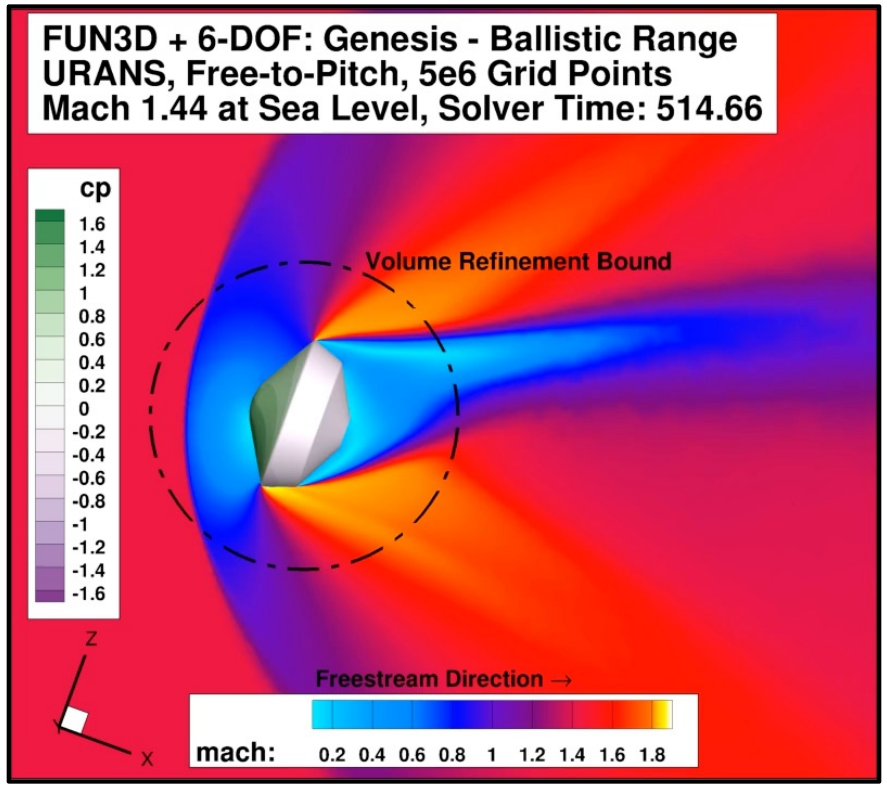

**Army-Navy Finner (ANF) geometry in unpowered 6-DOF free flight, Mach 2 condition at $t_{final}$**

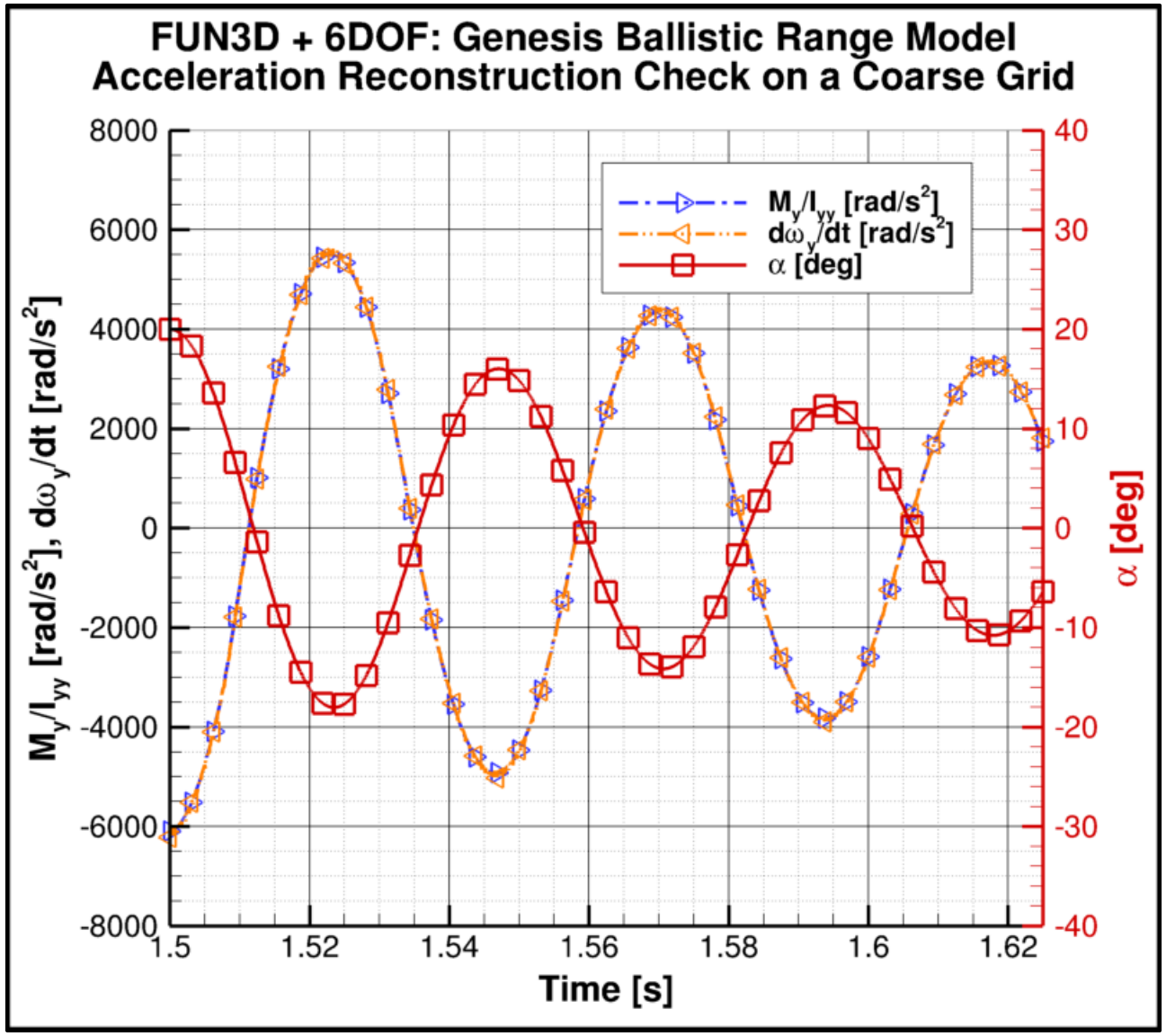



**Solutions verify solvers behaving as expected**

# Verification: Blunt Bodies

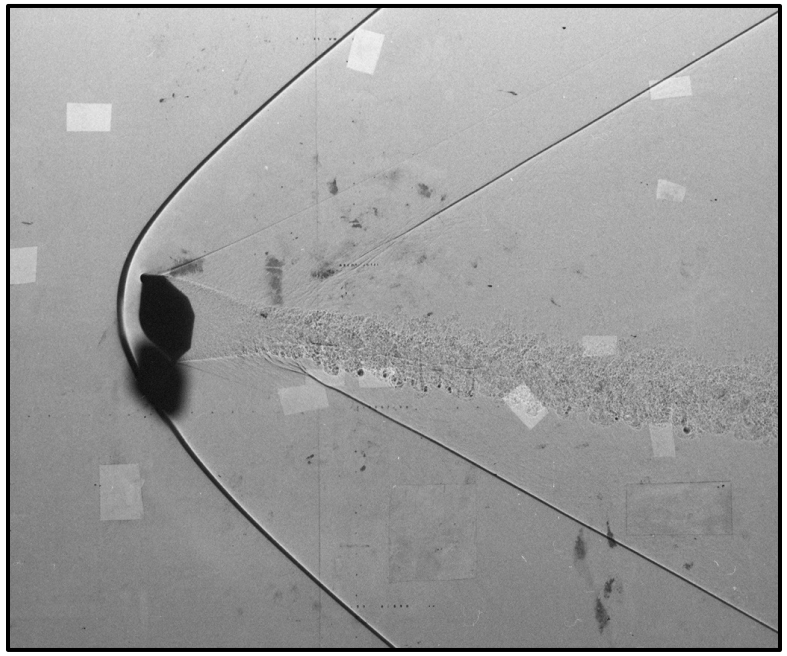
- Final step before application to flight vehicles
- Verify free-to-pitch solution against $M_i = I_{ii} \frac{d\omega_i}{dt}$



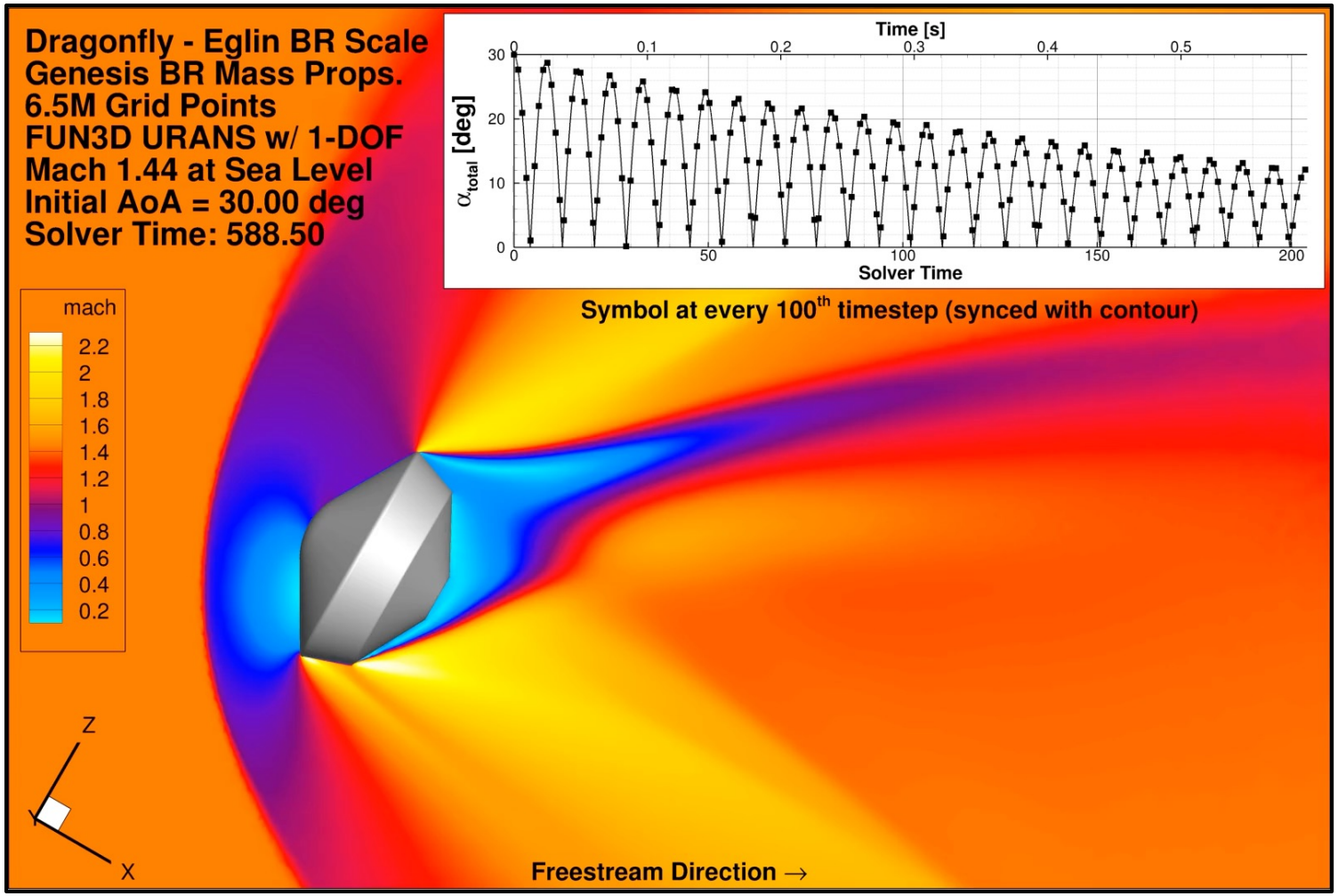



# Flight Project Applications: Dragonfly

- Dragonfly Entry Capsule
- TDT and Genesis ballistic range conditions [1]

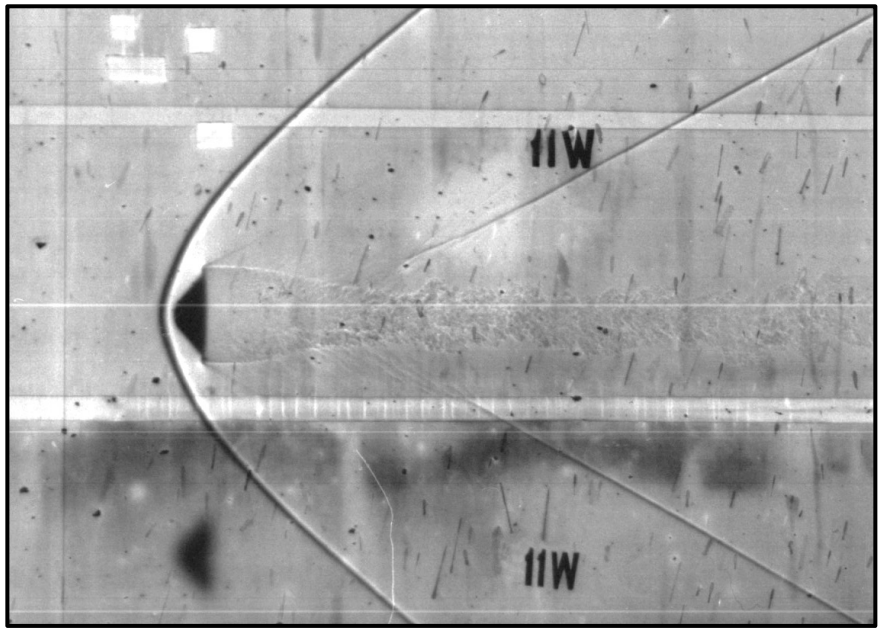


**Genesis Model in the Eglin Ballistic Range (rescanned)**

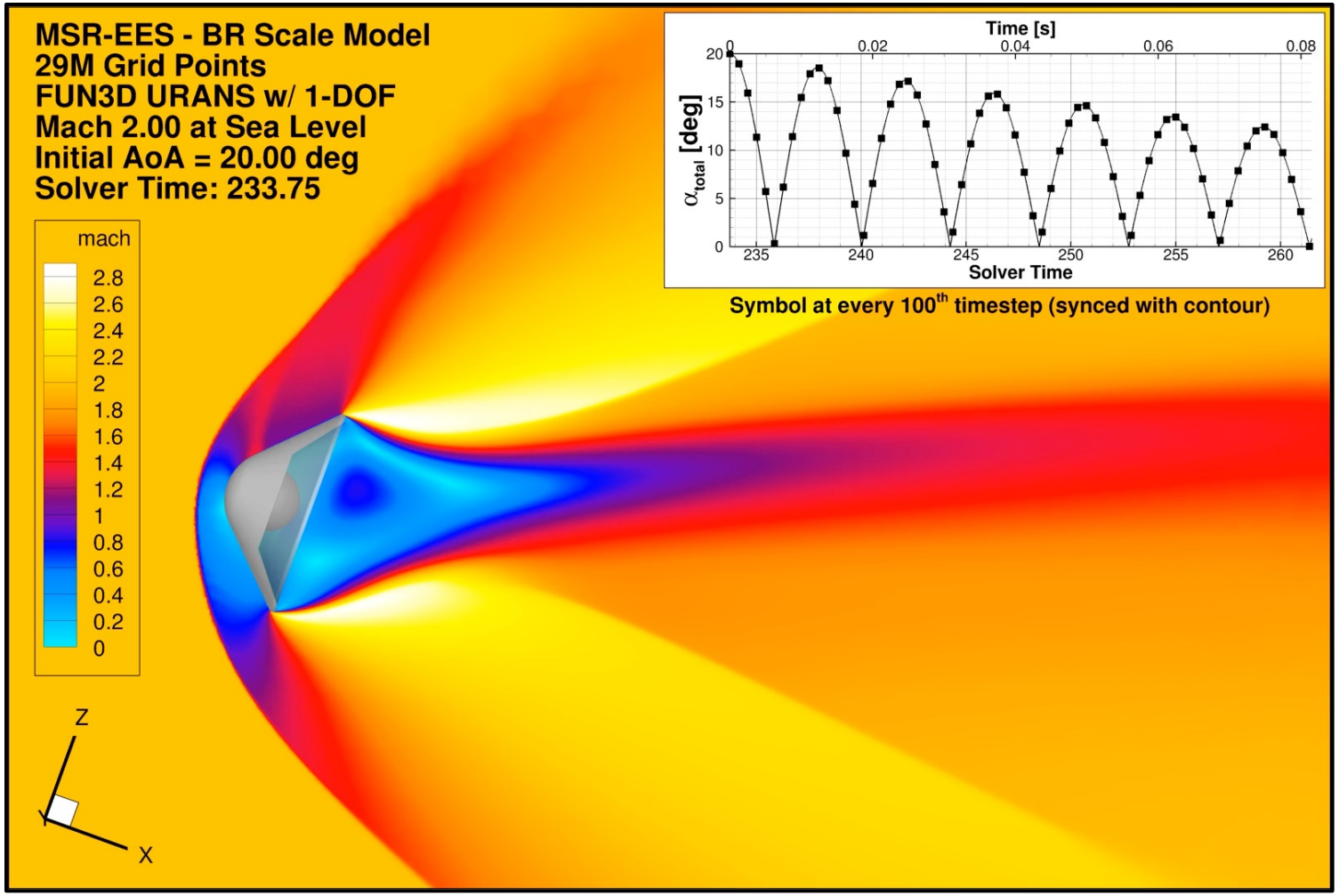


# Flight Project Applications: Mars Sample Return

- Earth Entry System (EES)
  - Current focus on ballistic range conditions
  - Expand to compare with recent TDT testing

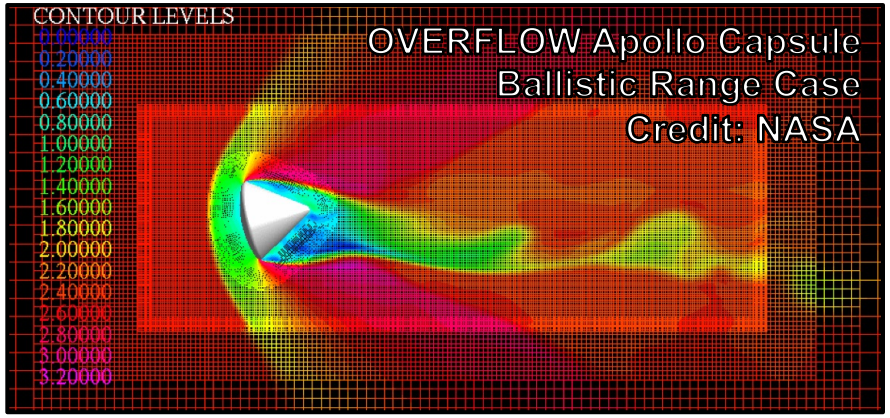



EES Model in Ballistic Range

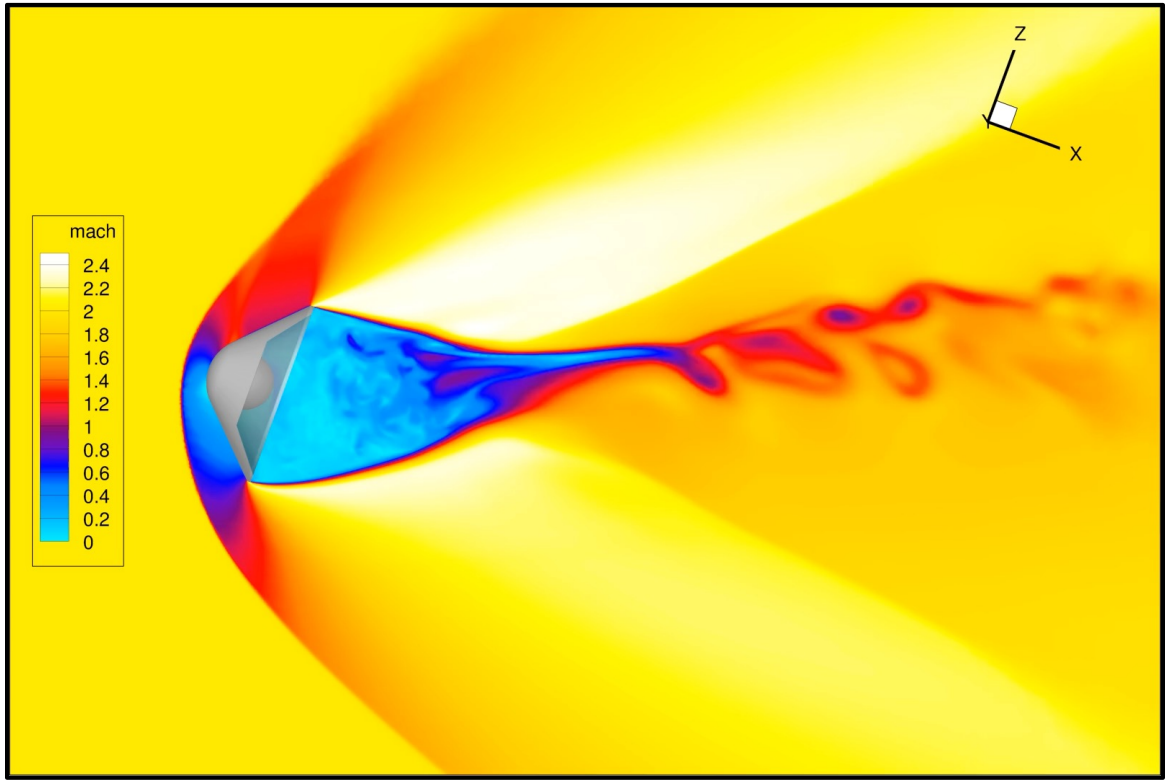


# Future Work

- Data Reduction Pipeline
- Lower-Transonic Free-to-Pitch
  - Dynamically scale to match recent testing in TDT
- Scale Resolving
  - Refine back-shell contribution
  - Large difference in temporal scales
- Validation by ground test data
- Comparisons to other solvers




**MSR-EES, Free-to-Pitch, Ballistic Range**
**Preliminary FUN3D DDES (29M grid points)**
**Mach 2.0 at Sea Level**




**Multiple orders of magnitude difference in temporal scales to be resolved between fluid and rigid body motion. Further work needed to investigate resolving three-dimensional breakdown in the shear layer.**

# Summary

- FUN3D's 6-DOF path has been brought into active use at NASA LaRC
  - Enhance and expand dynamic stability characterization efforts
- Multiple tests have verified the functionality of this solver for use
- Applications to EDL flight projects have begun
- The data produced in upcoming work will:
  - Be compared to ground test data
  - Enable future validation efforts of the FUN3D + 6-DOF solver
  - Contribute to dynamic stability characterization of entry capsules

**Return to use, verification, and Dragonfly application efforts with FUN3D's 6-DOF solver are funded by the NASA Engineering and Safety Center (NESC)**

# References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# Questions?