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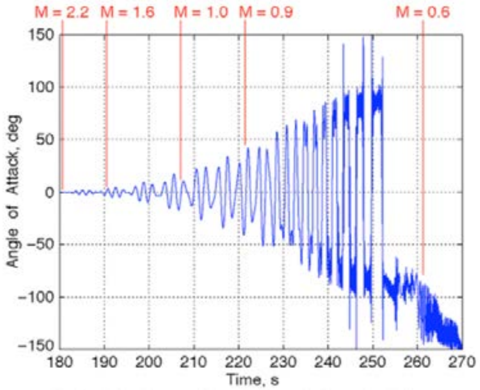
National Aeronautics and Space Administration

PROGRESS ON FREE-FLIGHT CFD SIMULATION FOR BLUNT BODIES IN THE SUPERSONIC REGIME

www.nasa.gov/spacetech

Blunt Body Dynamic Stability

Genesis Sample Return Capsule (Desai, 2008)



- **Blunt-body capsules are very effective at reducing heating to the surface**
- **Dynamic instabilities often arise at low-supersonic and transonic Mach numbers**
- **Dynamic stability is characterized exclusively through experiment — forced-, free-oscillations, ballistic range, and flight tests — however each has drawbacks/ difficulties**
  - **In all cases, flight similitude parameters are difficult to achieve**

- CFD is an integral part of *static* aerodynamic characterization and design.
- Would be desirable to have similar capability for *dynamic* aerodynamics

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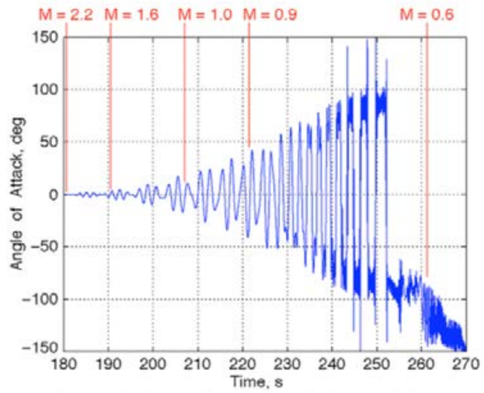

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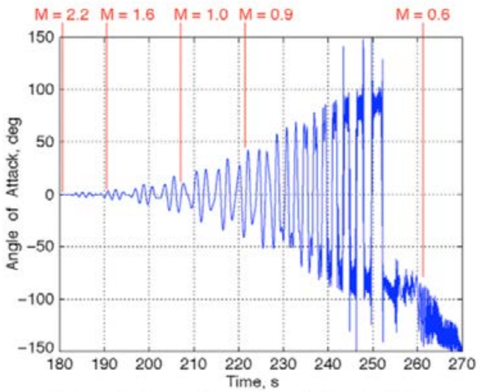

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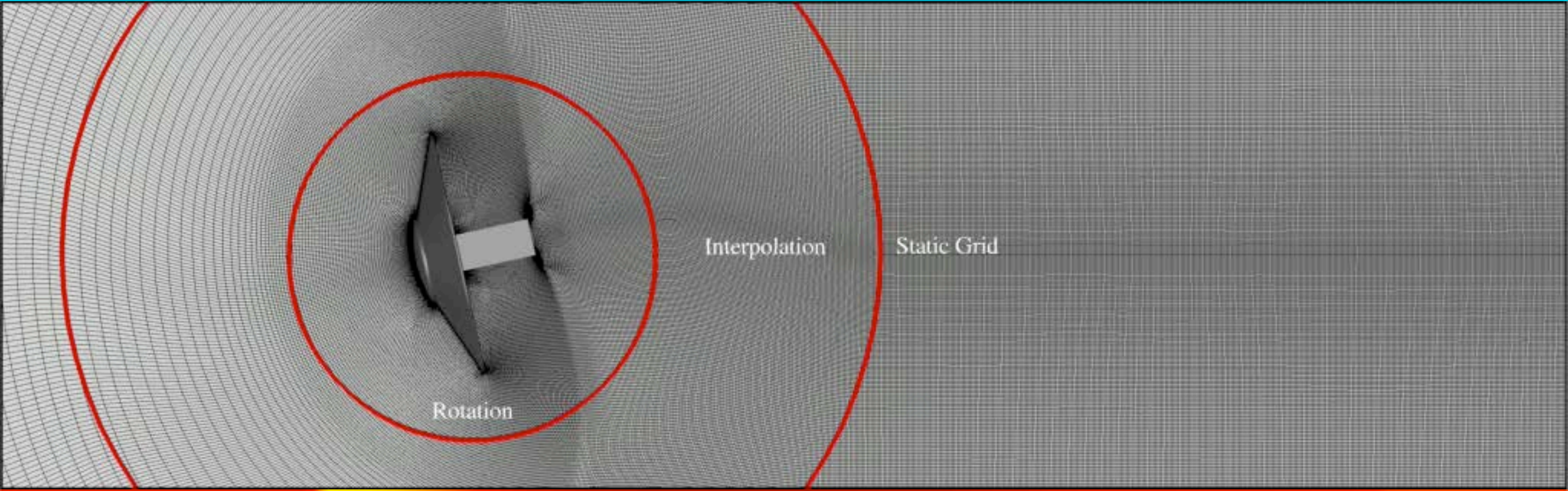
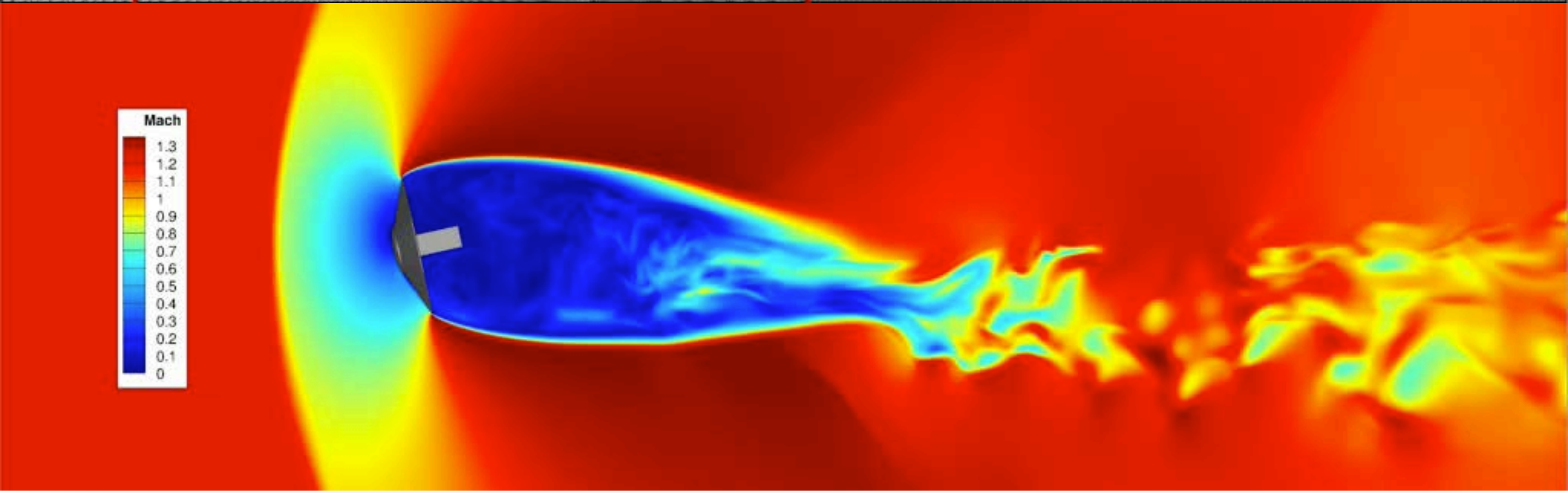
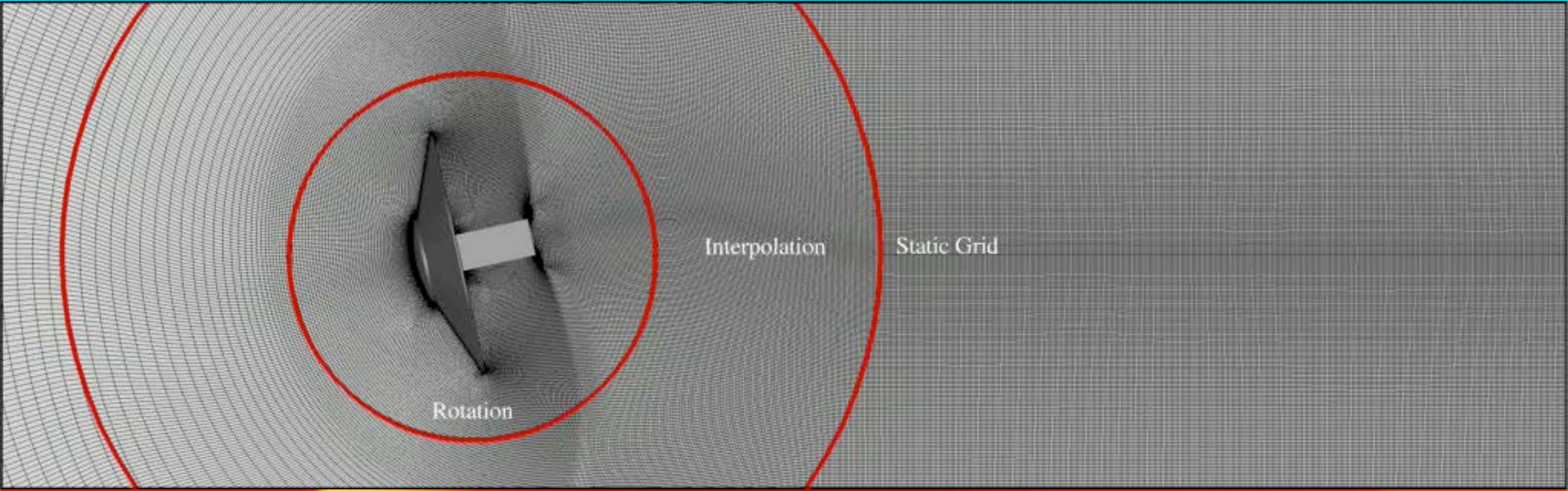
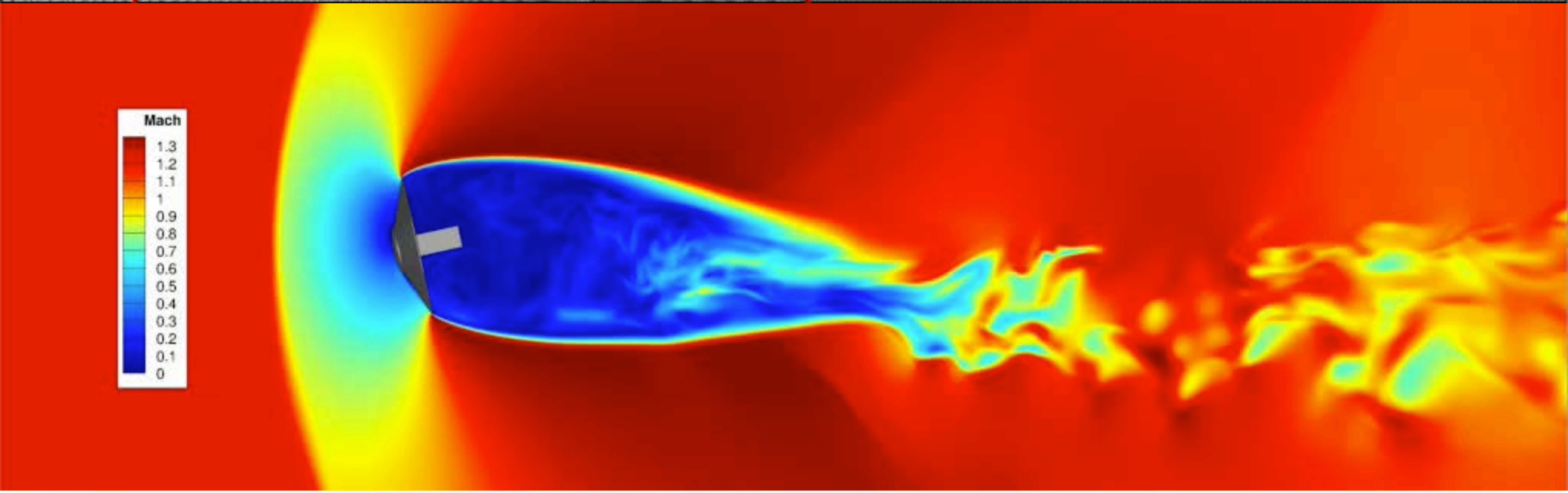
Free-Flight CFD with US3D



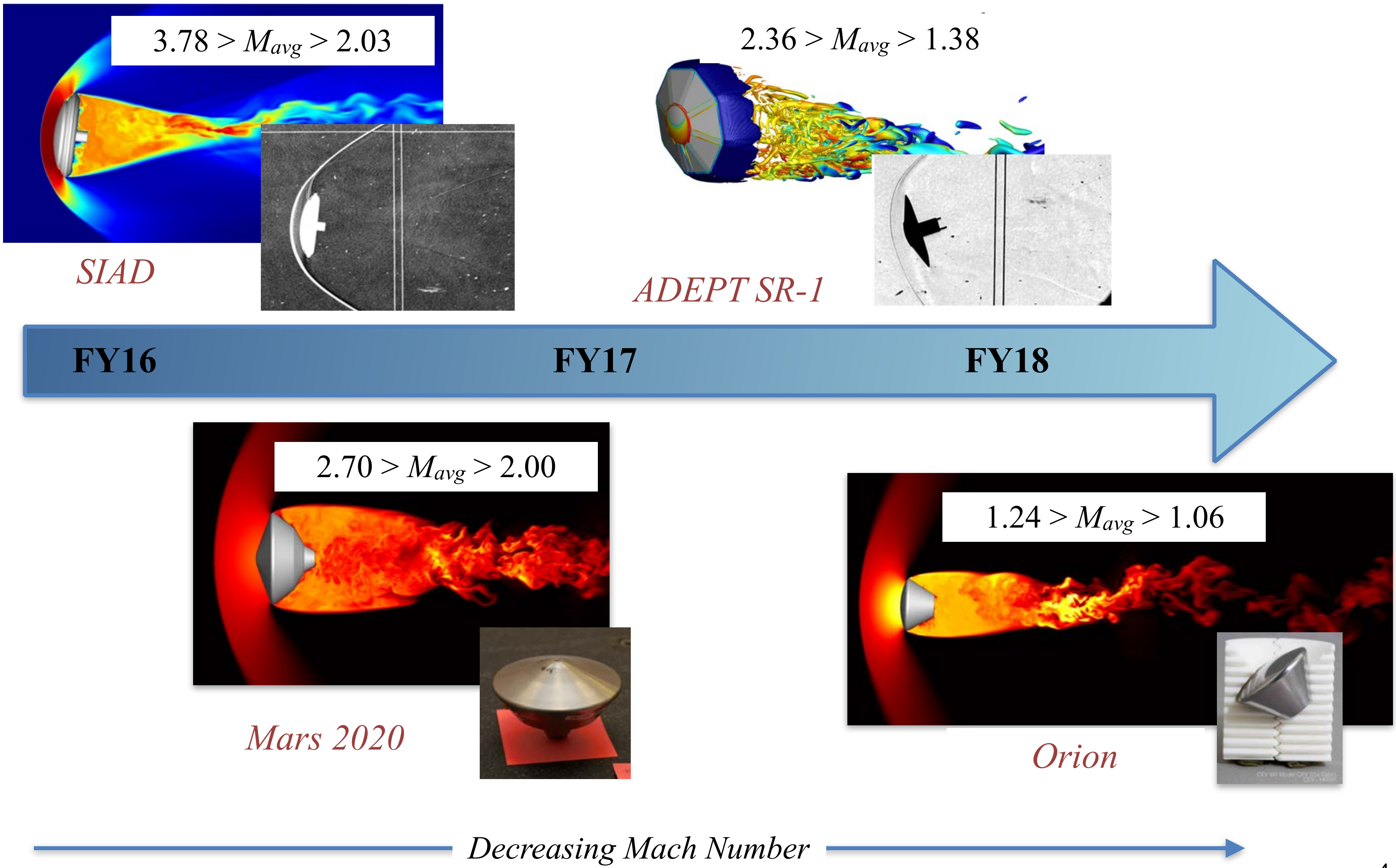


Free-Flight CFD with US3D

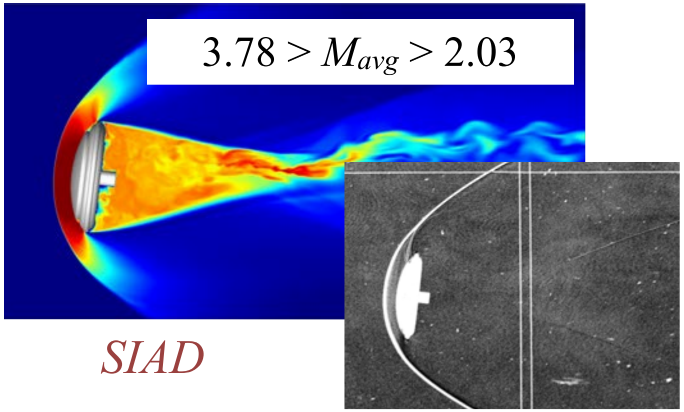




Development Roadmap



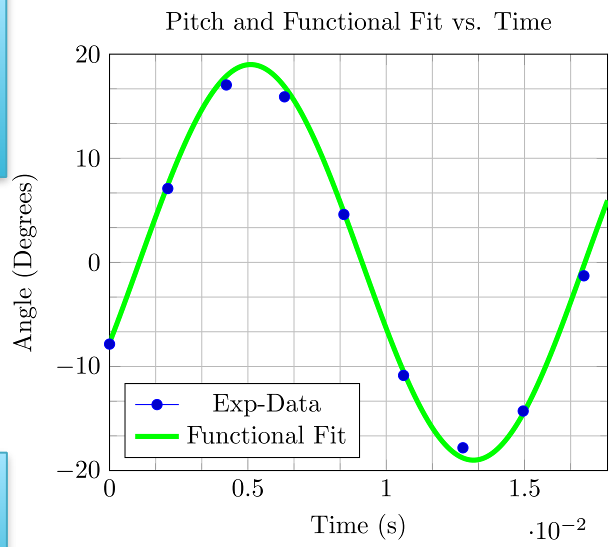
Development Roadmap



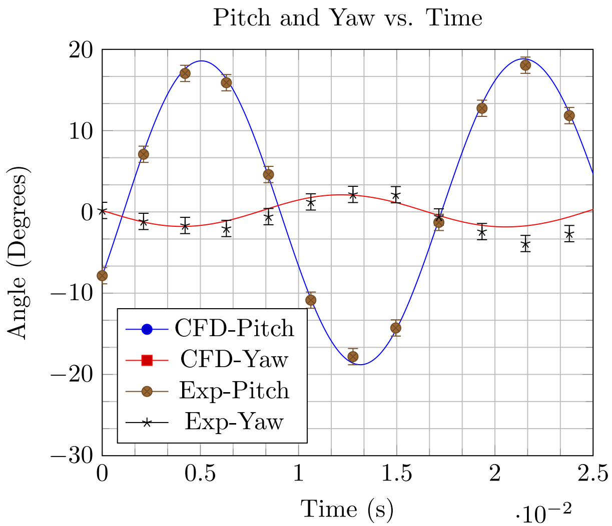
SIAD

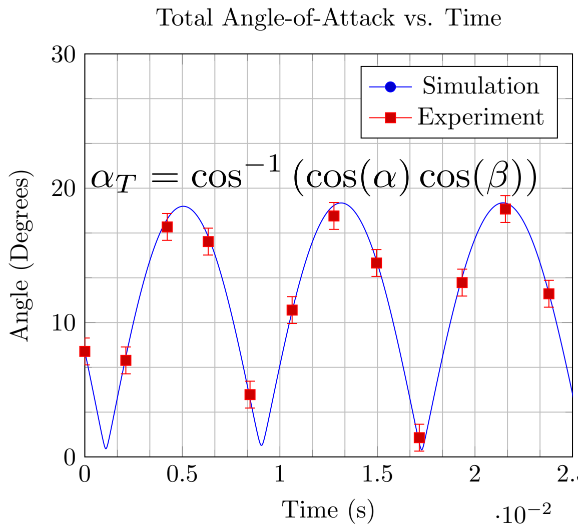
FY16

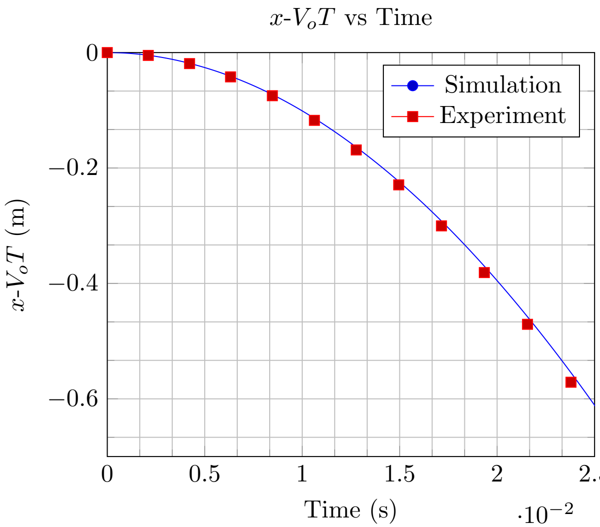
Creation of Methodology Fitted with cosine function and taking the first derivative for tip-off rates



Simulation data for pitch, yaw, total angle of attack and downstream distance is compared against experimental data







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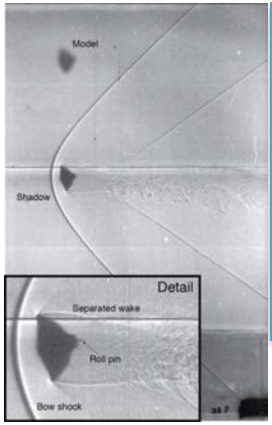
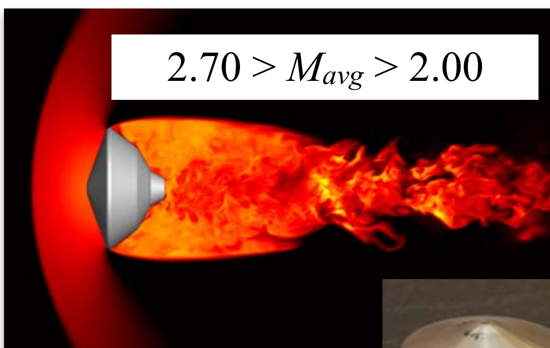
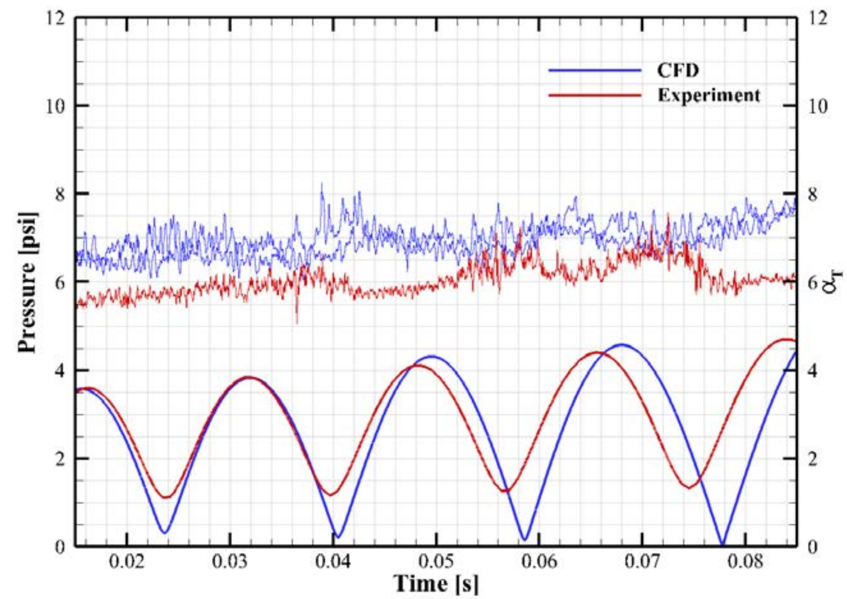


Experiment and accompanying free-flight CFD support meant to provide informed advice on placement of backshell pressure measurement for Mars 2020 EDL experiment.

FY16 **FY17**



Mars 2020



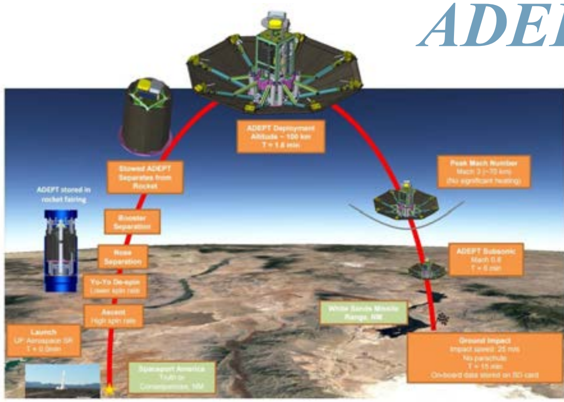
Simulation results show:

- Amplitude growth predicted well by CFD
- Mismatch in frequency
- Backshell pressure show reasonable agreement

Simulations were performed *a-priori* at "relevant" experimental conditions. Current efforts look to run at exact experimental conditions.

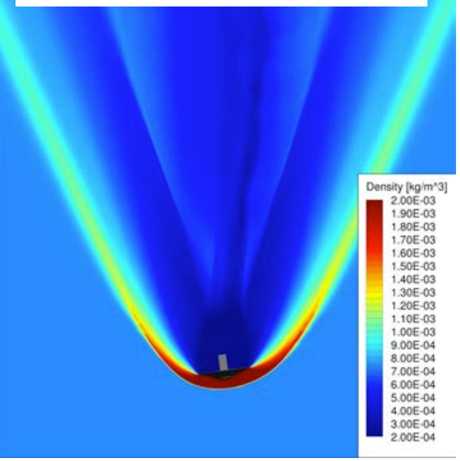
Development Roadmap

ADEPT SR-1

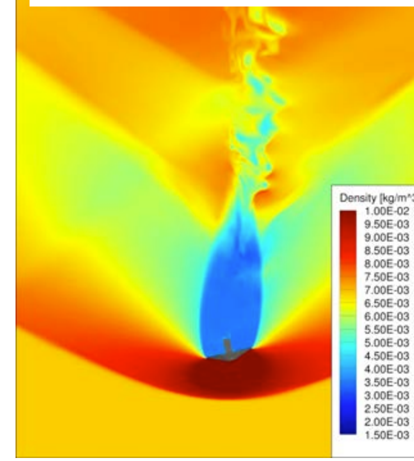


FY16 **FY17**

High-Altitude Segment of ADEPT SR-1 Trajectory



Low-Altitude Segment of ADEPT SR-1 Trajectory



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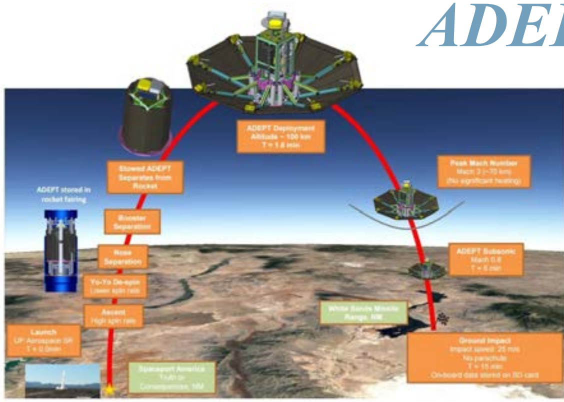

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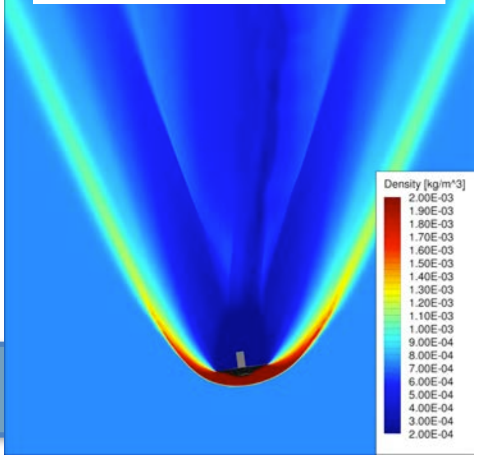

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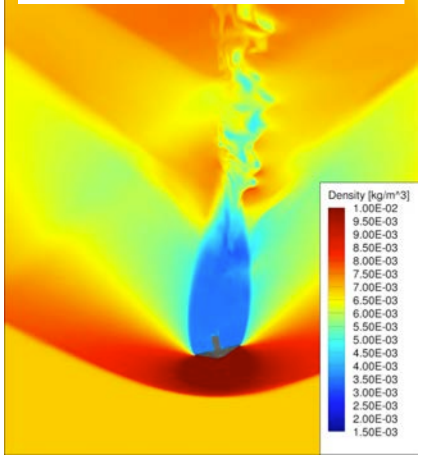
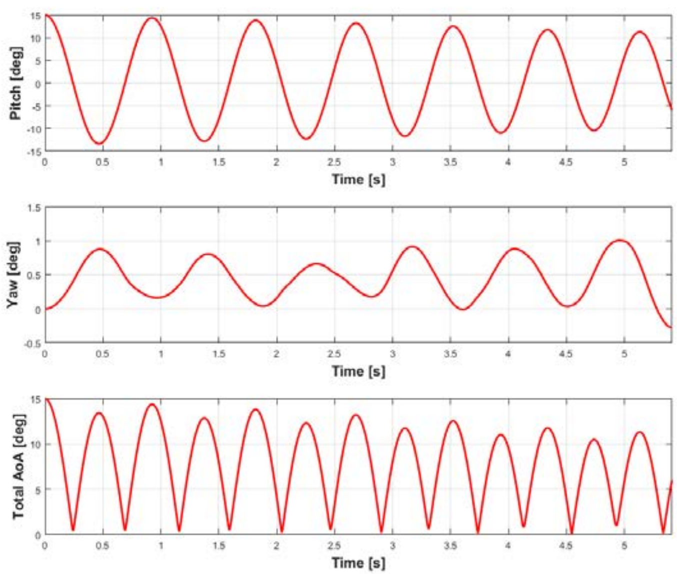


High Altitude



Development Roadmap

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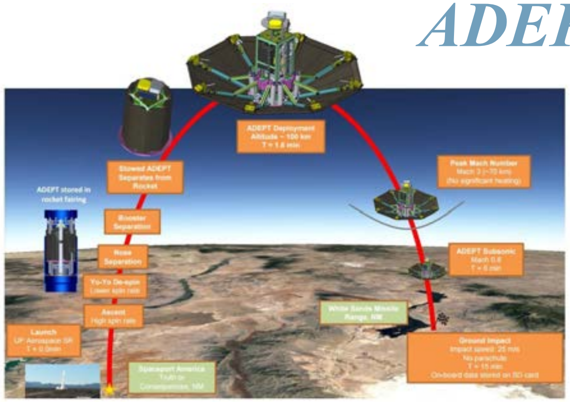

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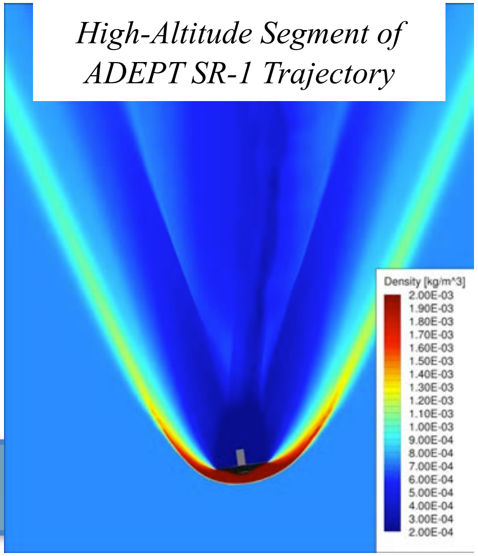

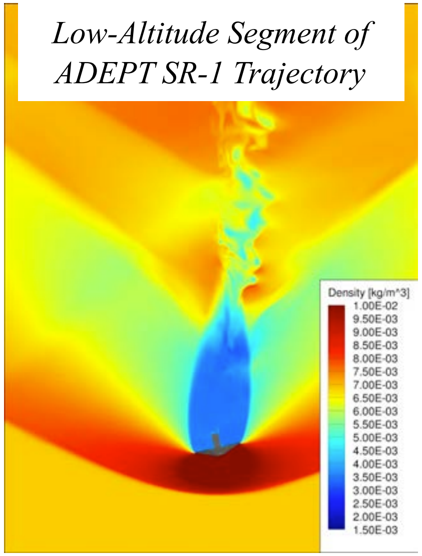

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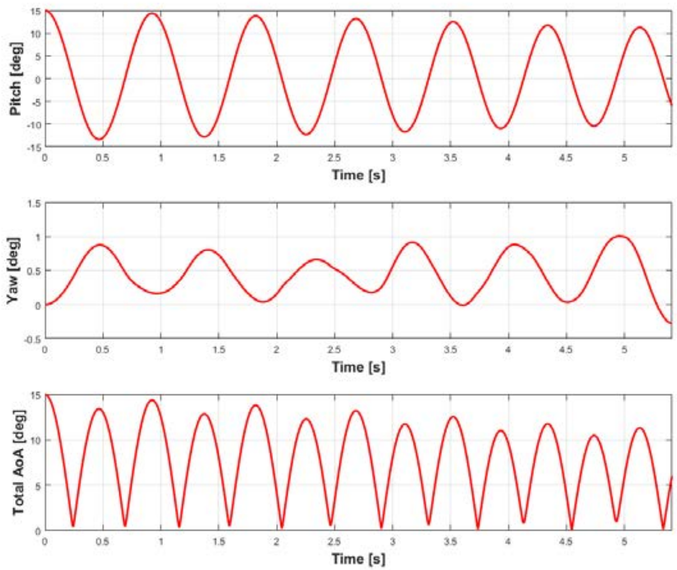
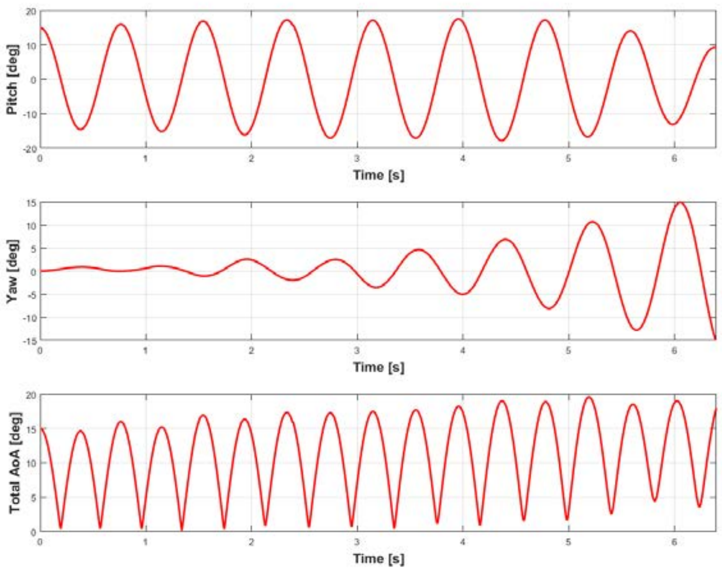


Low Altitude



Dynamic Data Comparisons

FY16 **FY17** **FY18**

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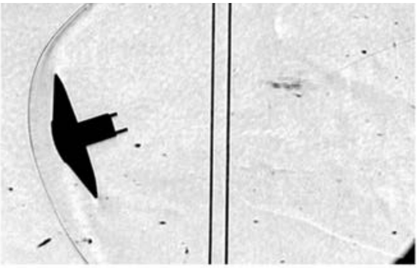
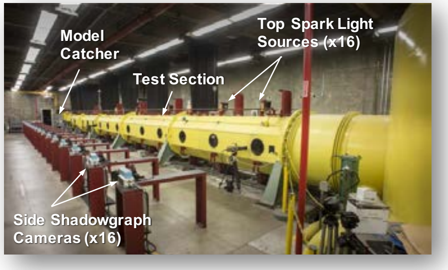
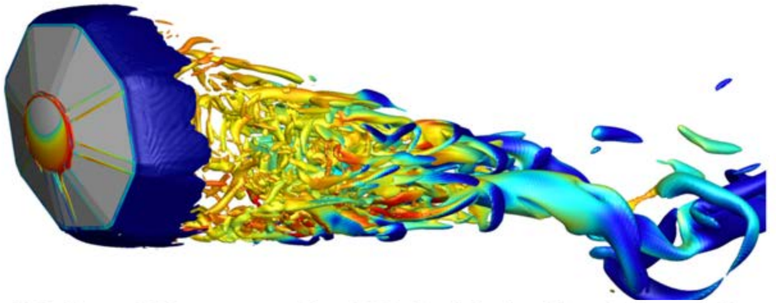
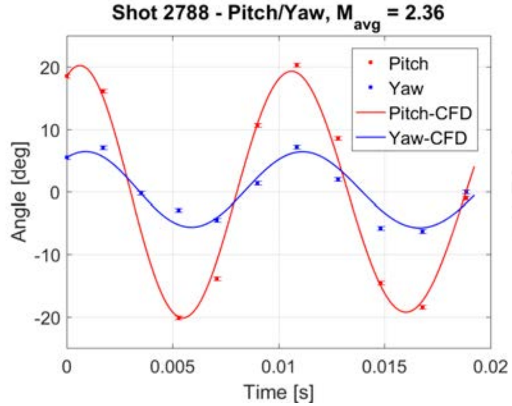
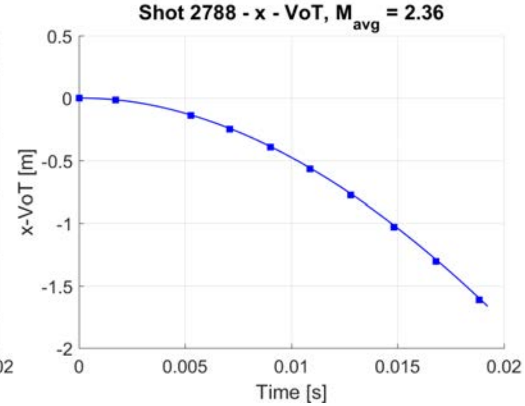


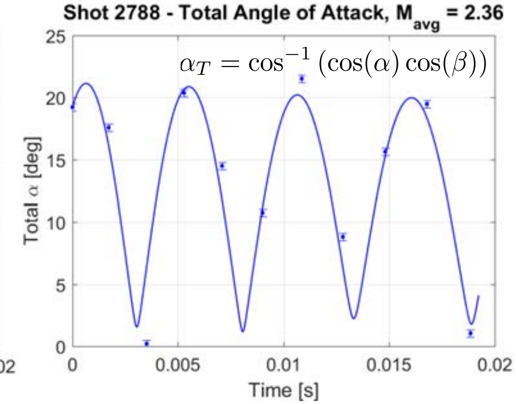




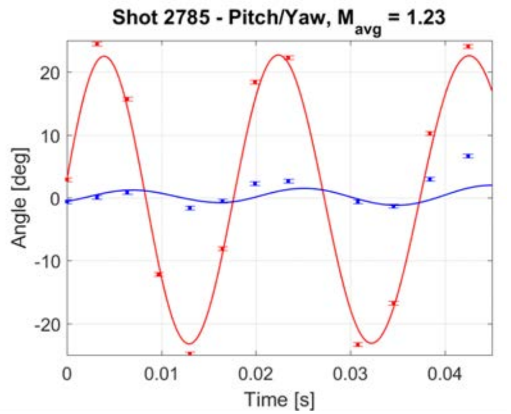
Mach = 2.36

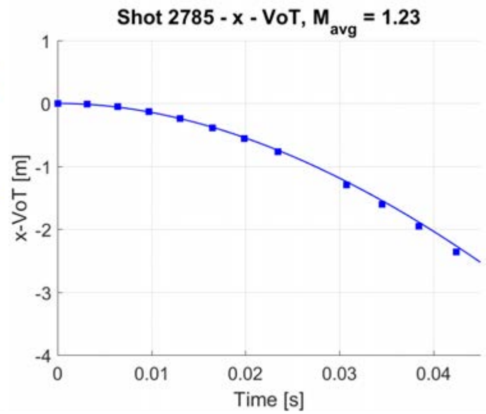




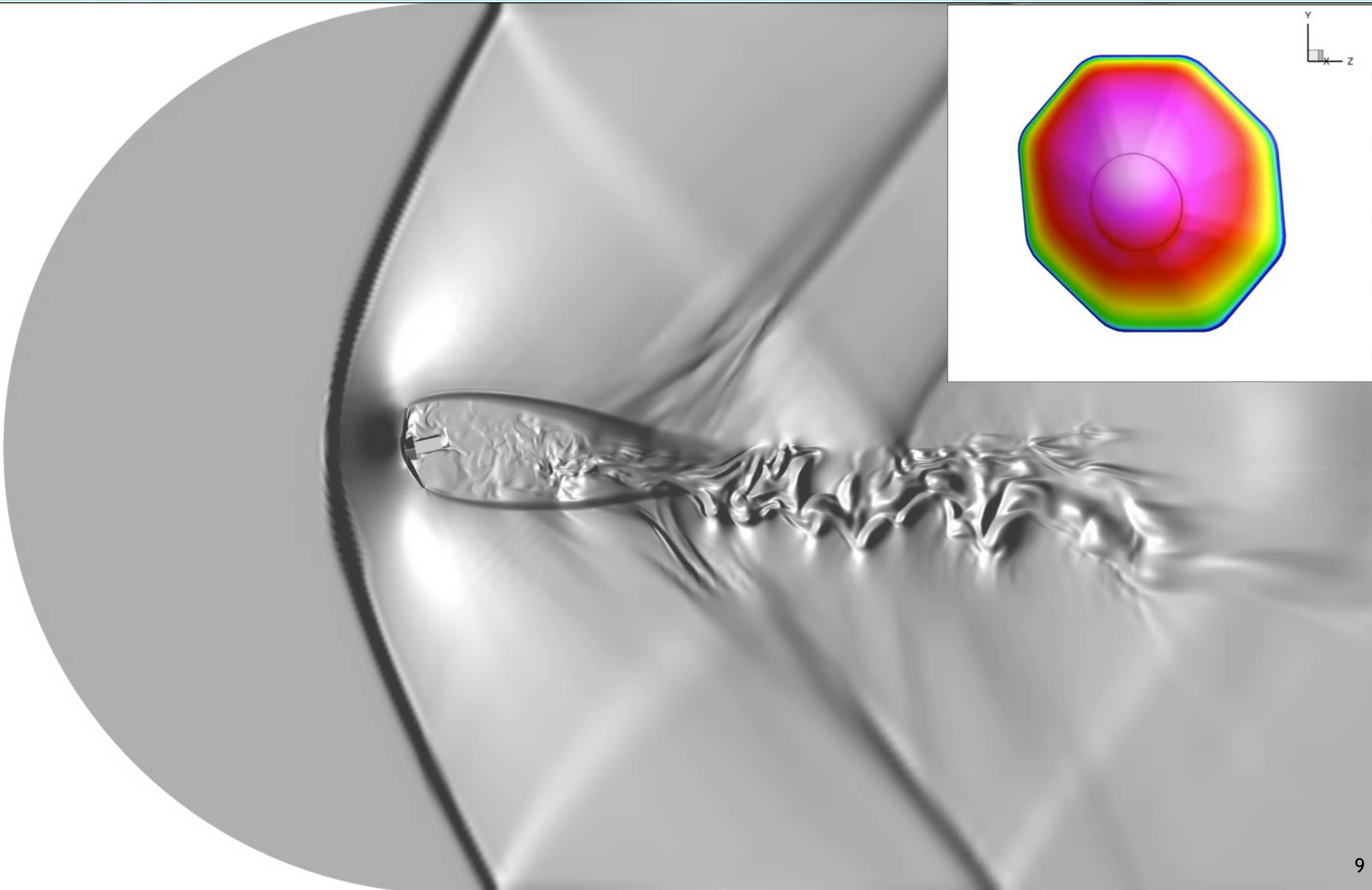


Mach = 1.23





Passing Through Transonic



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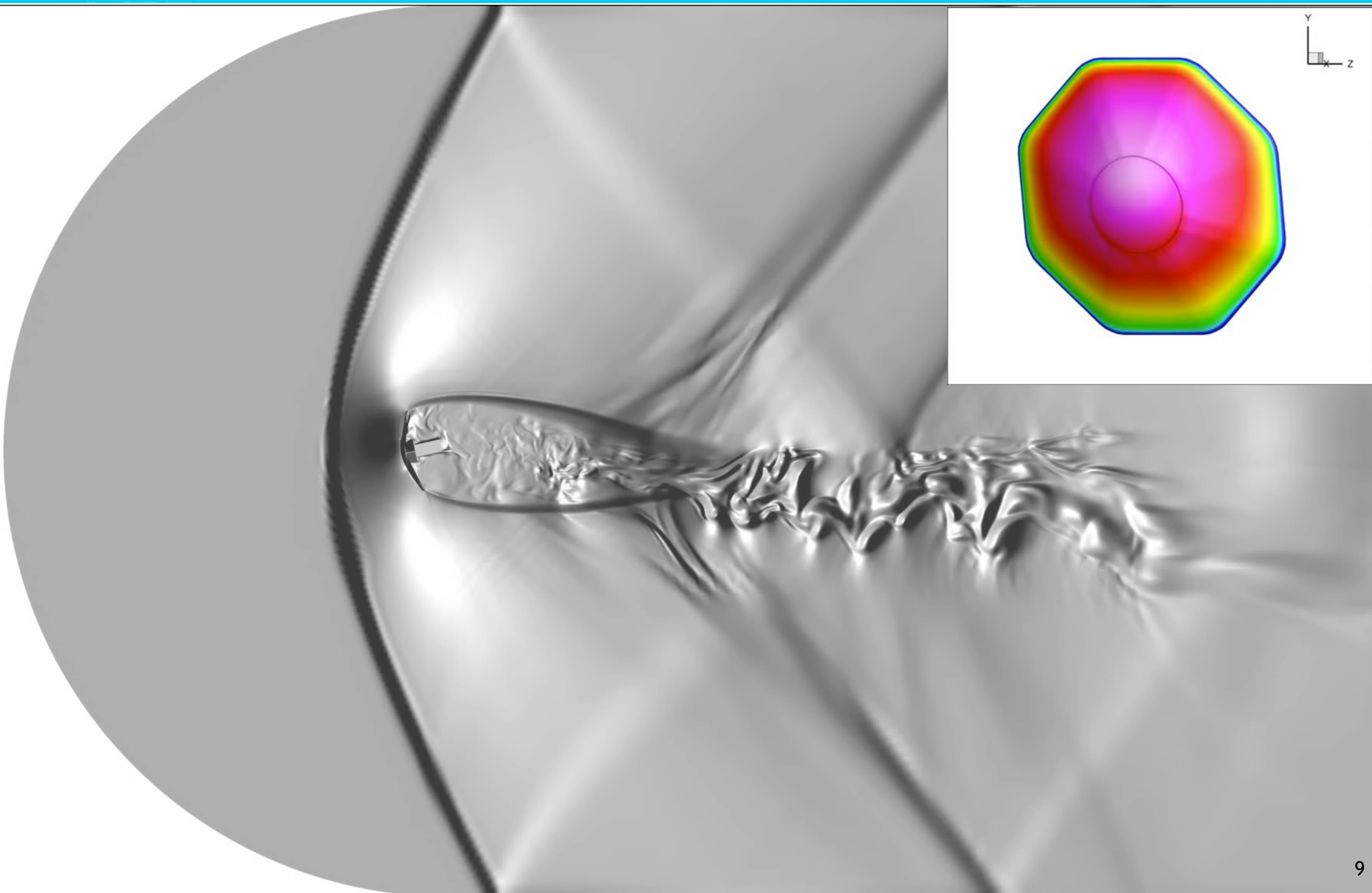

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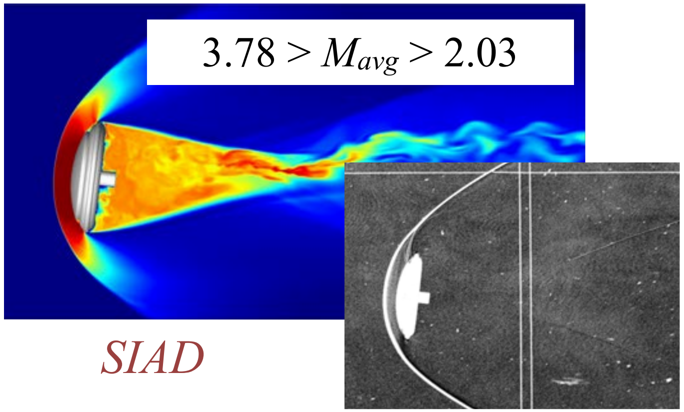
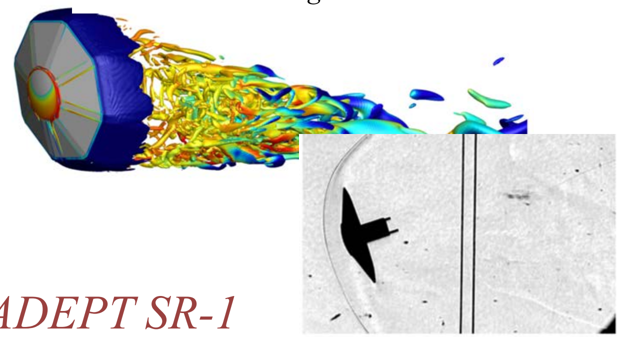


SIAD

$2.36 > M_{avg} > 1.38$



ADEPT SR-1

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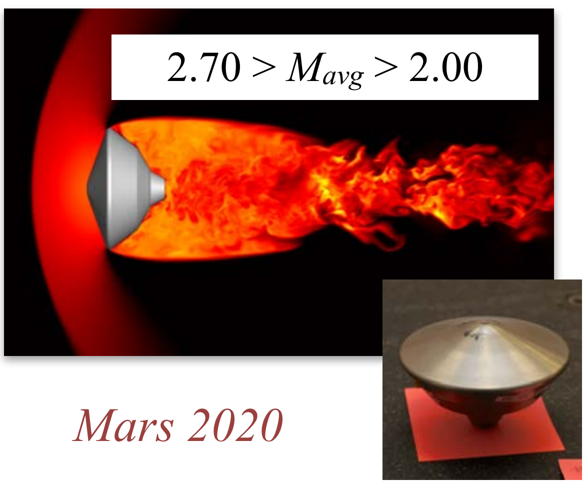
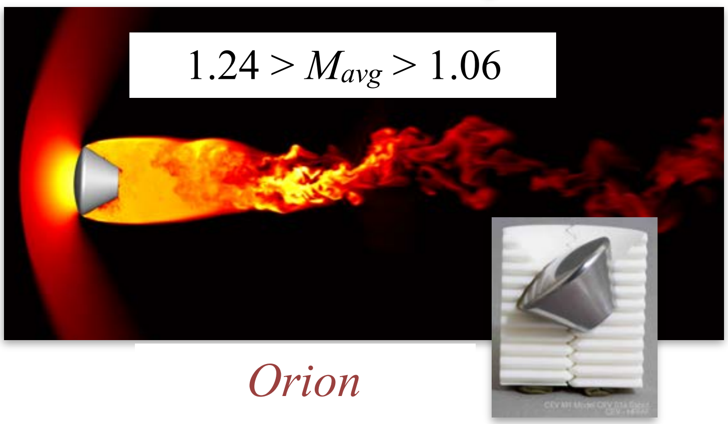


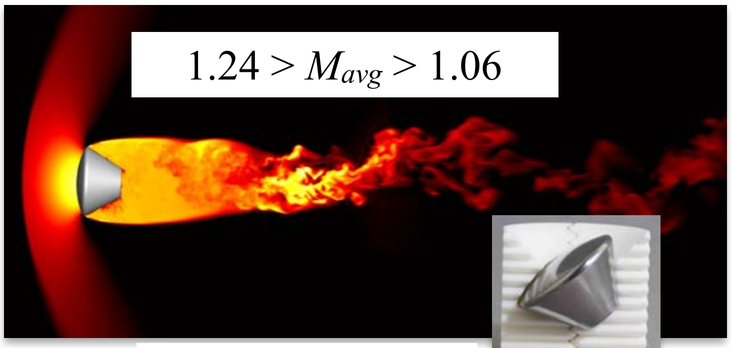
Mars 2020



Orion

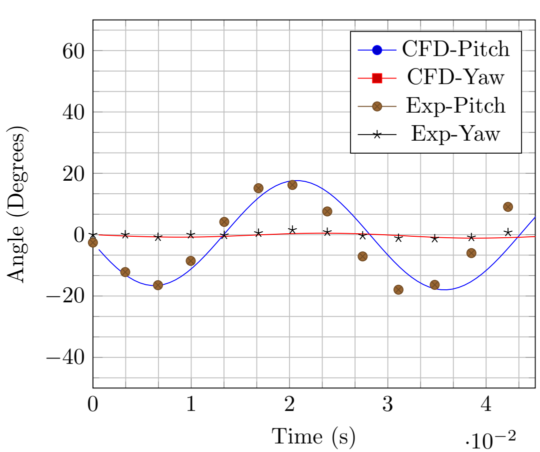
Decreasing Mach Number →

Recent Results

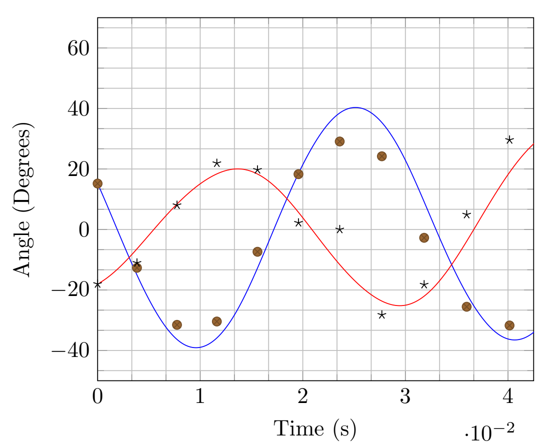


Orion

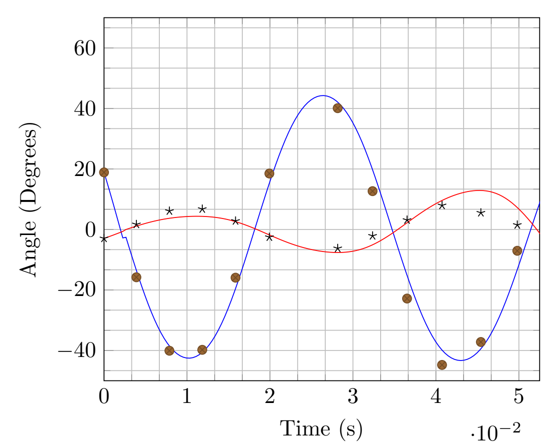
$Mach = 1.24$
(Shot 2439)



$Mach = 1.07$
(Shot 2366)



$Mach = 1.06$
(Shot 2379)



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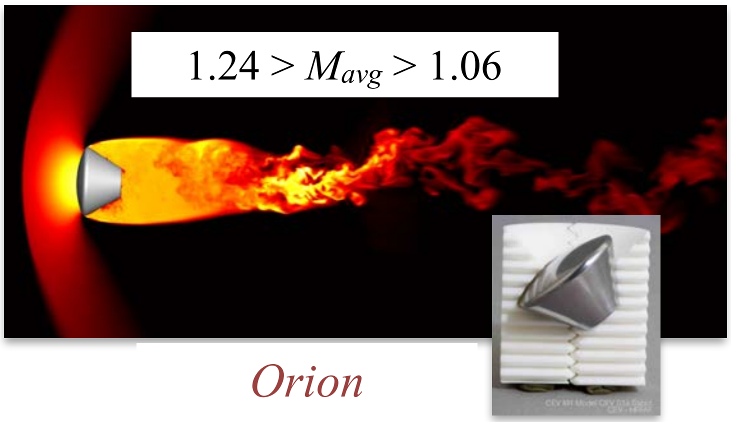

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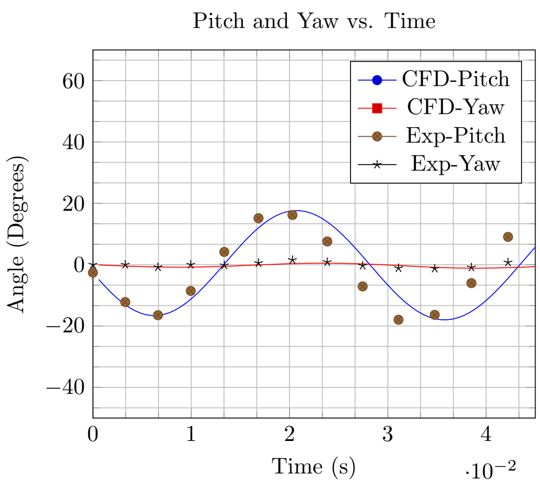

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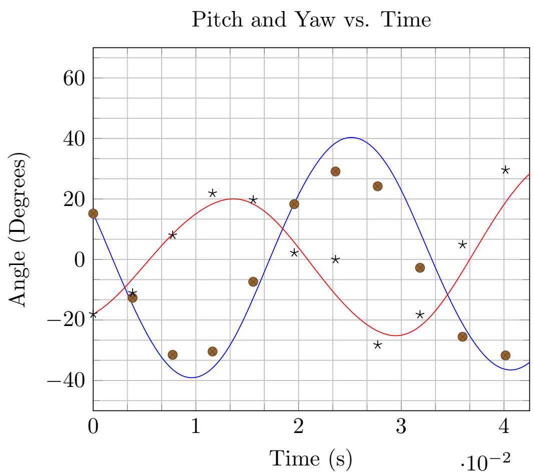

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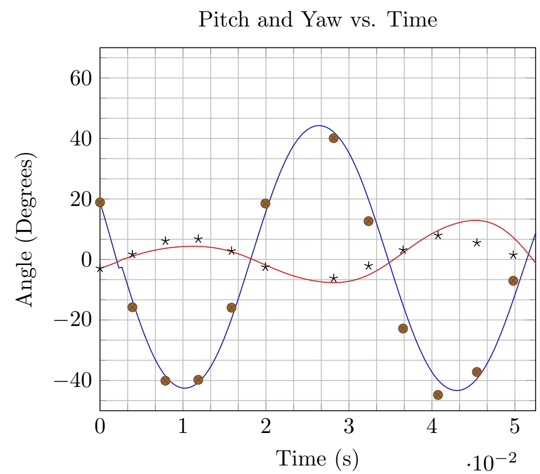

Dynamic Data Comparisons

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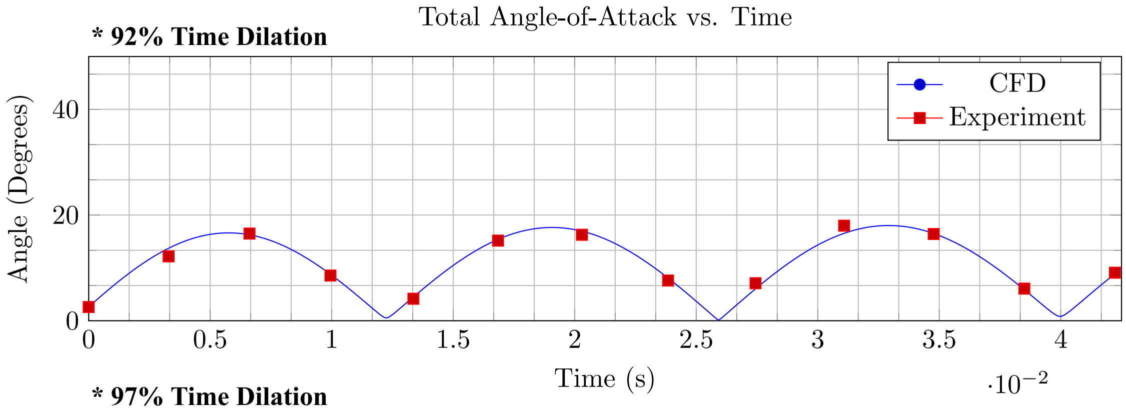

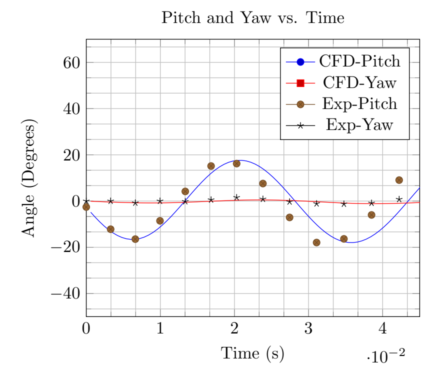

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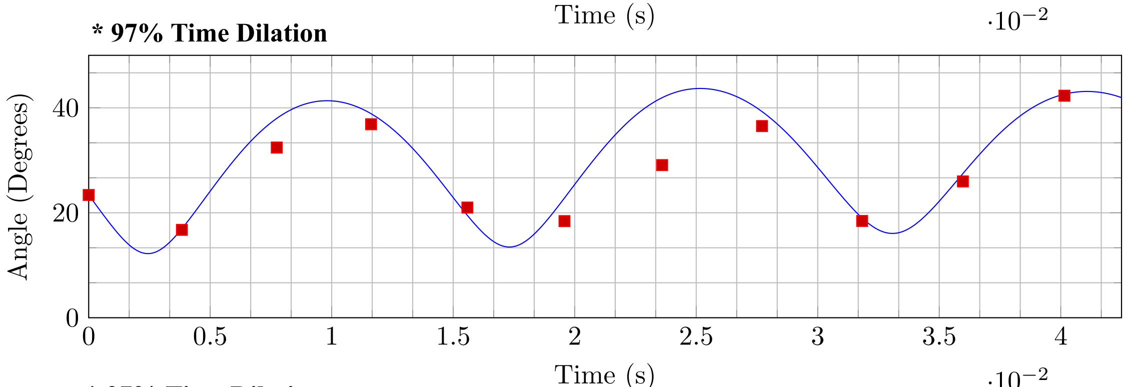

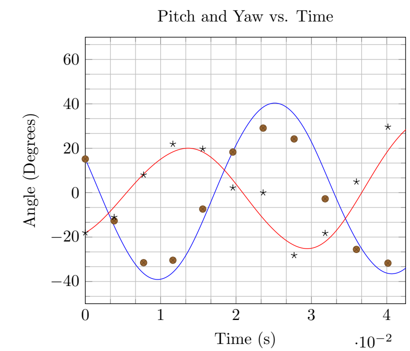

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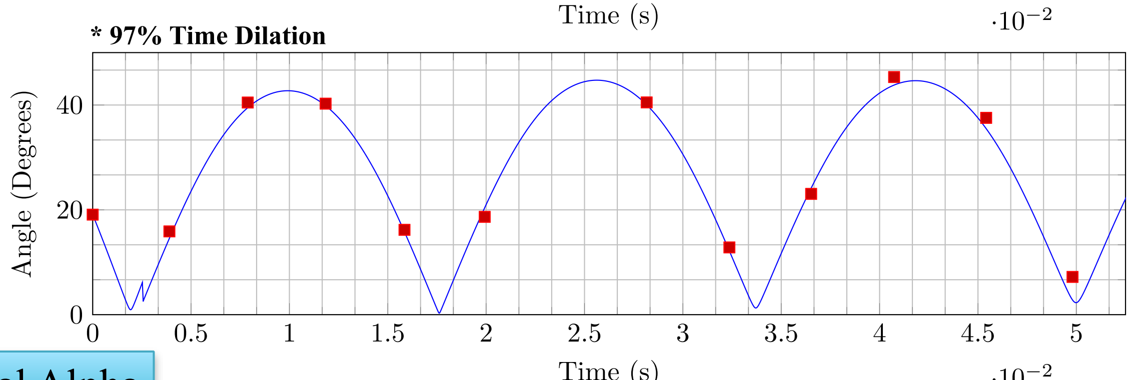
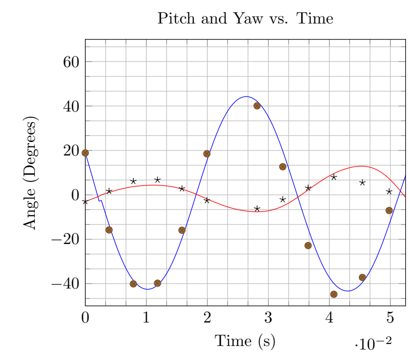


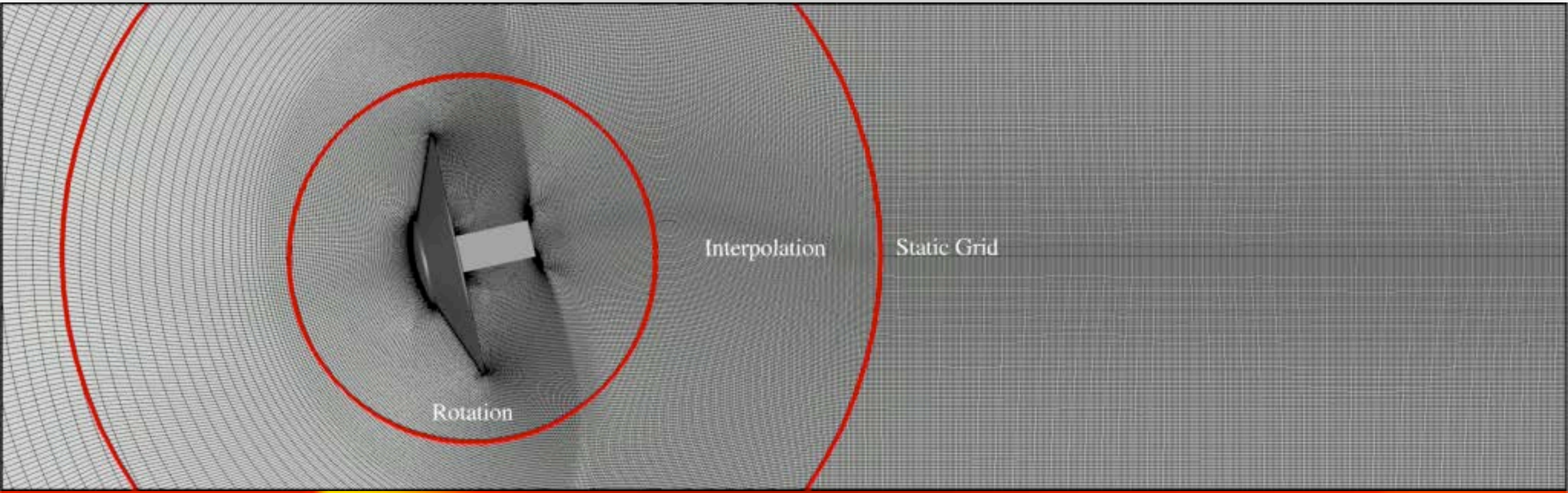


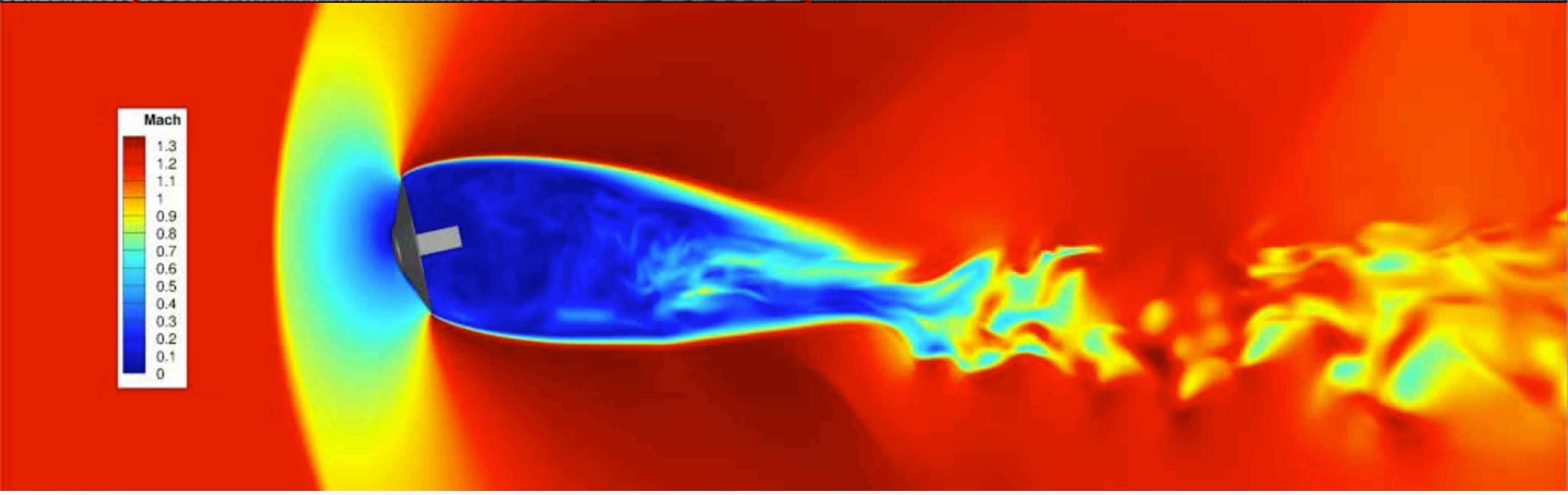
~10% Error in Total Alpha

Summary

- **Free-Flight CFD as been applied for the range of Mach numbers 3.7-1.0**
  - **High Mach number cases show excellent agreement with experiment**
  - **Lower Mach number cases show reasonable agreement against experiment**
    - **Roughly 10 percent error in total alpha**
- **Solver has also been applied to full-scale trajectory**
  - **High altitude portion shows stable flight dynamics**
  - **Lower altitude shows total amplitude growth**
- **Recent updates to Free-Flight solver look to extend capabilities and improve accuracy**
  - **Mesh deformation technique**
  - **Implementation of multi-body dynamics**
- **Future work topics include; longer ballistic range experiments, flight relevant trajectories, and multi-body dynamics**

Previous Mesh Deformation Approach





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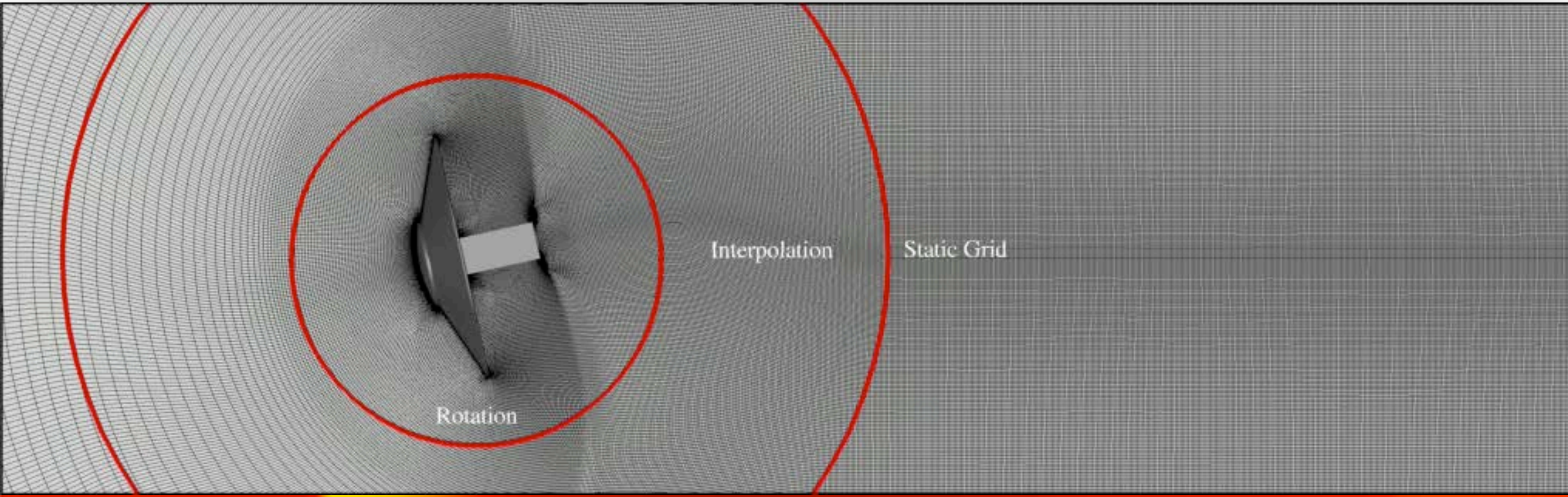
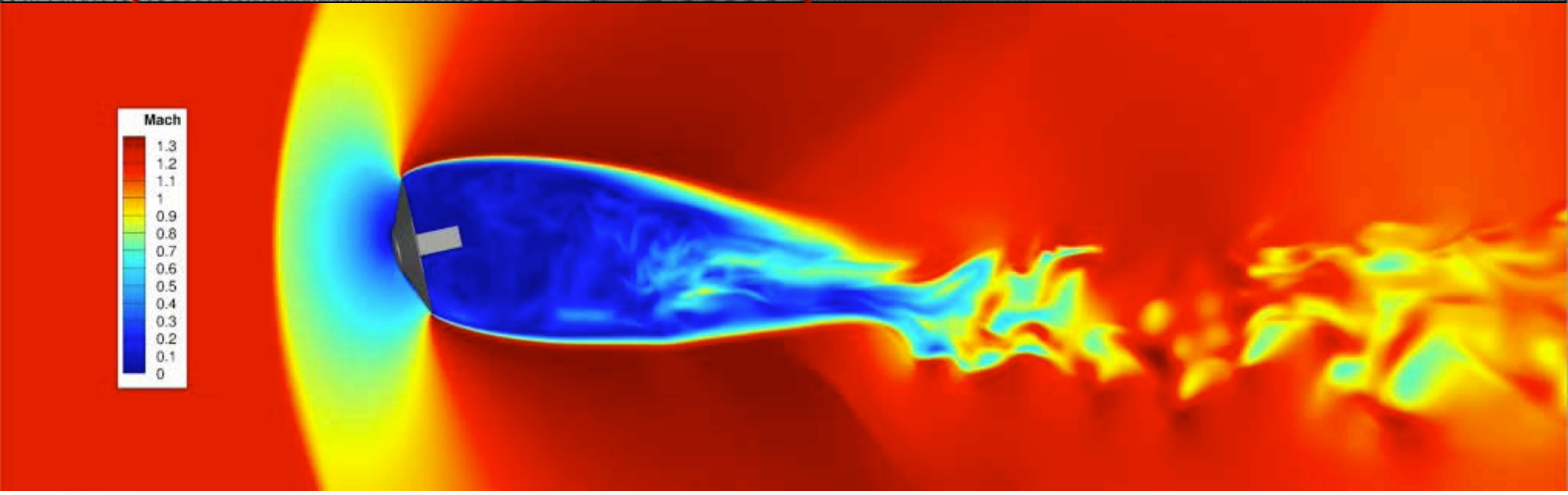
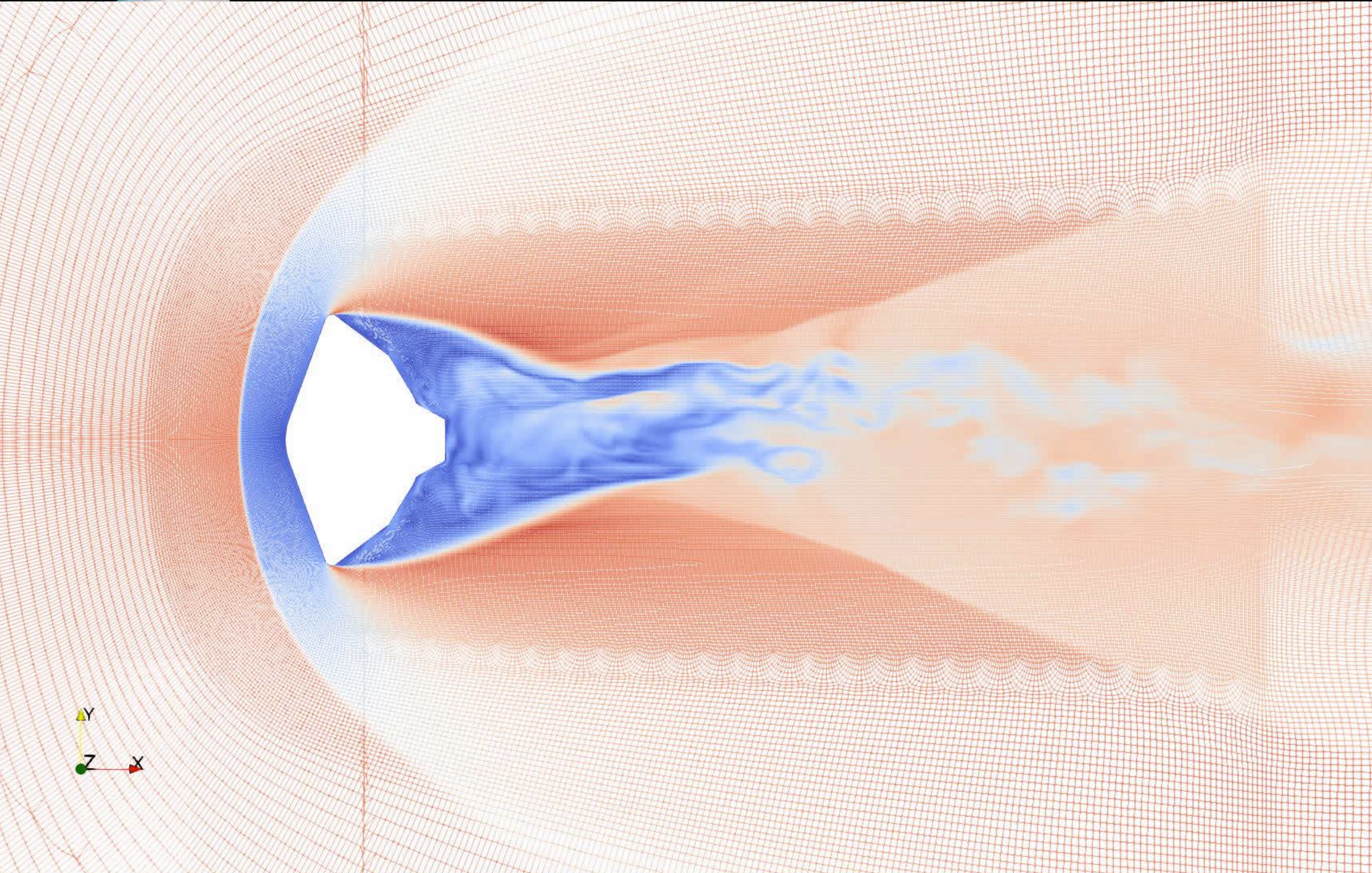




New Mesh Deformation Approach



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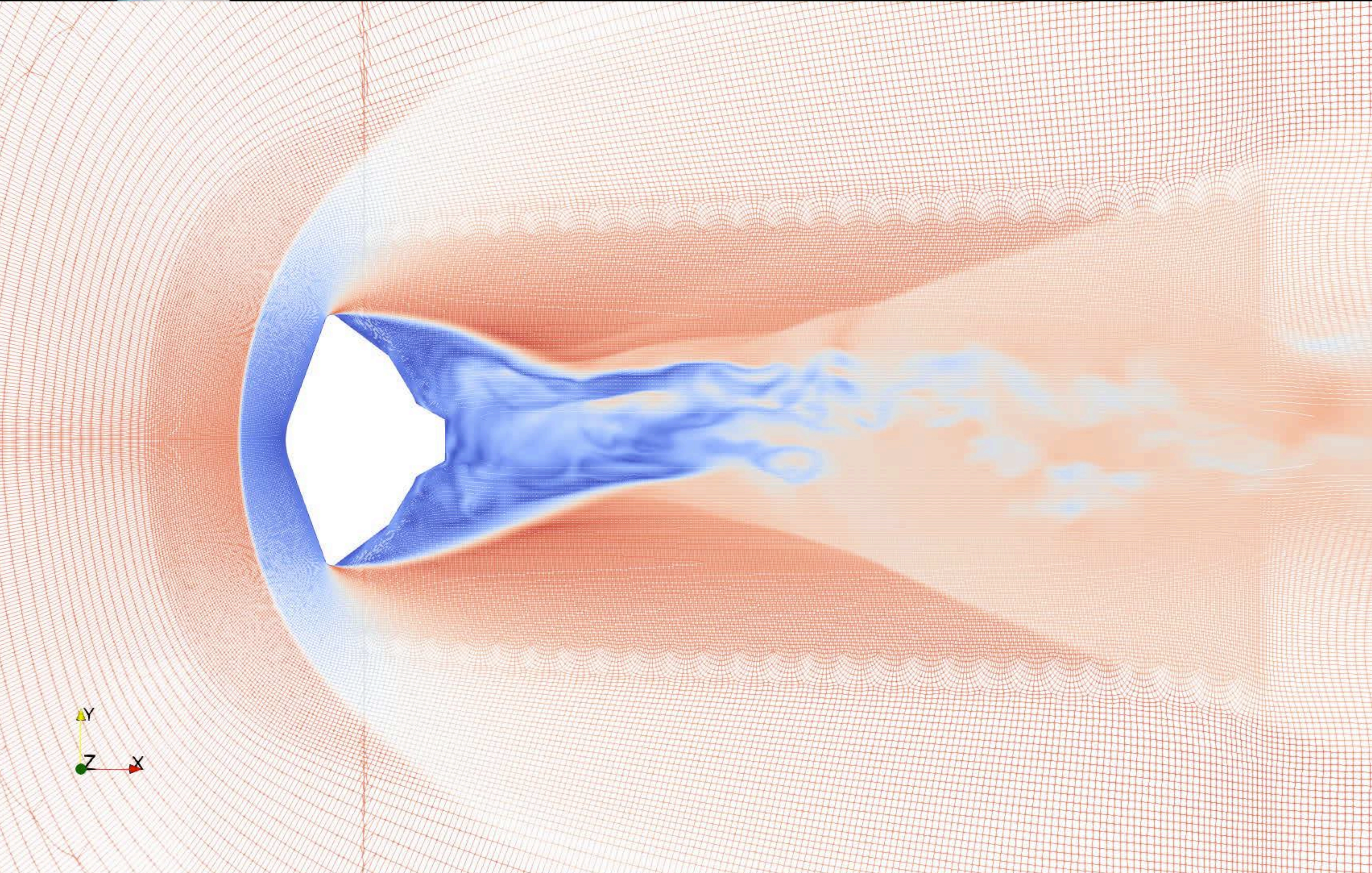
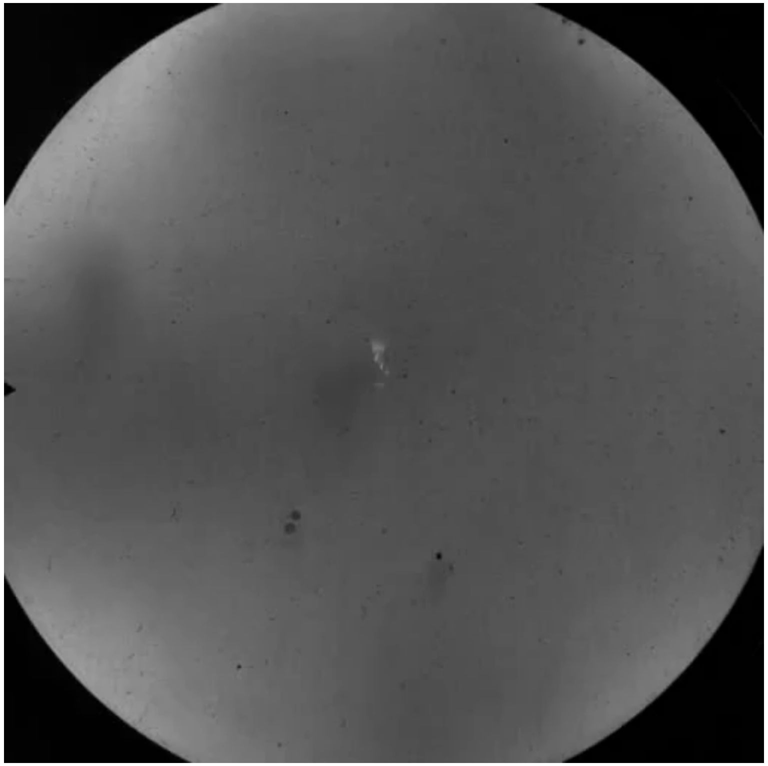
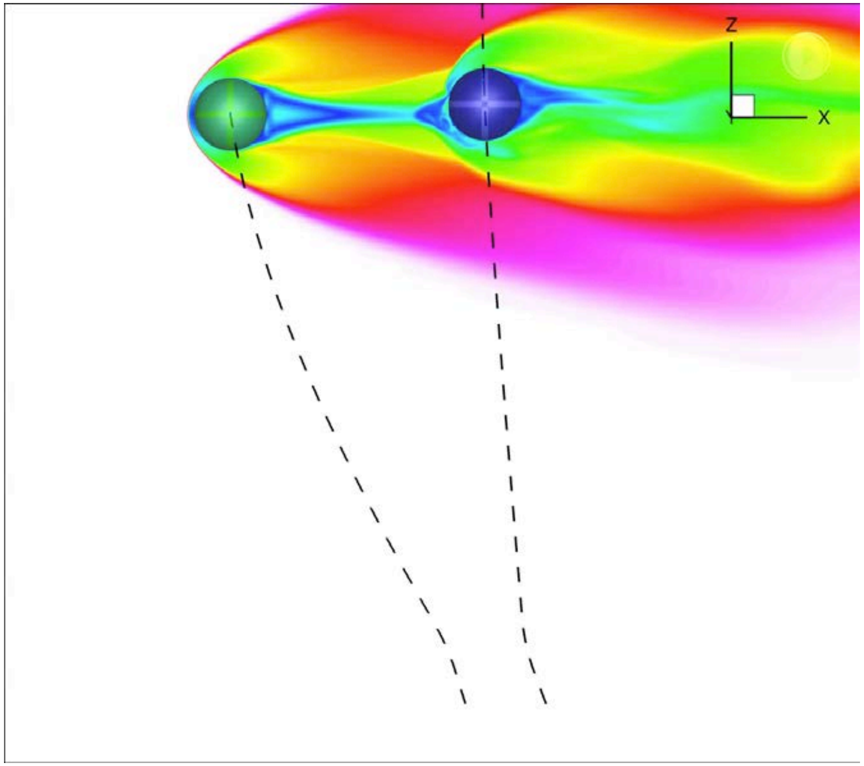


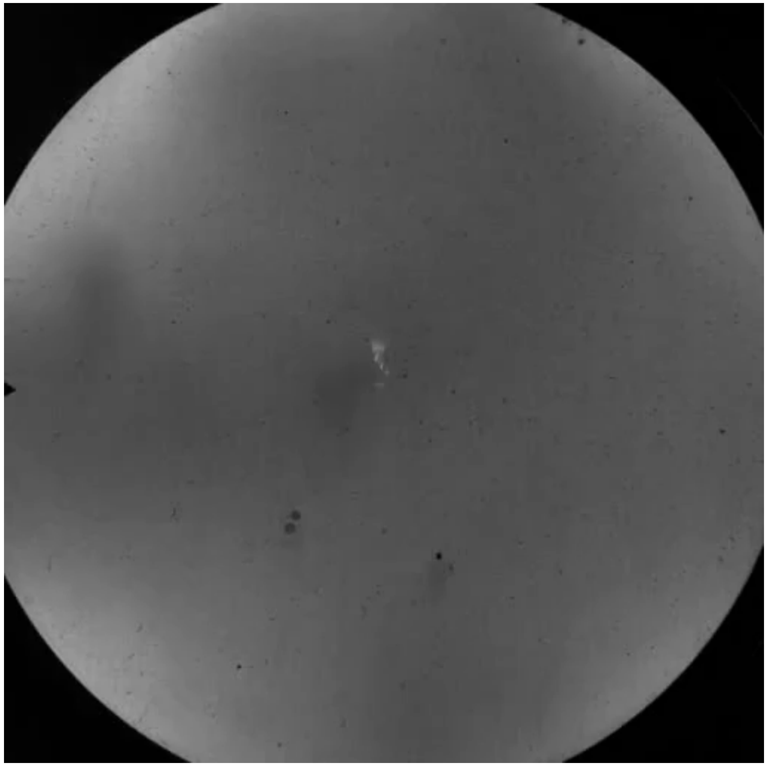
Multi-Body Dynamic Capabilities

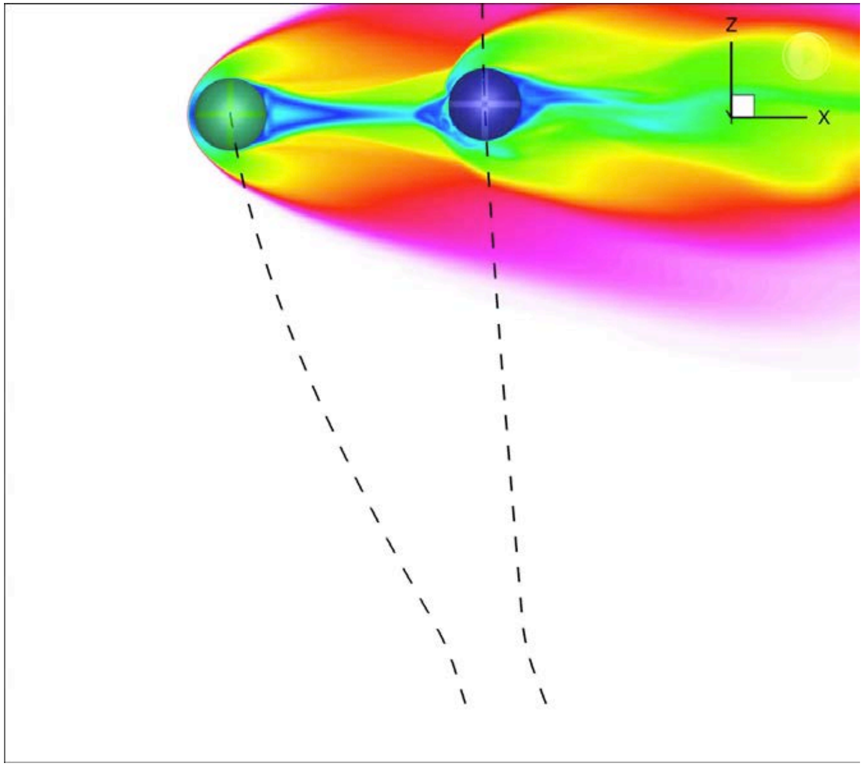




We are partnering with the Asteroid Threat Assessment project under SMD to study free-flight behavior of multi body (and their interactions). This effort will compliment future work to model EDL separation events.

Multi-Body Dynamic Capabilities





We are partnering with the Asteroid Threat Assessment project under SMD to study free-flight behavior of multi body (and their interactions). This effort will compliment future work to model EDL separation events.

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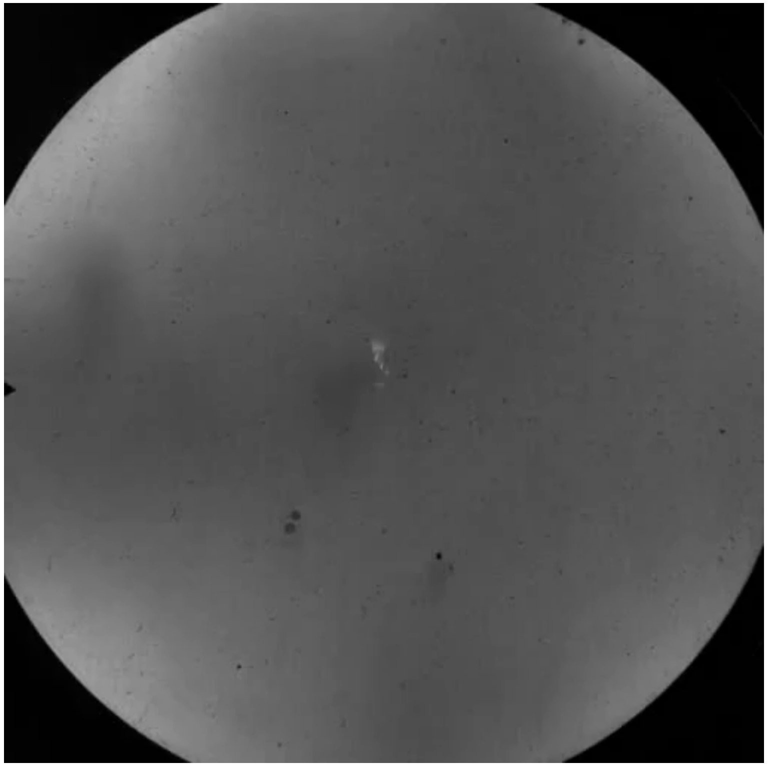

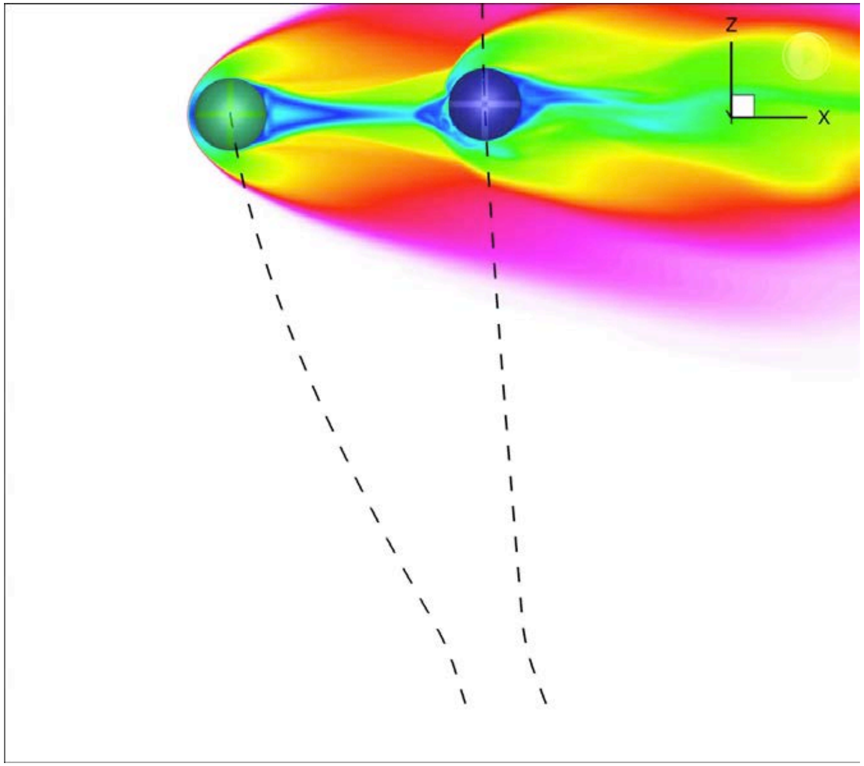

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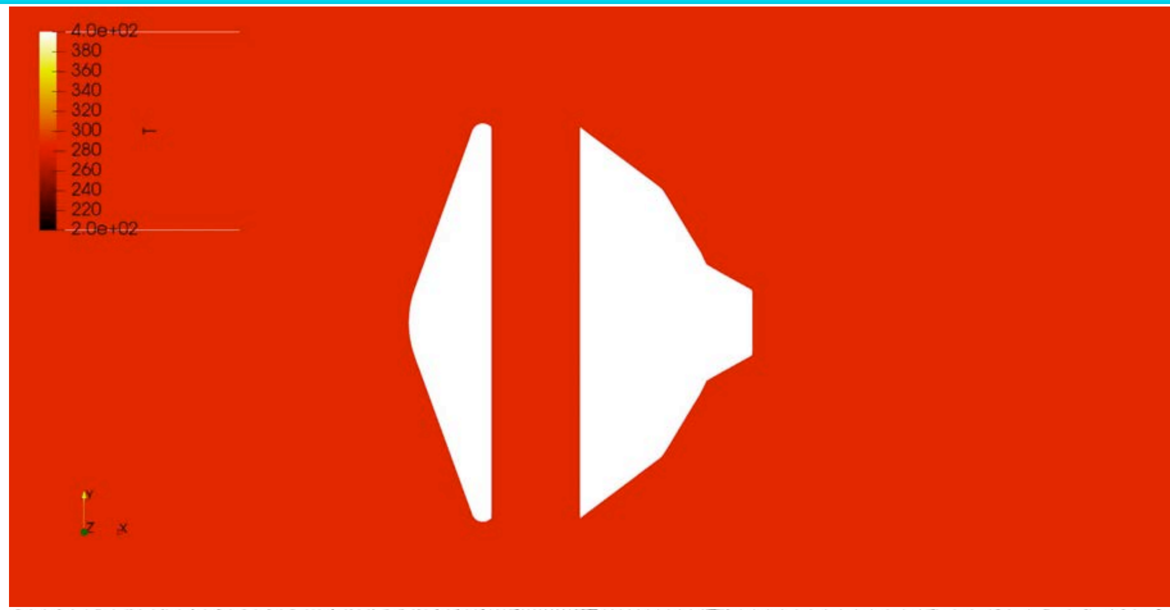

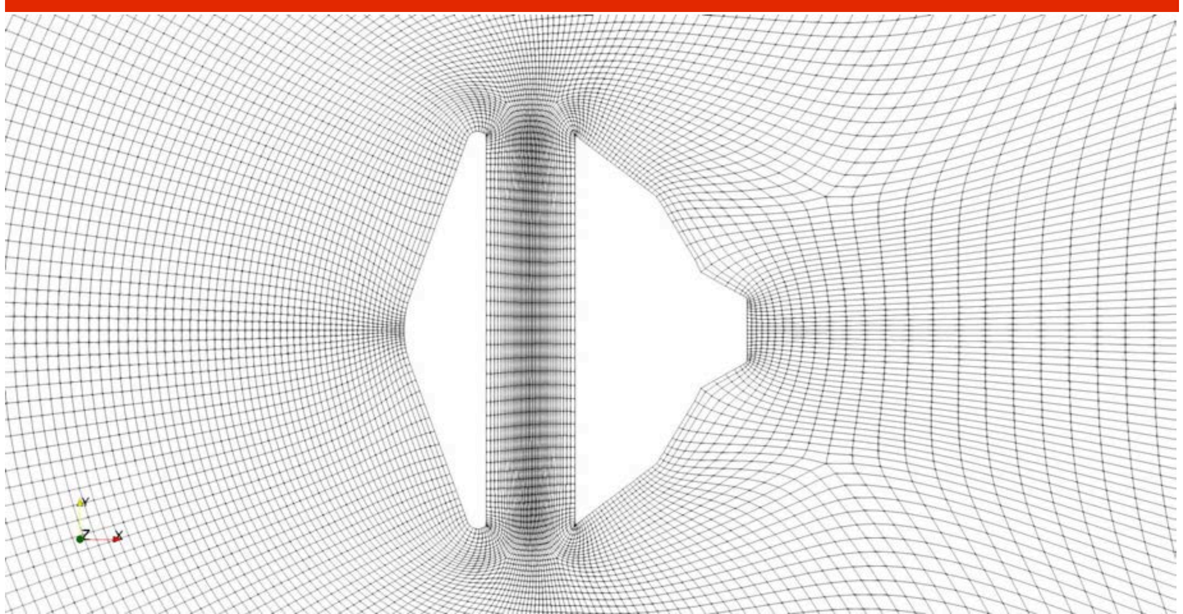

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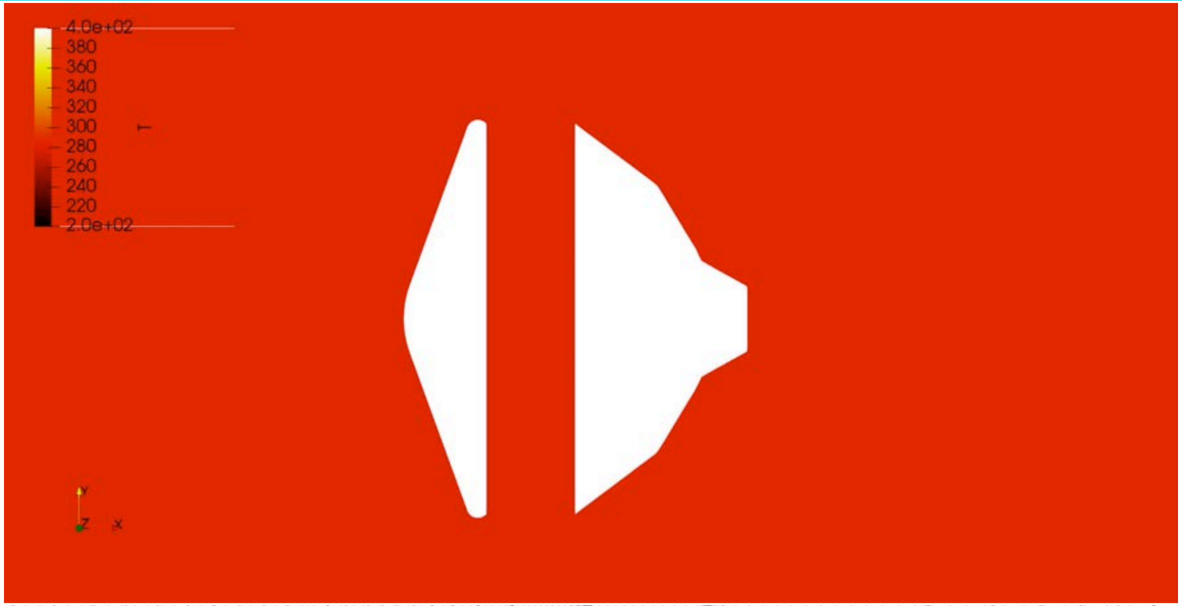

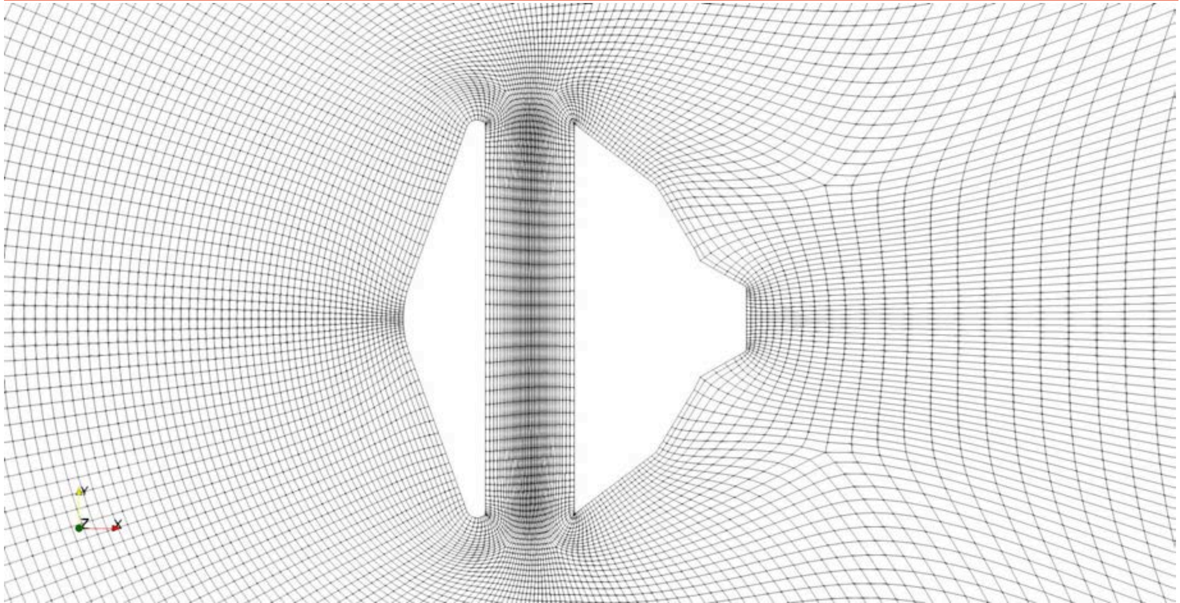

Acknowledgements

- Entry Systems Modeling (ESM) project within NASA's Game Changing Development Program
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- AMA Inc. under contract NASA NNA15BB15C
- GoHypersonic Inc.

Backup

US3D Flow Solver

- **Developed at the University of Minnesota by Graham Candler and students**
- **3-dimensional parallel unstructured cell-centered finite-volume Navier-Stokes solver**
  - **Ability to solve on structured, unstructured, and hybrid grid topologies**
  - **Spatial fluxes can be;**
    - **2nd and 3rd order upwind fluxes**
    - **2nd, 4th, and 6th order Kinetic Energy Consistent (KEC)[5] low-dissipation fluxes**
  - **Time integration achieved through 3rd order explicit (RK3), or second order implicit (DPLR and FMPR) schemes**
  - **Finite Rate chemistry and vibrational-electronic energy relaxation**
  - **Turbulence modeling available through;**
    - **Algebraic Baldwin Lomax model**
    - **One equation Sapalart Almaras model [6]**
    - **Shear-Stress-Transport (SST) k-omega model**
  - **Wall model LES implemented using DES97, DDES, IDDES [7]**
  - **Mesh motion capability to perform dynamic simulations**