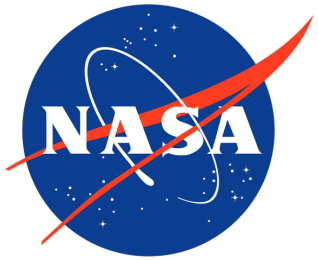
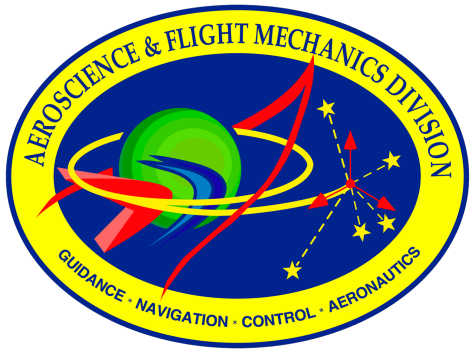


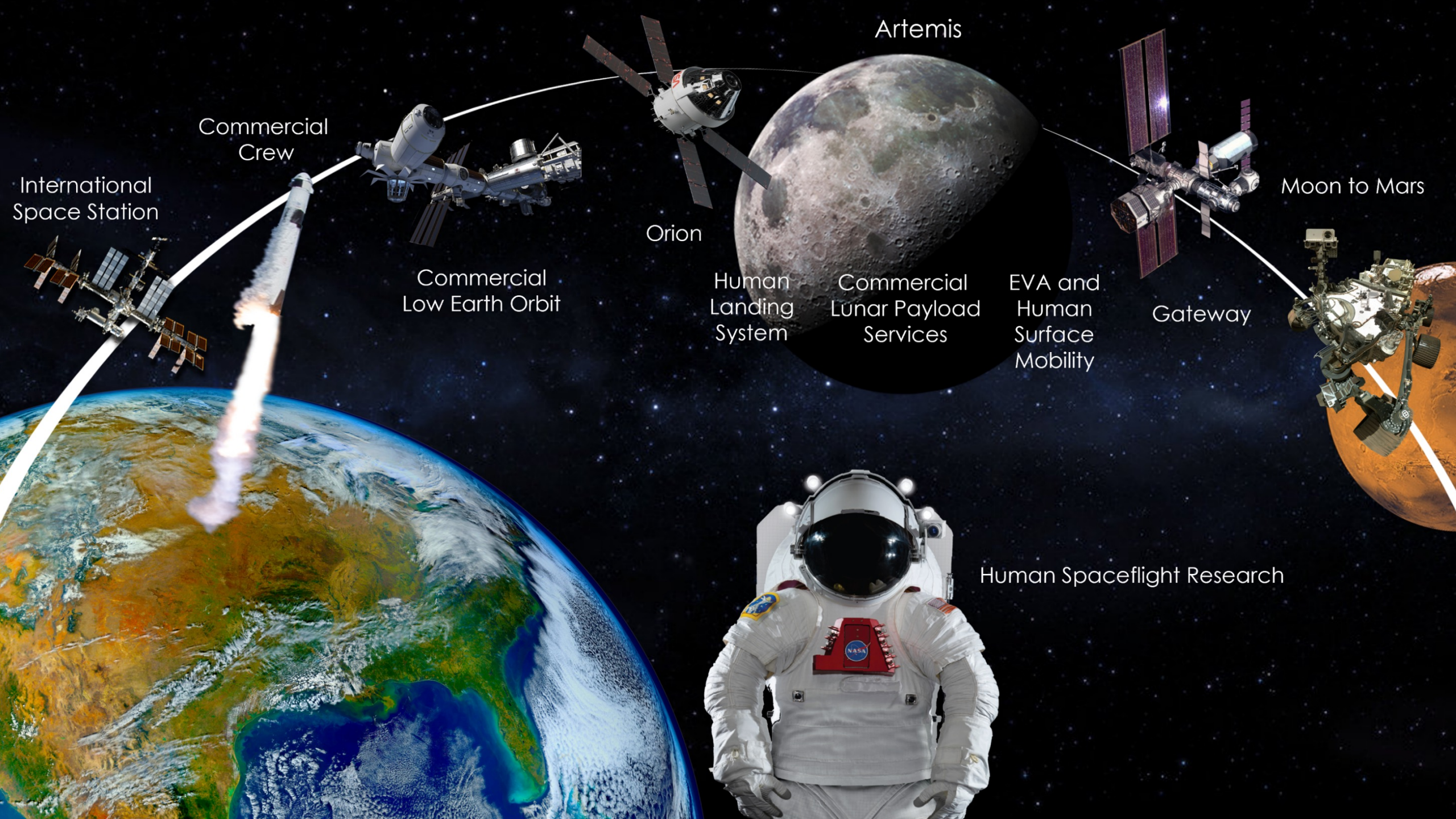
Recent Applications Supporting Human Spaceflight



Jim Greathouse, NASA/JSC
Stuart Rogers, NASA/ARC
Guy Schauerhamer, NASA/ARC
Alan Schwing, NASA/JSC
Darby Vicker, NASA/JSC

15th Symposium on Overset Composite Grids and Solution Technology
November 3rd, 2022

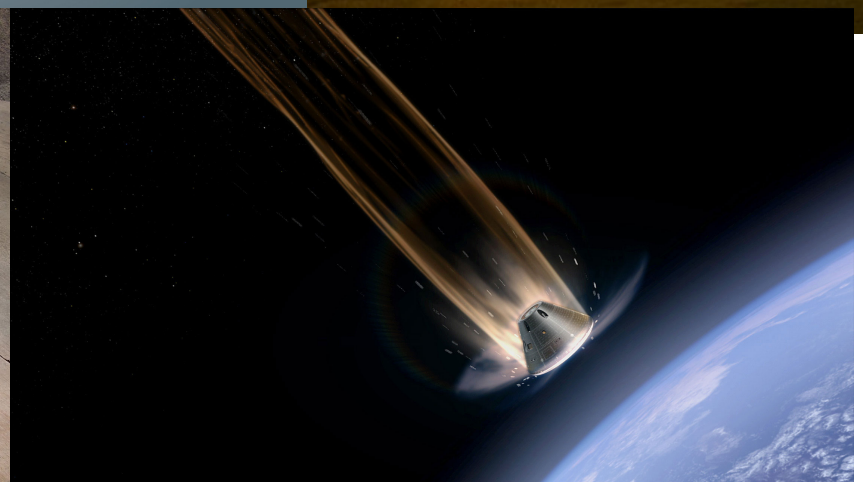
Contents


Artemis
Commercial Crew
International Space Station
Orion
Commercial Low Earth Orbit
Human Landing System
Commercial Lunar Payload Services
EVA and Human Surface Mobility
Gateway
Moon to Mars
Human Spaceflight Research

Orion/SLS

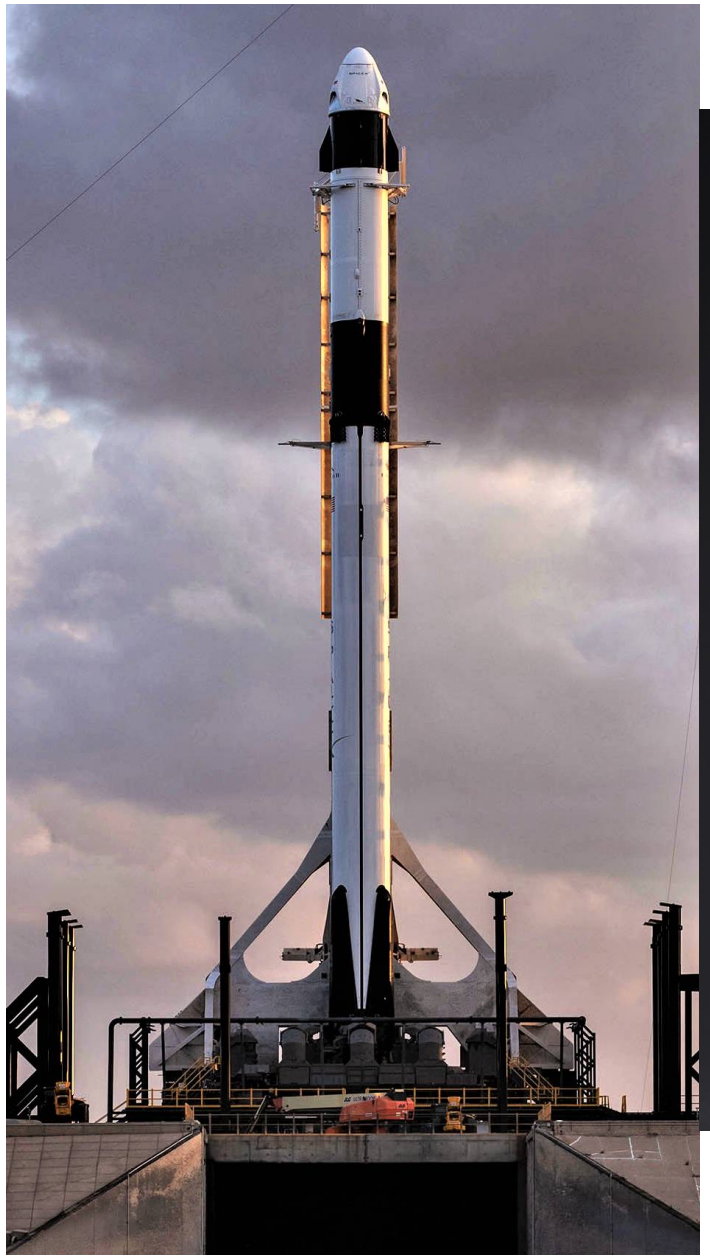

ARTEMIS


ORION
LAUNCH ABORT SYSTEM
ABORT MOTOR
JETTISON MOTOR
ATTITUDE CONTROL MOTOR
CREW MODULE
SERVICE MODULE
SPACECRAFT ADAPTER
CREW MODULE ADAPTER
EUROPEAN SERVICE MODULE
SPACECRAFT ADAPTER JETTISONABLE PANEL
AUXILIARY THRUSTERS
ORION MAIN ENGINE
REACTION CONTROL SYSTEM



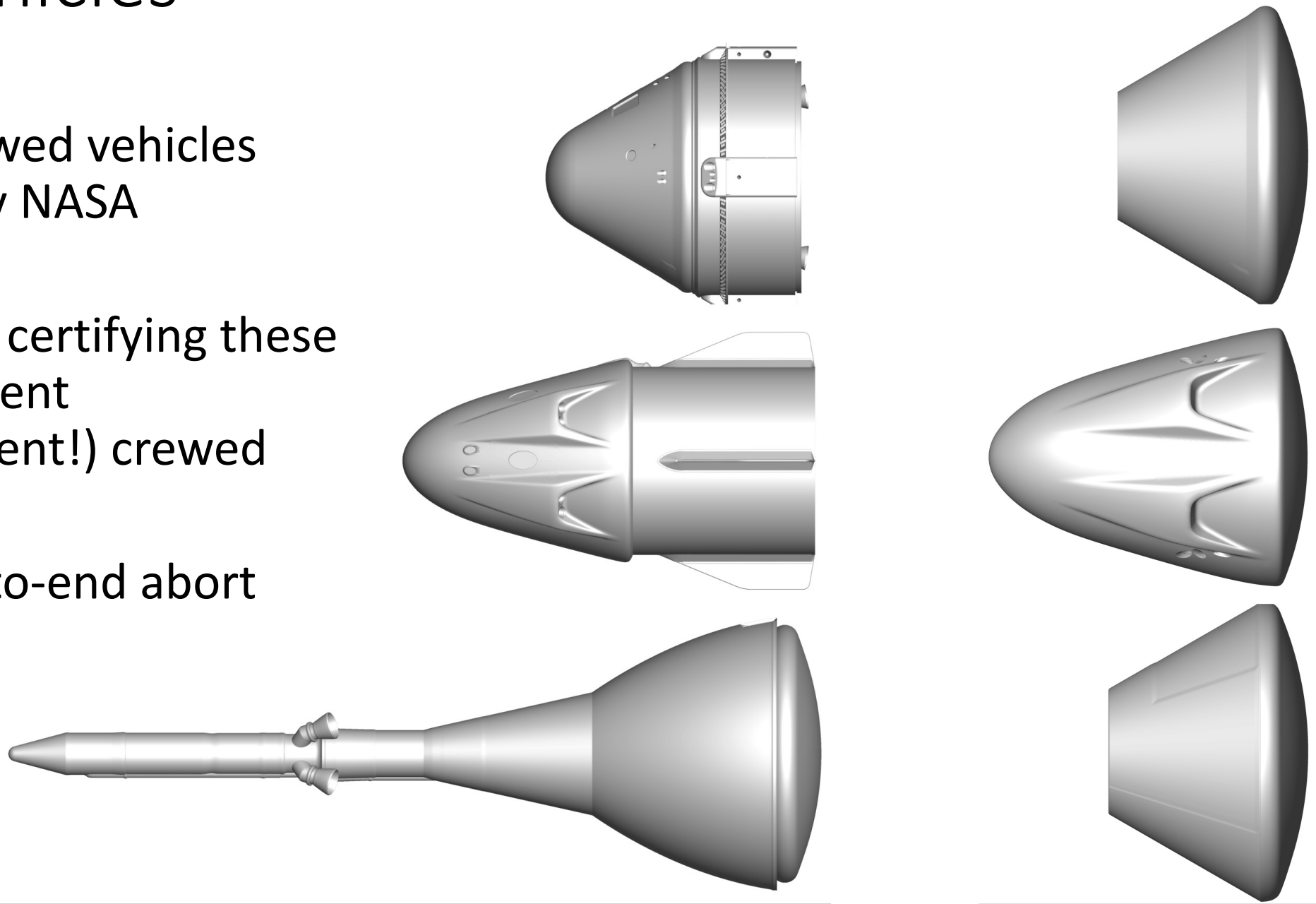
Starliner/Atlas V

Dragon/Falcon 9



Crewed Vehicles

- Currently 3 crewed vehicles scheduled to fly NASA astronauts
- Simultaneously certifying these three independent (and very different!) crewed spacecraft
- All 3 have end-to-end abort capability



Analyses

Commercial Crew

Boeing Starliner

- Nominal entry aerodynamics
  - Base static aerodynamics
  - Ascent cover increments
  - Dynamic aerodynamics
  - Reaction Control System (RCS) jet interaction
- Abort aerodynamics
  - Launch vehicle/spacecraft separation
  - **Crew Module (CM) /Service Module (SM) separation and OMAC jet interaction**
  - **Abort RCS jet interaction**

SpaceX Dragon

- Nominal entry aerodynamics
  - Base static aerodynamics
  - RCS jet interaction
  - **Dynamic aerodynamics**
- Abort Aerodynamics
  - Launch vehicle/spacecraft separation
  - RCS jet interaction

Bolded items summarized in this presentation

Artemis

Orion

- Ascent Abort 2 flight reconstruction
  - Drag miss
- Abort aero database development
- Entry aero database development
- Crew Module wake modeling
  - Supporting parachute analysis

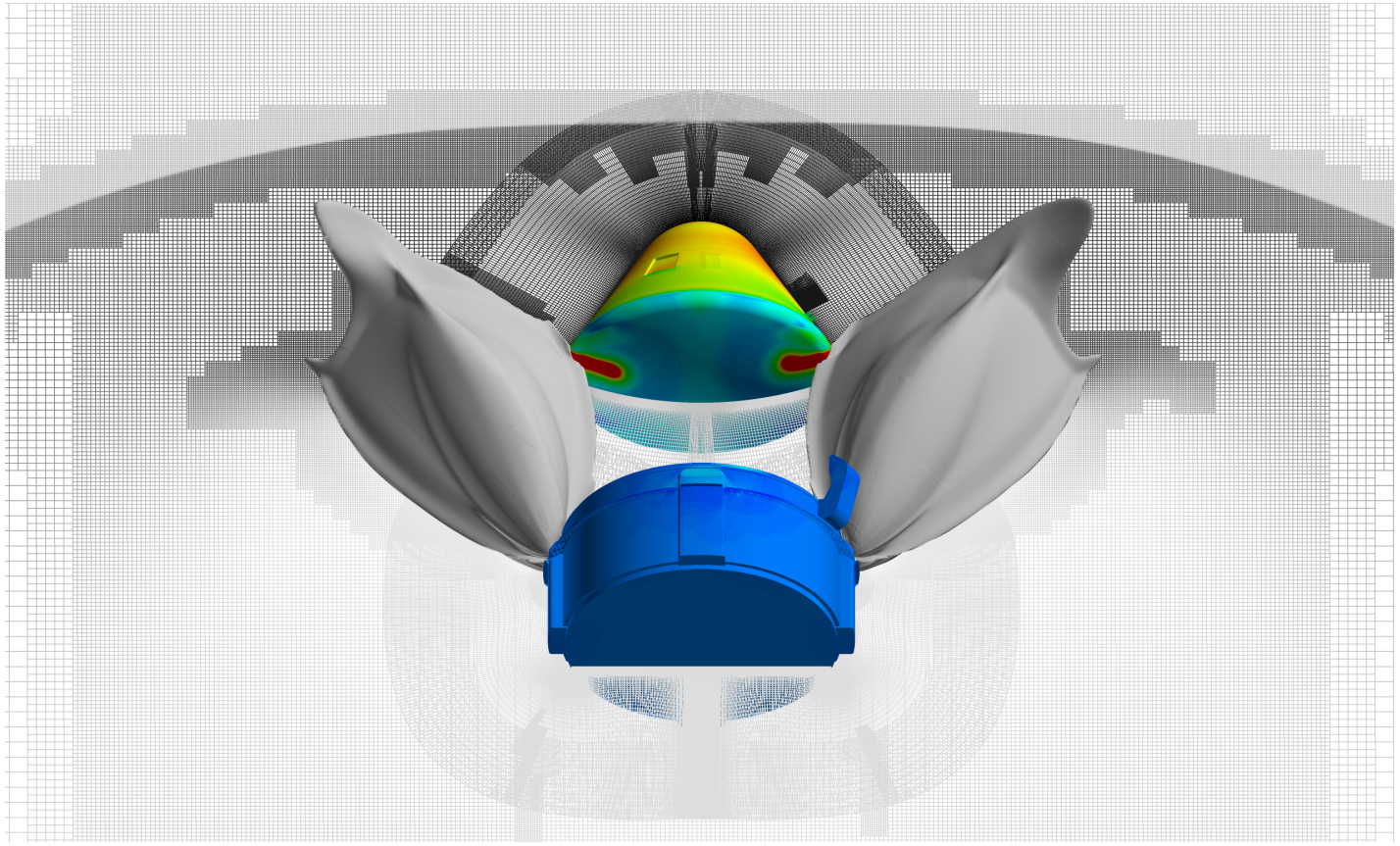
Space Launch System (SLS)

- Databases for Block 1, Block 1B, Block 2
  - **Booster separation aero database**
  - Protuberance ascent airloads
  - Surface pressure database (used for venting)
  - Ascent aero line-load database

Starliner CM/SM Abort Separation

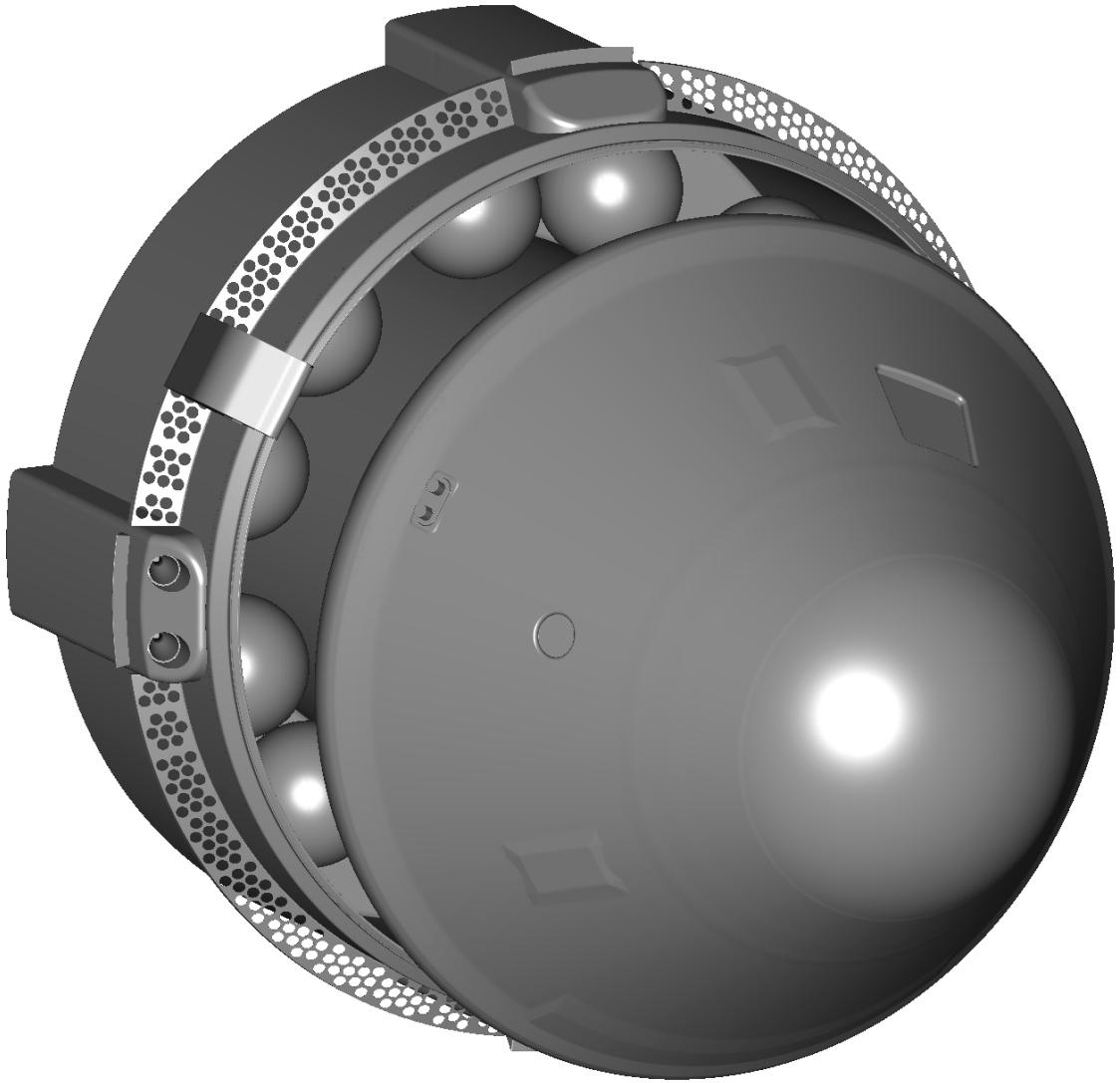
Analysis Highlights

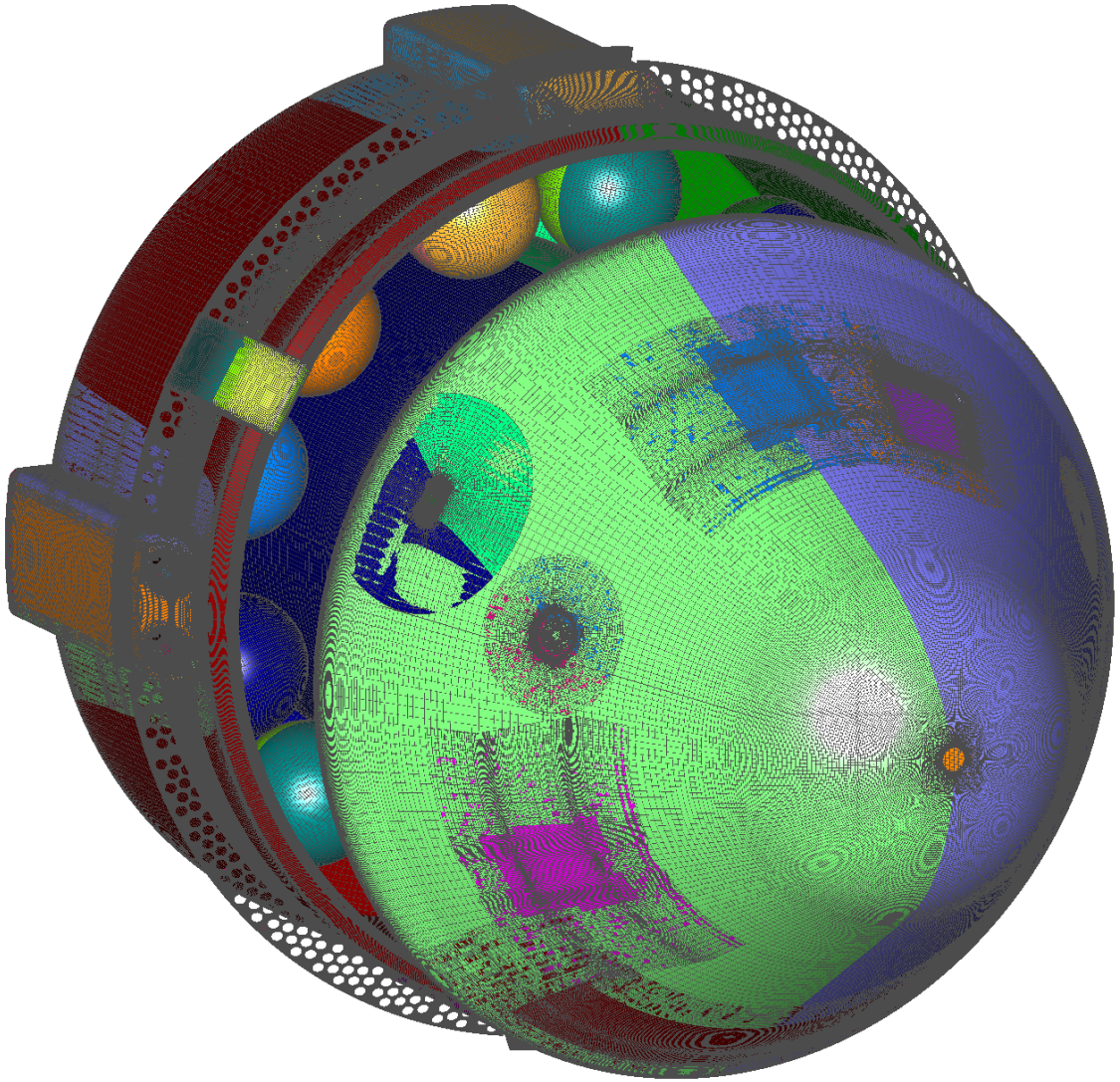
- Very complex physics – supersonic retropulsion with multiple bodies, plume impingement on CM
- 9-dimensional analysis space
- Hybrid DCF/Pegasus with near-body and off-body grid adaptation
- Final product is to check the forces and moments induced on the CM as a function of the 9 independent variables
- Stats
  - Base grid is ~1400 grids, 575e6 points, adapting to 20,000+ grids, 1e9 points
  - Unique grid for each case (due to adaption and relative motion)
  - 60k to 80k CPU hours per case
  - 170 cases, 10 million CPU hours total



Aero = f(Mach, CM_α, CM_β, SM_α, SM_β, DX, DY, DZ, qbar)

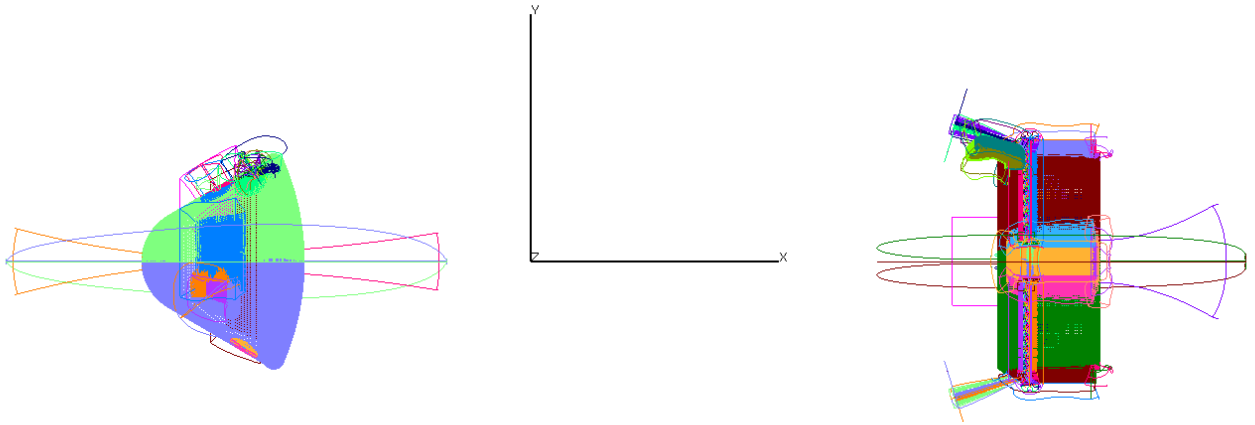
Geometry and Surface Grid Details





Hybrid DCF/Pegasus

- Run Pegasus on the two bodies with enough separation so they don't touch
- Pegasus does the hole cutting and overlap minimization among the grids in each body
- Use Config.xml to position each body
- Overflow generates the box grids
- XRINFO cuts the boxes and between the two bodies



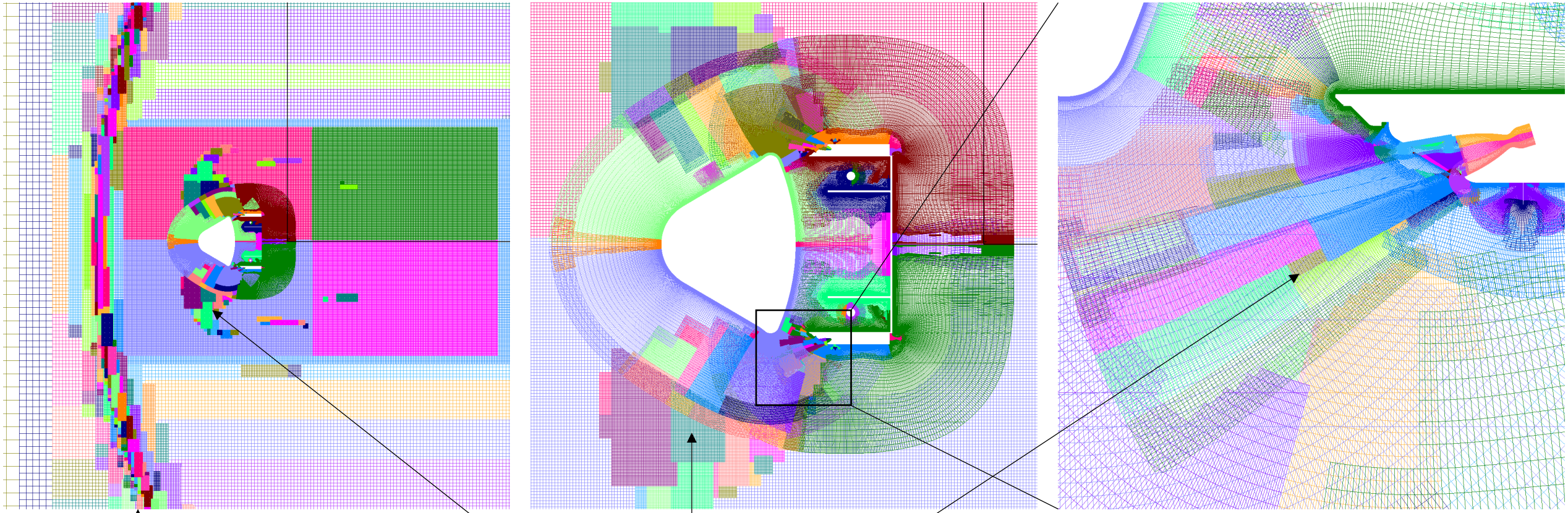
overflow.inp

```
! cm_cut_in_boxes
 $XRINFO
     IDXRAY  = 1,
     IGXLIST = -1,
     XDELTA  = 90.0,
     $END

! cm_far_cut_in_sm
 $XRINFO
     IDXRAY  = 2,
     IGXLIST = 27,28,29,30,26,31,108,109,110,111,112,113,114,115,116,...
     XDELTA  = 30,
     $END

! sm_far_cut_in_cm
 $XRINFO
     IDXRAY  = 5,
     IGXLIST = 1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,
     XDELTA  = 30,
     $END
```

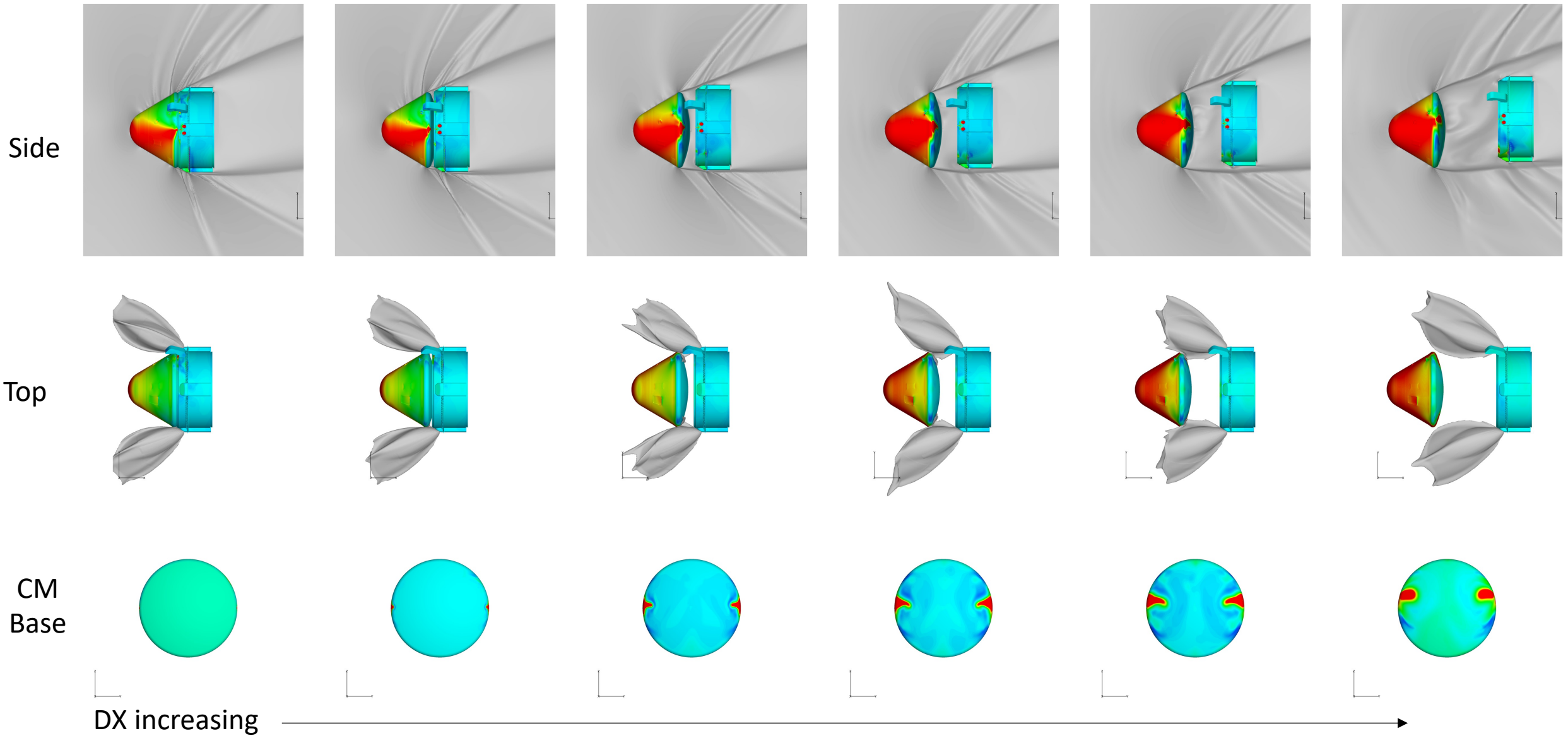
Config.xml

```
<?xml version='1.0' encoding='utf-8'?>
<Configuration AngleUnit='degree'>

   <Component Name='CM' Type='struc'>
      <Data> Grid List=1-25 </Data>
   </Component>

   <Component Name='SM' Type='struc'>
      <Data> Grid List=26-1371 </Data>
      <Transform>
        <Rotate Center="412.07, 0.0, 0.0" Axis="0.0, 1.0, 0.0" Angle="4.78256015812529" />
        <Rotate Center="412.07, 0.0, 0.0" Axis="0.0, 0.0, 1.0" Angle="17" />
        <Translate Displacement="-505.115967832892, 36, -19.8247431184158" />
      </Transform>
   </Component>

</Configuration>
```

Adaption Examples

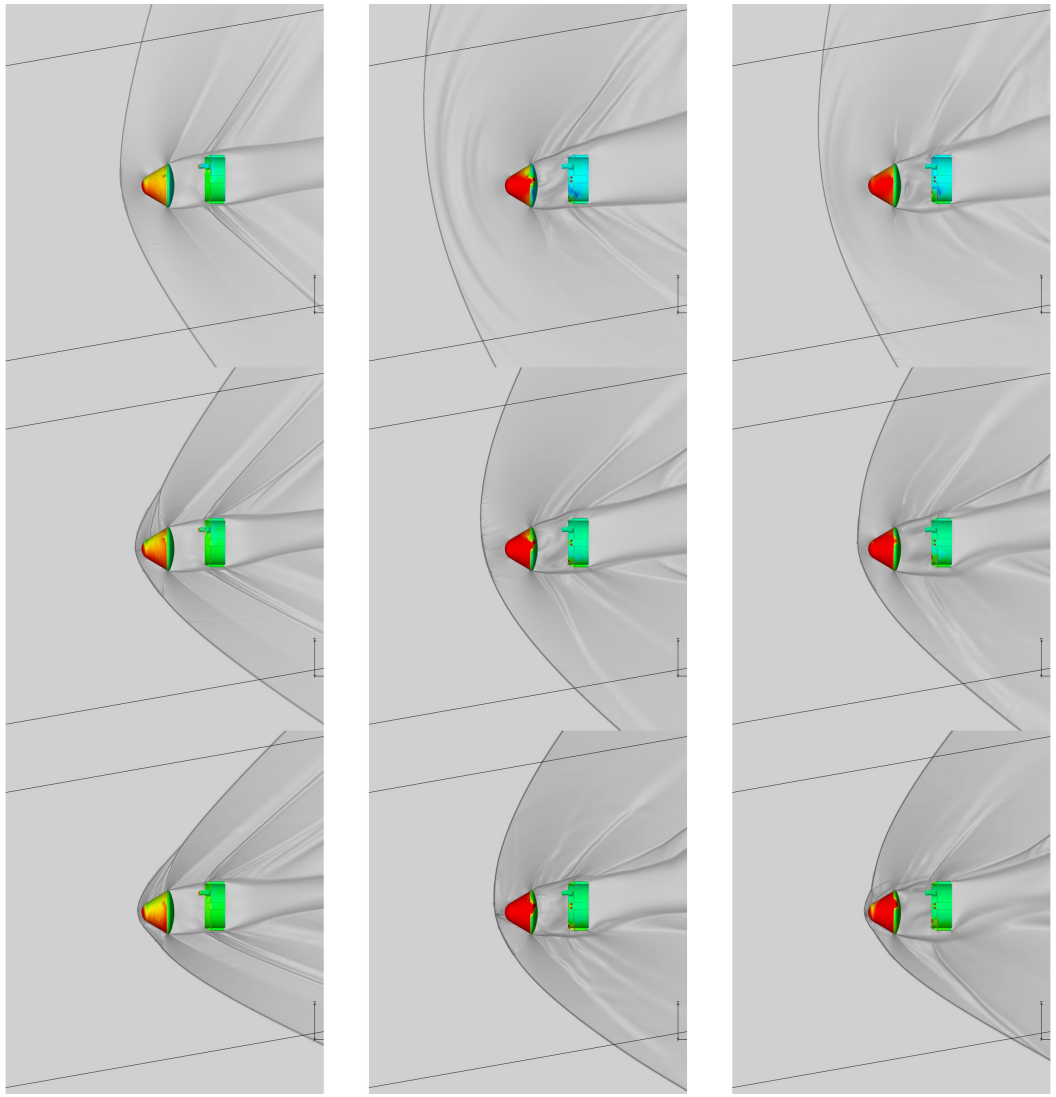


Starliner CM/SM Abort Separation



Starliner CM/SM Abort Separation

Mach Increasing



Power off

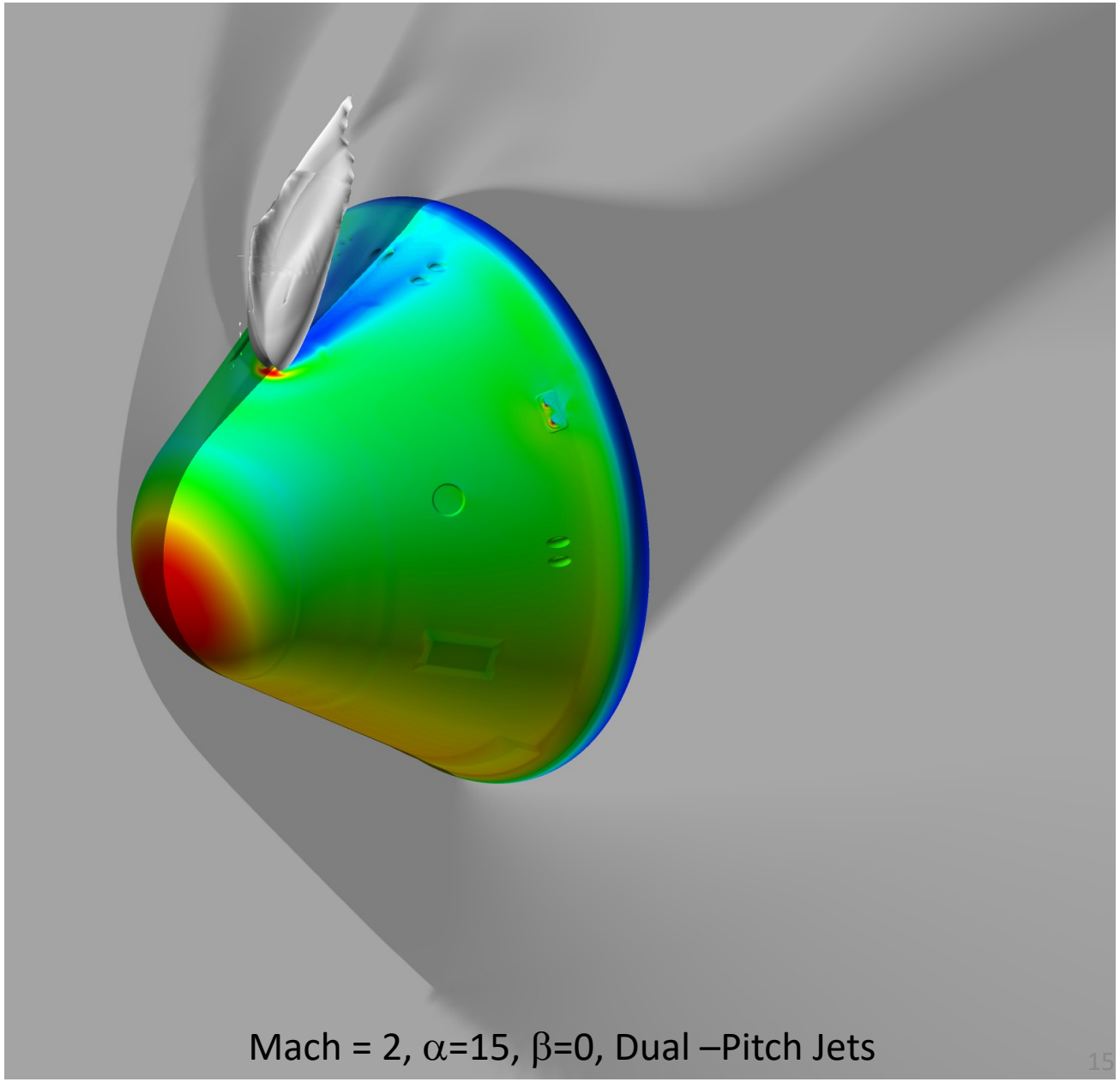
SM power on, low qbar

SM power on, high qbar

Starliner Abort RCS Jet Interaction

Analysis Highlights

- Utilized new L2X = 2 Pegasus option for optimal surface overlap
- Shock fitted grid to vehicle bow shock and rotated wakebox grid
  - Requires a separate grid for each Mach/alpha combination
- Final product is a check of the jets' aerodynamic interactions and their affect on the vehicle moments
- Stats
  - 69 zones, 115e6 points per grid system
  - 61 grids systems for analysis
  - 1000 to 5000 CPU hours per case
  - 428 cases, 800,000 CPU hours total

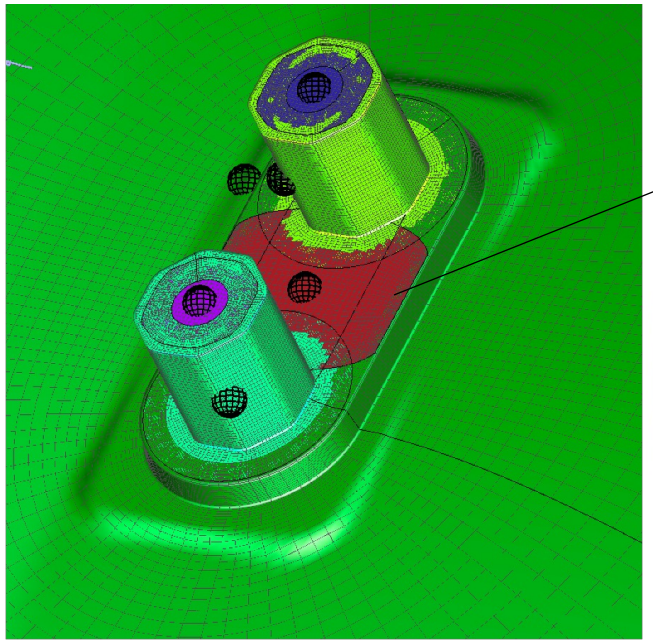


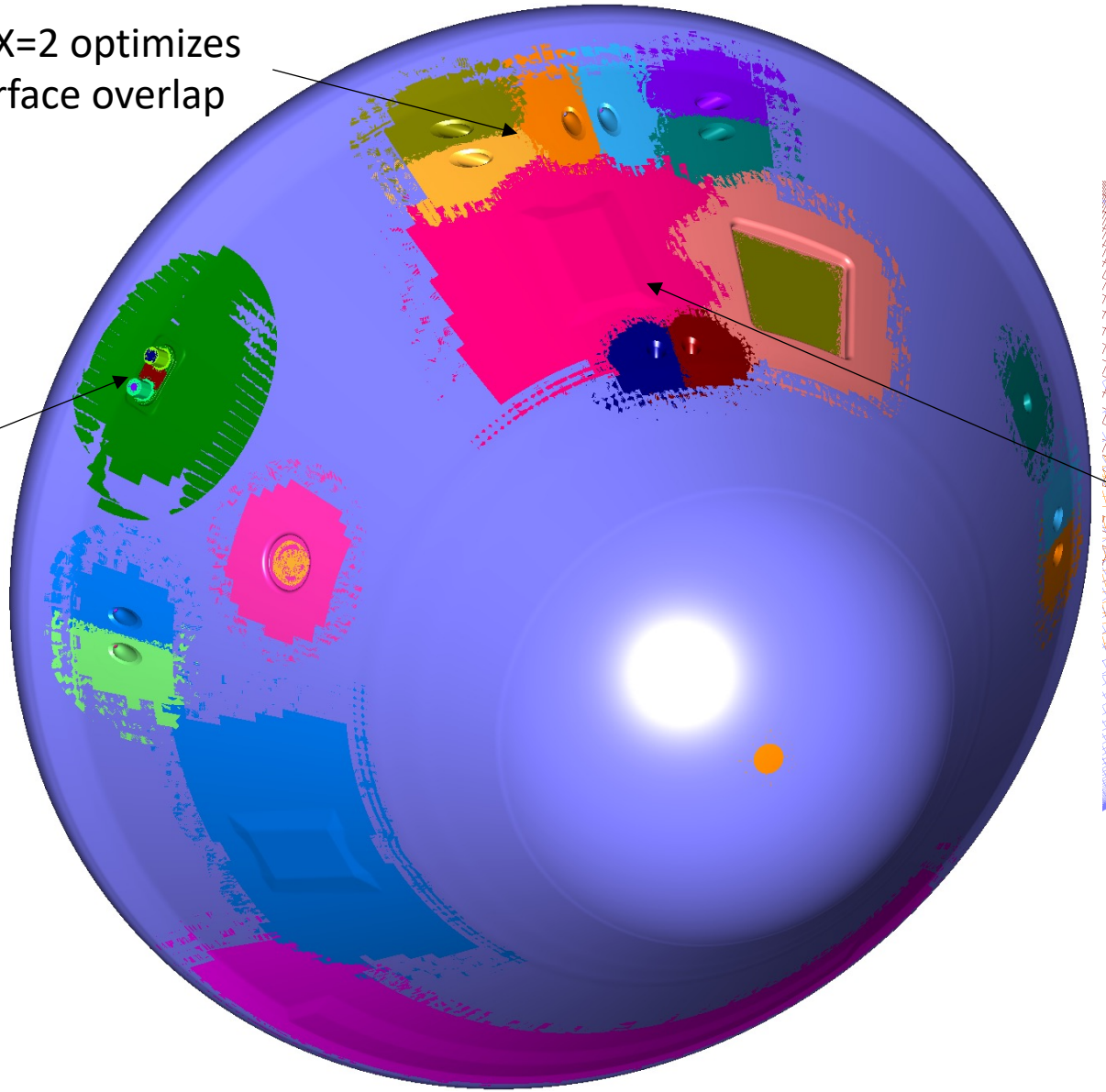
Mach = 2, α=15, β=0, Dual –Pitch Jets

Starliner Grid System for RCS Jet Interaction

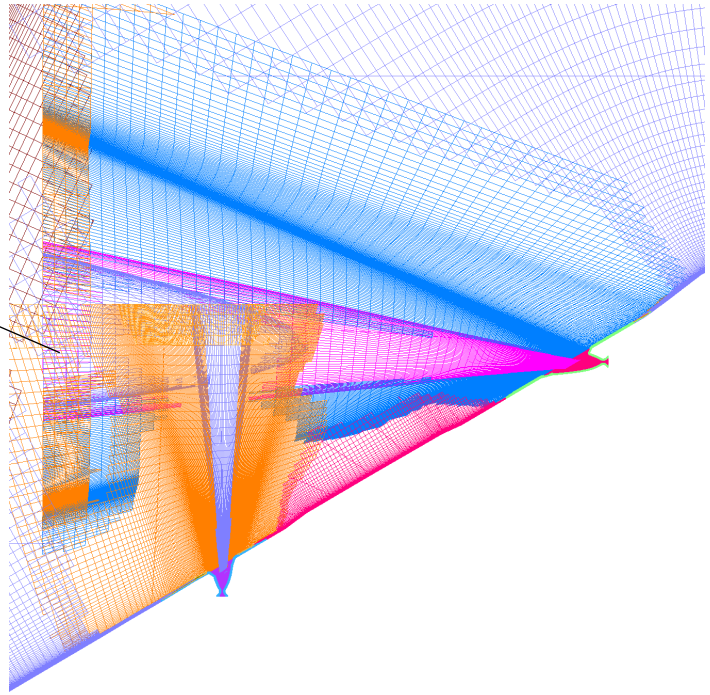
L2X=2 optimizes surface overlap

Protuberance Details

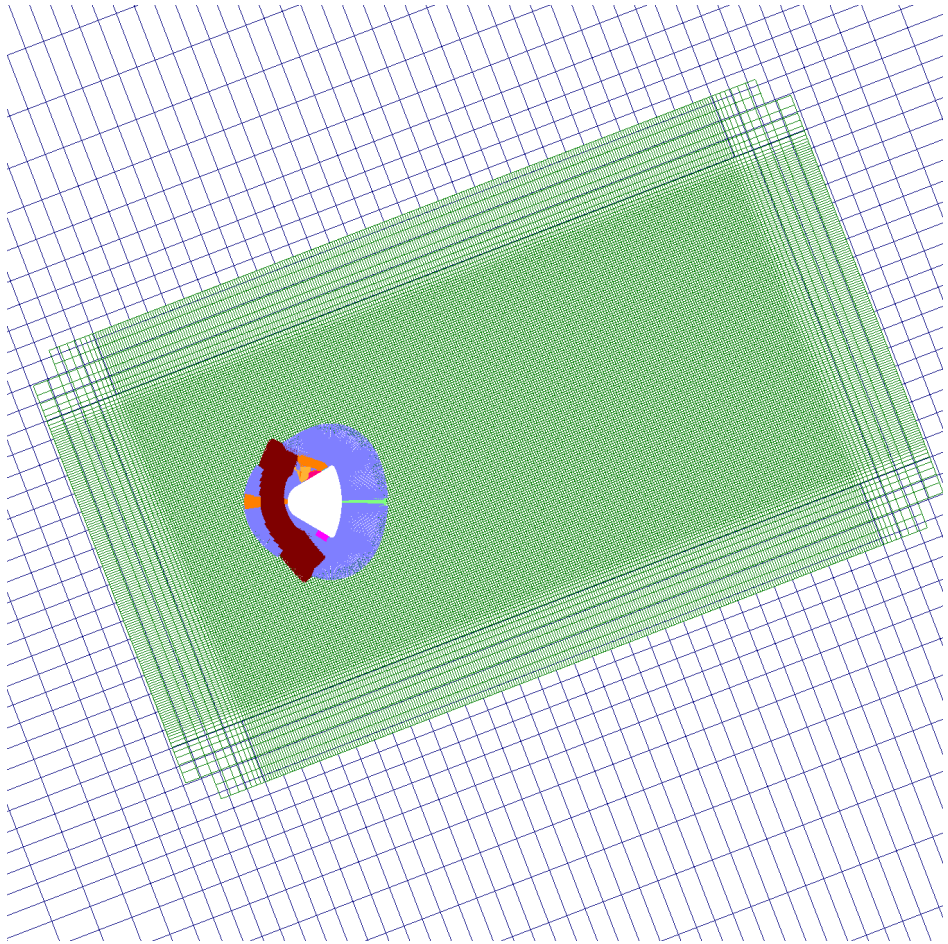




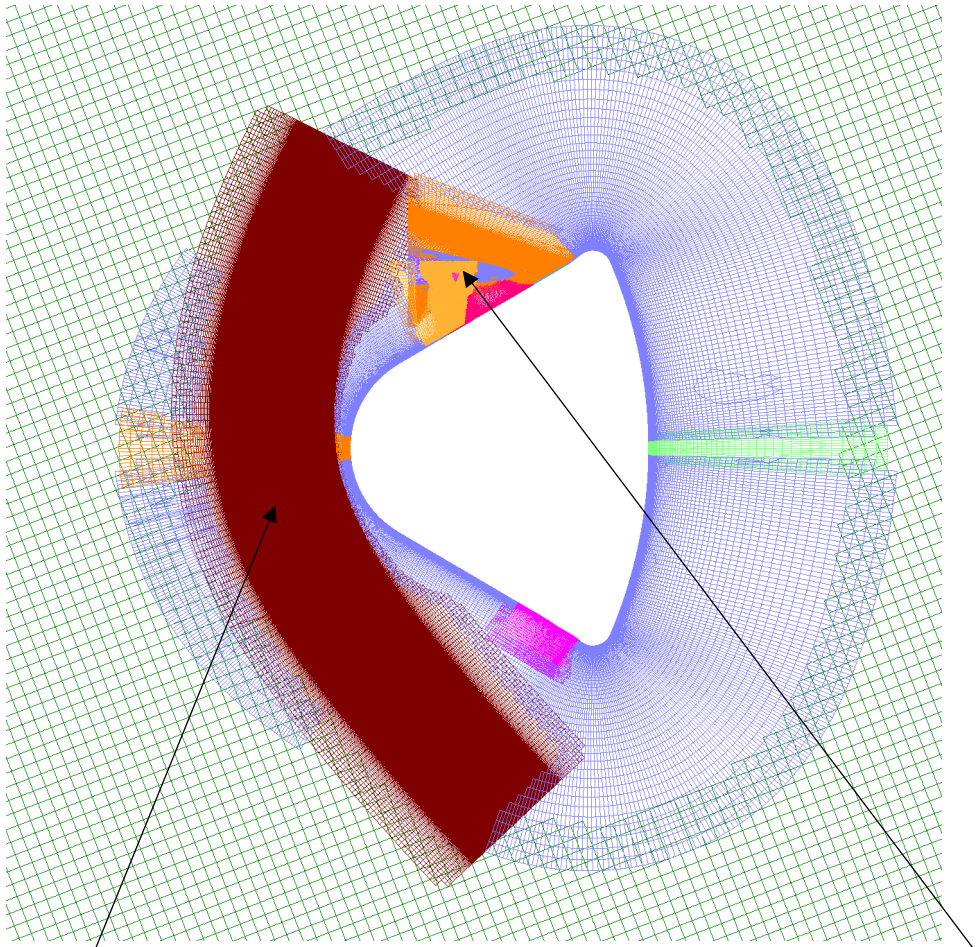
Y=0 Cut Through Plume Grids



Starliner Grid System for RCS Jet Interaction



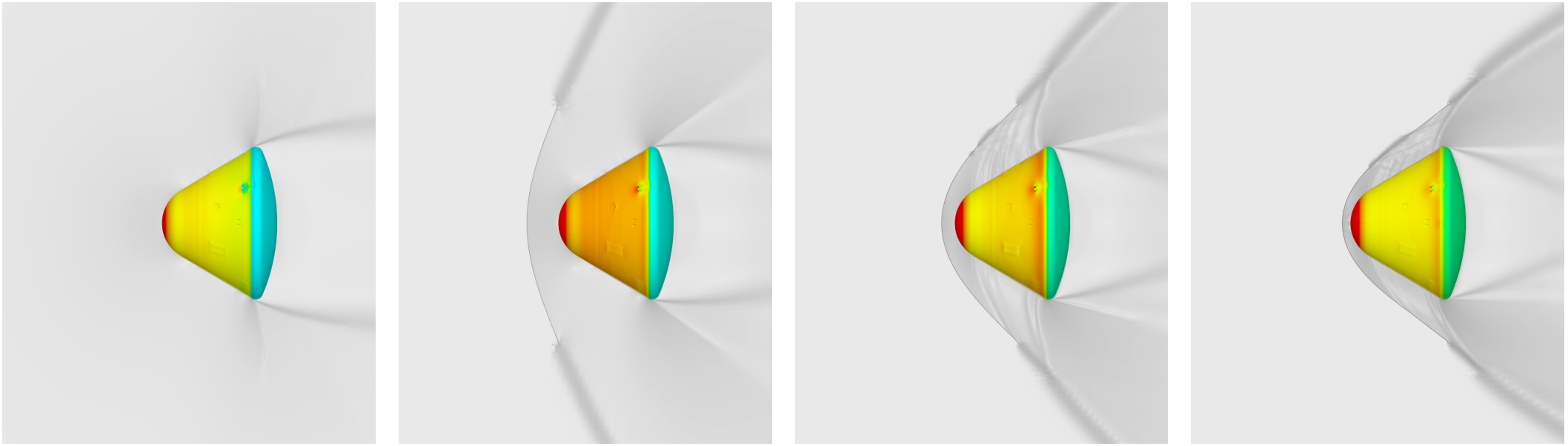
Wakebox grid matched to alpha (15degrees)



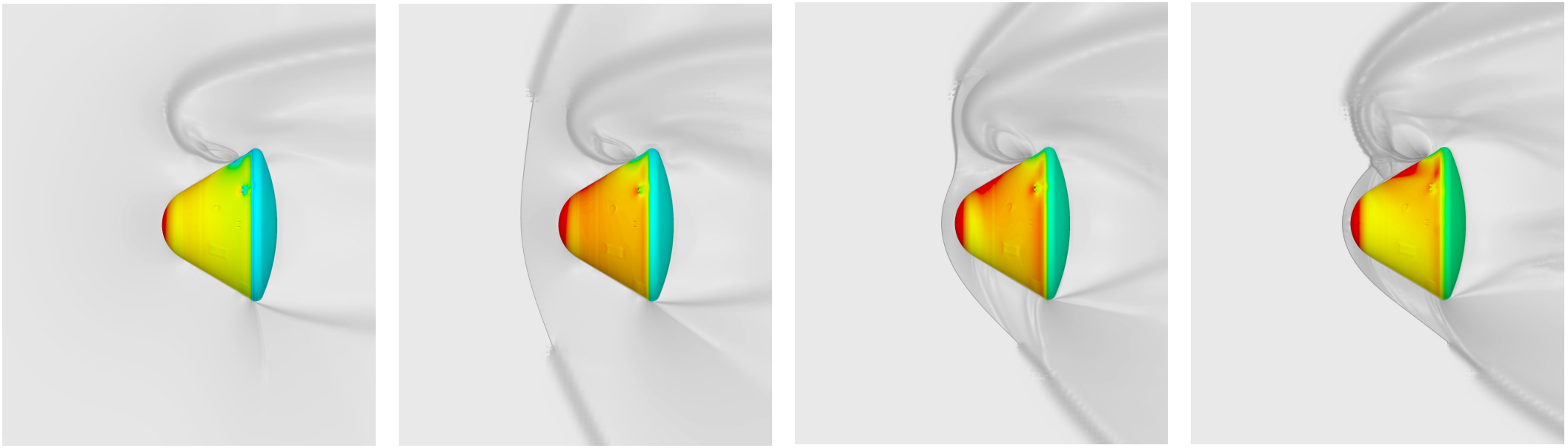
Shock refinement grid to resolve bow shock
Plume refinement grids to resolve RCS firings

Starliner Abort RCS Jet Interaction

Power Off



+Pitch Jet On

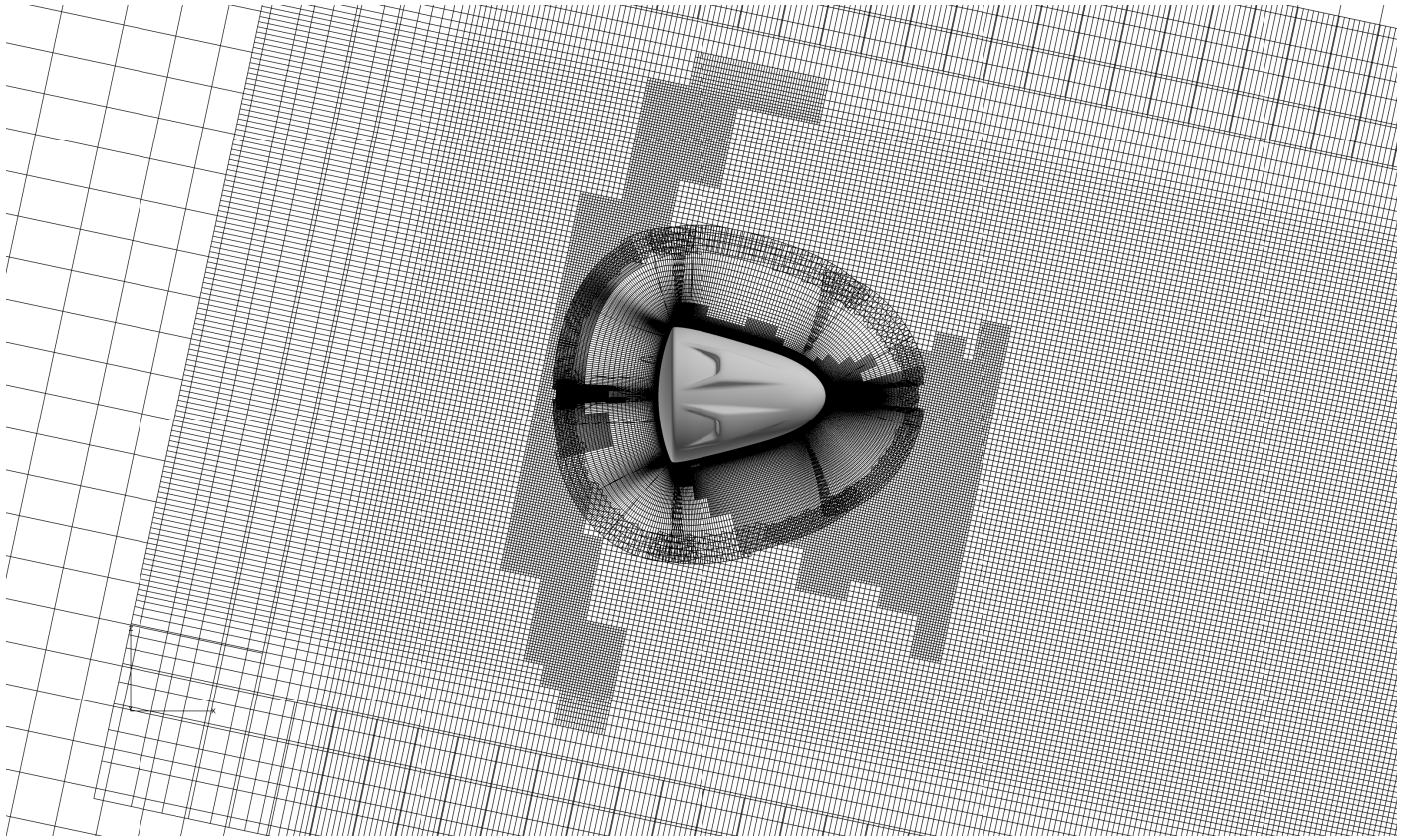


Mach Increasing

Dragon Dynamic Aero

Analysis Highlights

- Moving body, forced oscillation
- Unsteady DES
- Adaption
- Final product :
  - Cmq for comparison to wind tunnel test (WTT) data (forced oscillation)/sting interference
  - Extend data above WTT max Mach number
  - Compare forced/free oscillation
- Stats
  - Base grid is 24 grids, 40e6 points, adapting to ~2270 grids, 101e6 points
  - Unique grid for each case (due to adaption)
  - 30k to 120k CPU hours per case (depending on timestep & # of cycles modeled)
  - ~140 cases, ~8.6 million CPU hours total

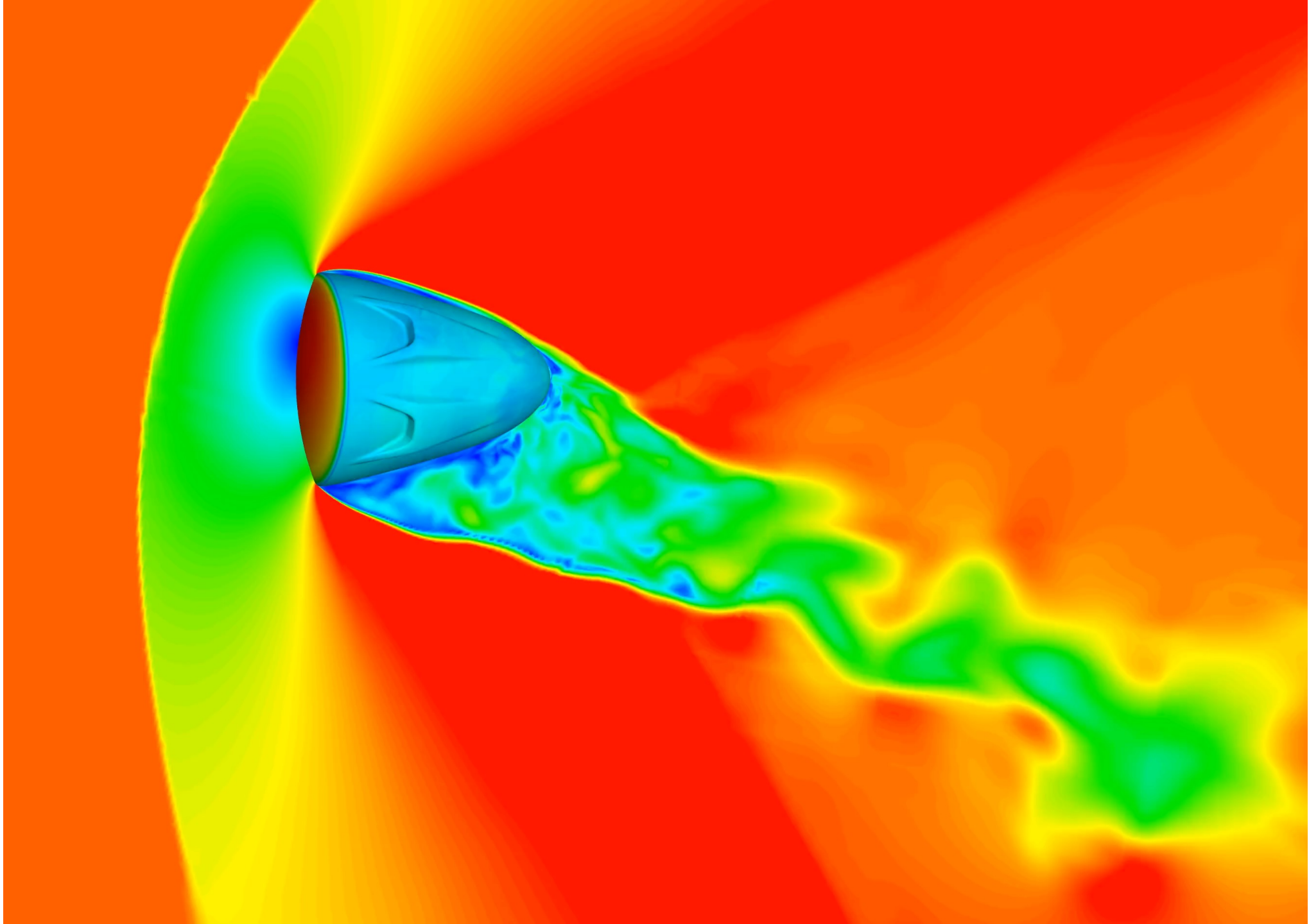


Forced Oscillation

- 0.32 Hz
- 4° amplitude

Wake/shedding frequency >> pitch motion

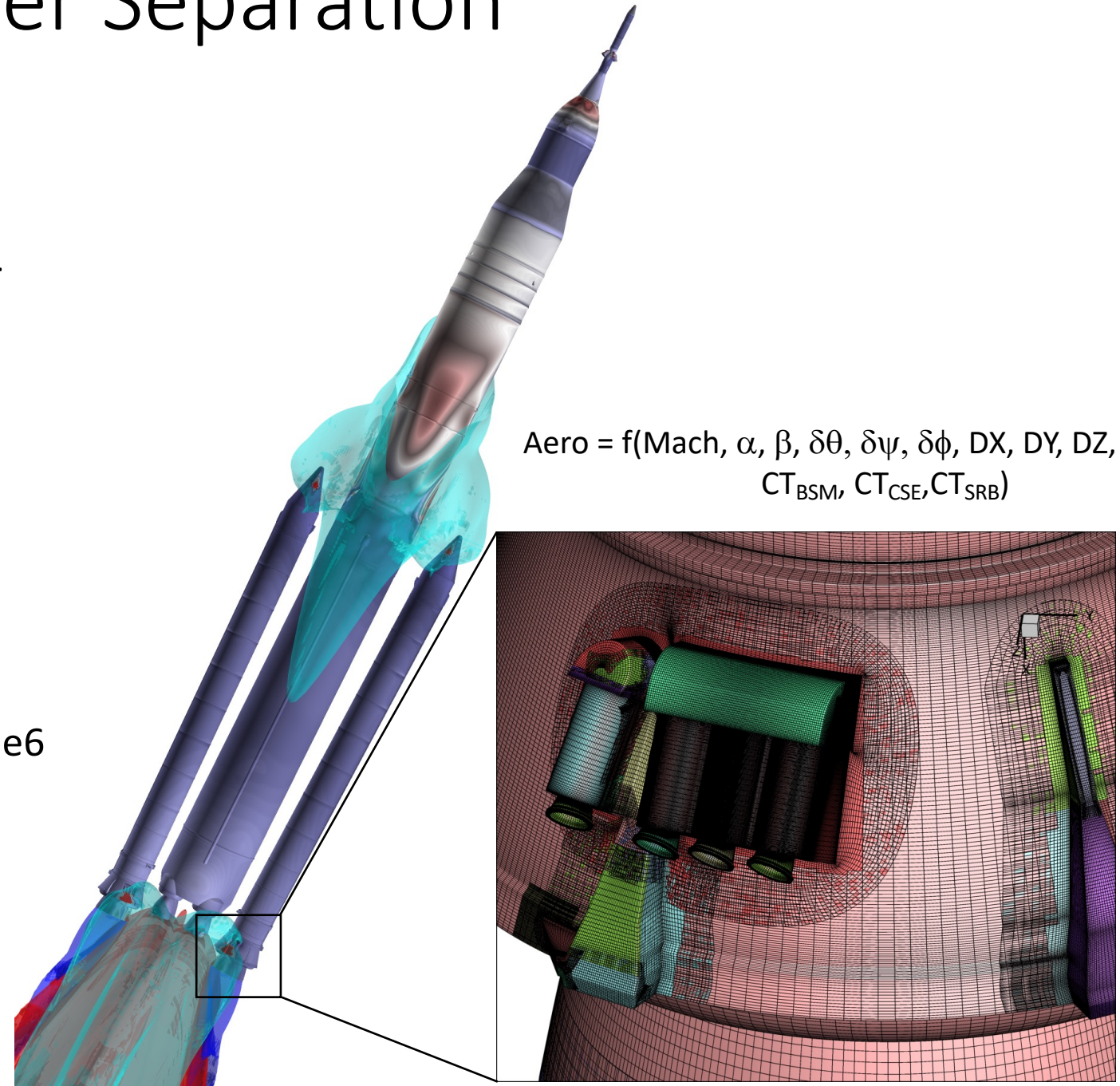
Note changes in leeward backshell separation



SLS Solid Rocket Booster Separation

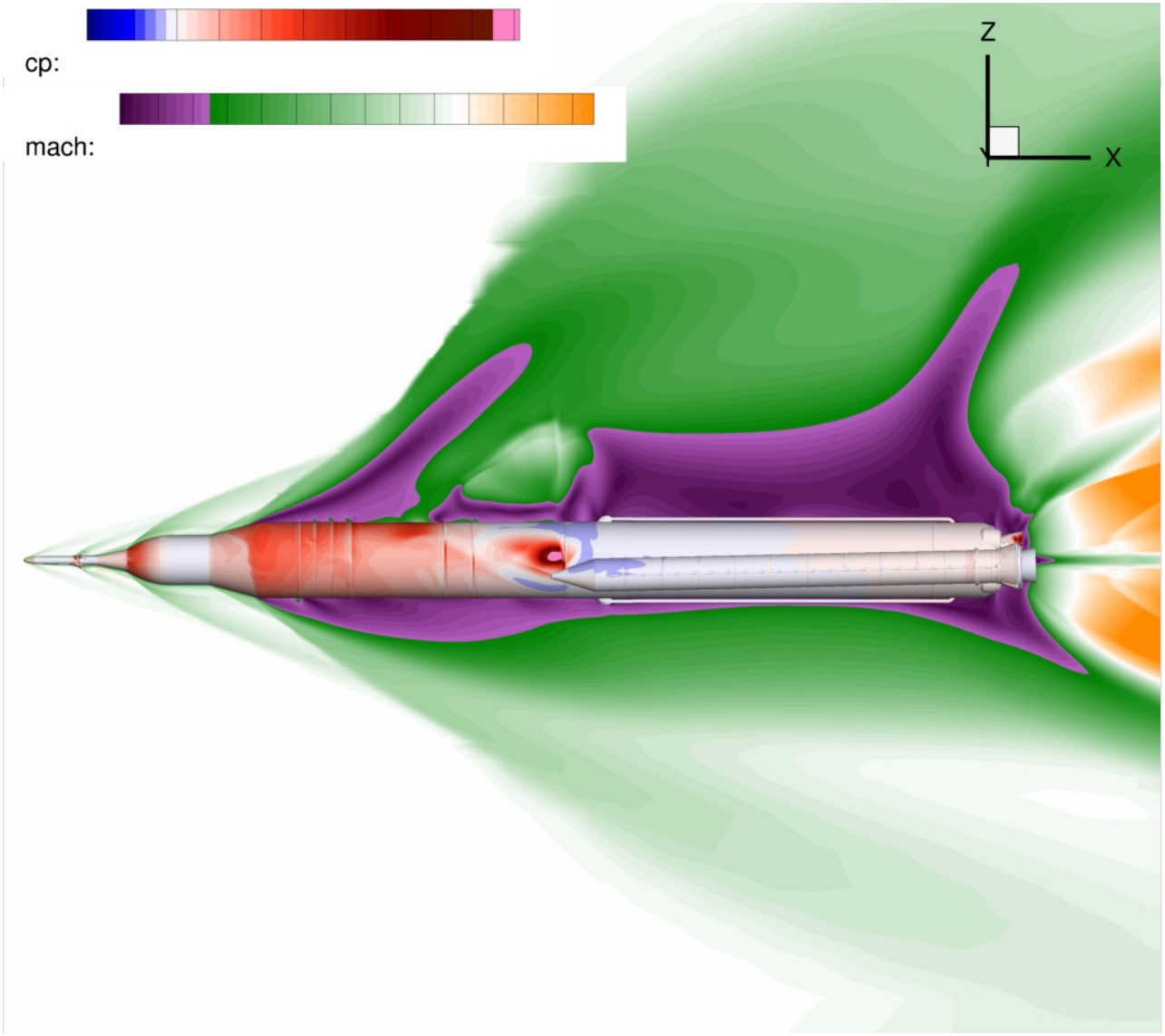
Analysis Highlights

- Very complex physics – supersonic, multi-body separation with plumes
- 22 powered nozzles – 8 on each SRB, 4 core stage (RS-25) and 2 Solid Rocket Boosters
- 12-dimensional analysis space
- Hybrid DCF/Pegasus with off-body grid adaptation
- Final product is aero coefficients used for creation of an aero database
- Stats
  - Base grid is 340e6 points, adapting to 425e6 points
  - O(40,000) CPU hours per case
  - 1500 fun3d simulations (!)
  - 100 overflow cases run to augment aero database (UQ creation)

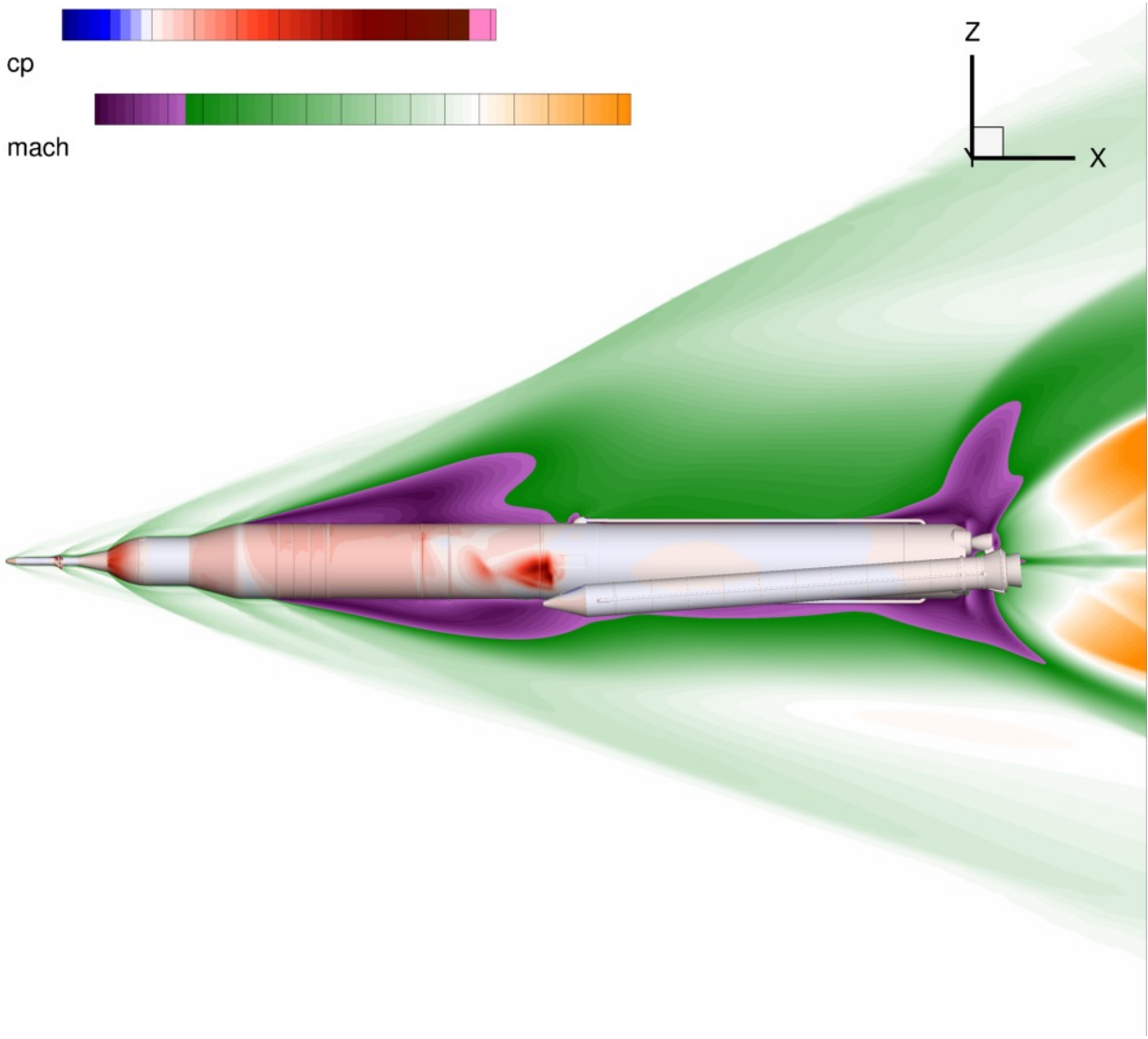


Aero = f(Mach, α, β, $\delta\theta$, $\delta\psi$, $\delta\phi$, DX, DY, DZ, CT_{BSM}, CT_{CSE},CT_{SRB})

SLS Solid Rocket Booster Separation

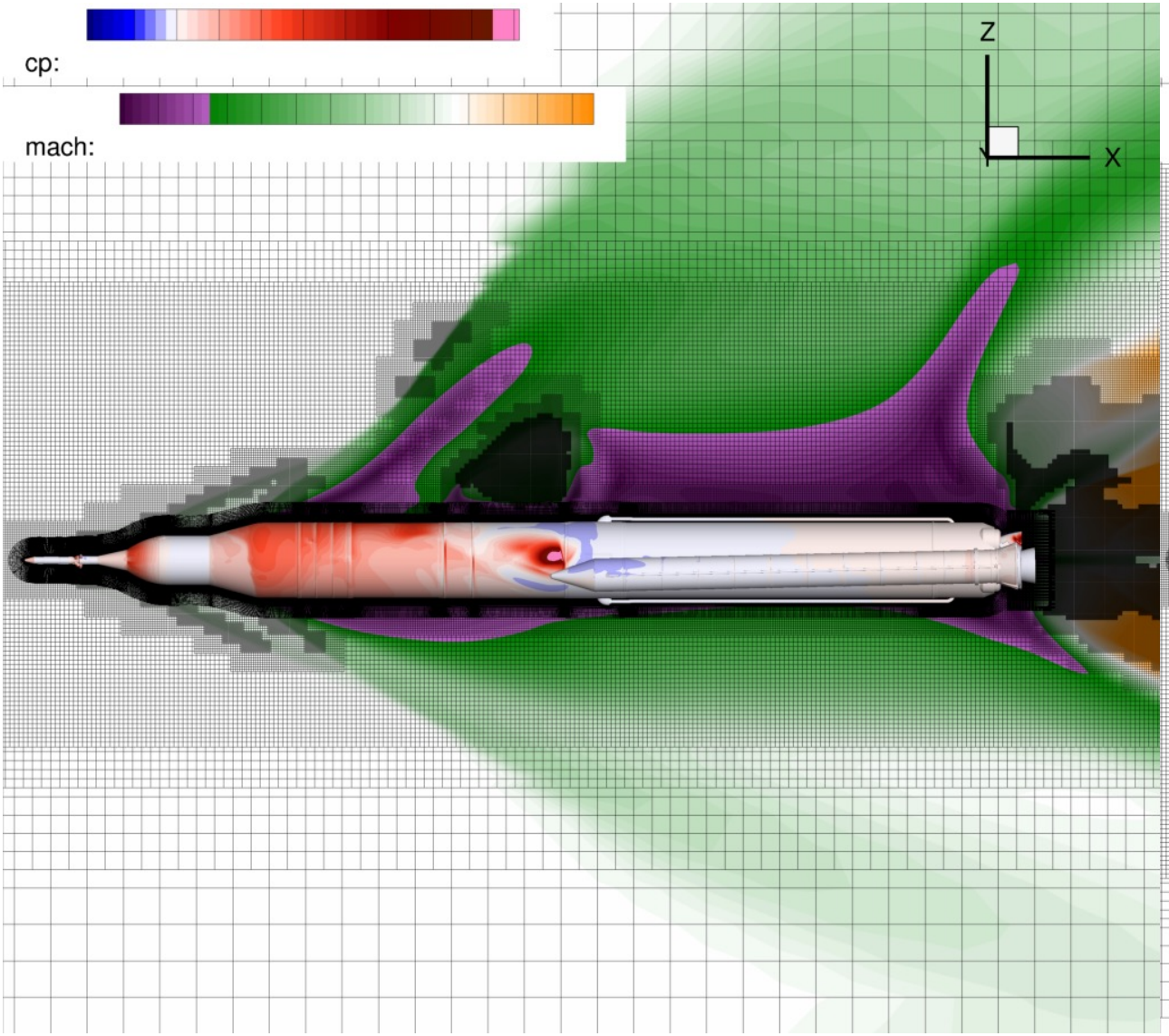


DX=4’, Max BSM power

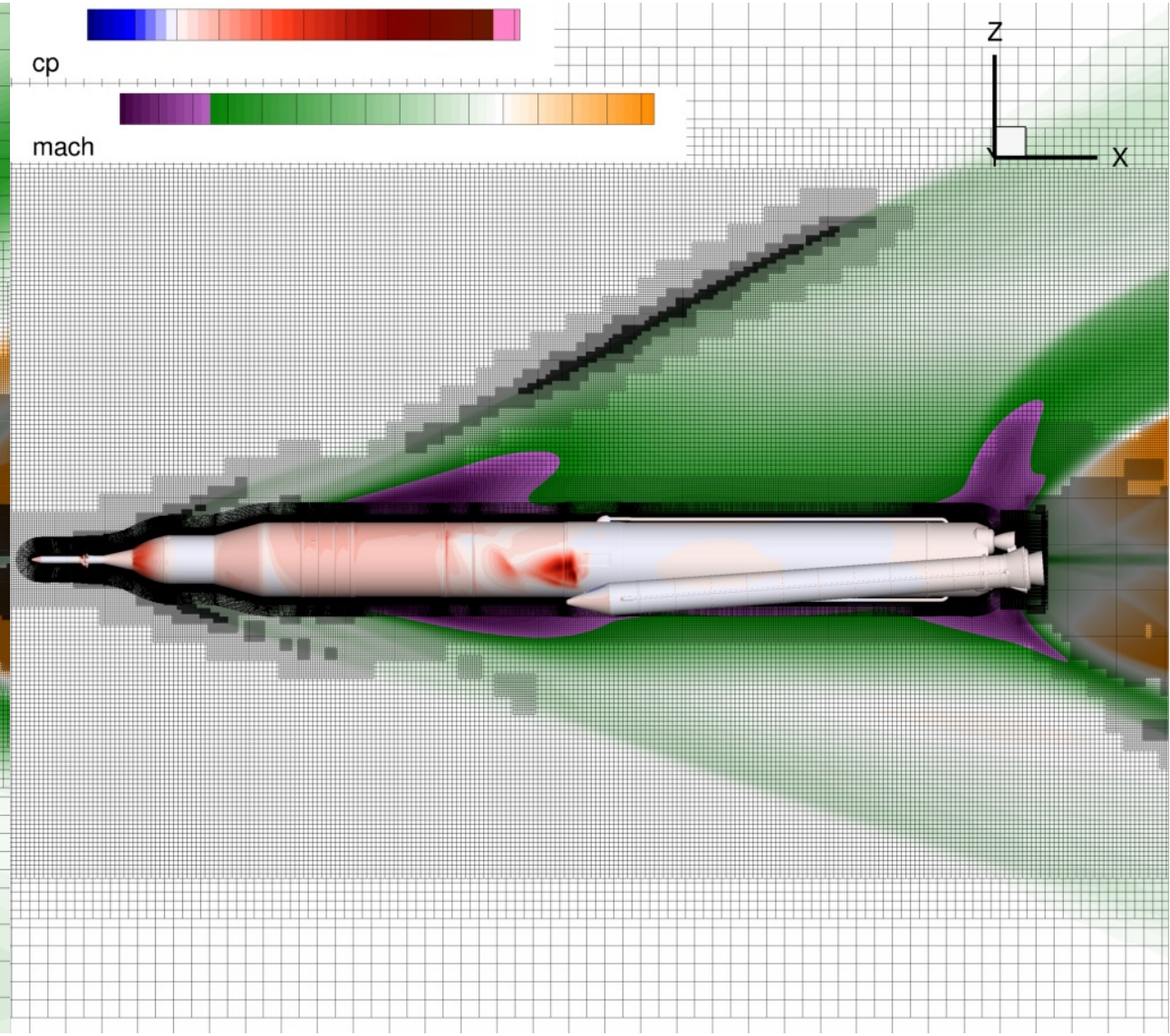


DX=10’, Low BSM power

SLS Solid Rocket Booster Separation



DX=4’, Max BSM power



DX=10’, Low BSM power

Questions?