National Aeronautics and Space Administration

Aerodynamic Databases for the Space Launch System

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NASA Ames Research Center

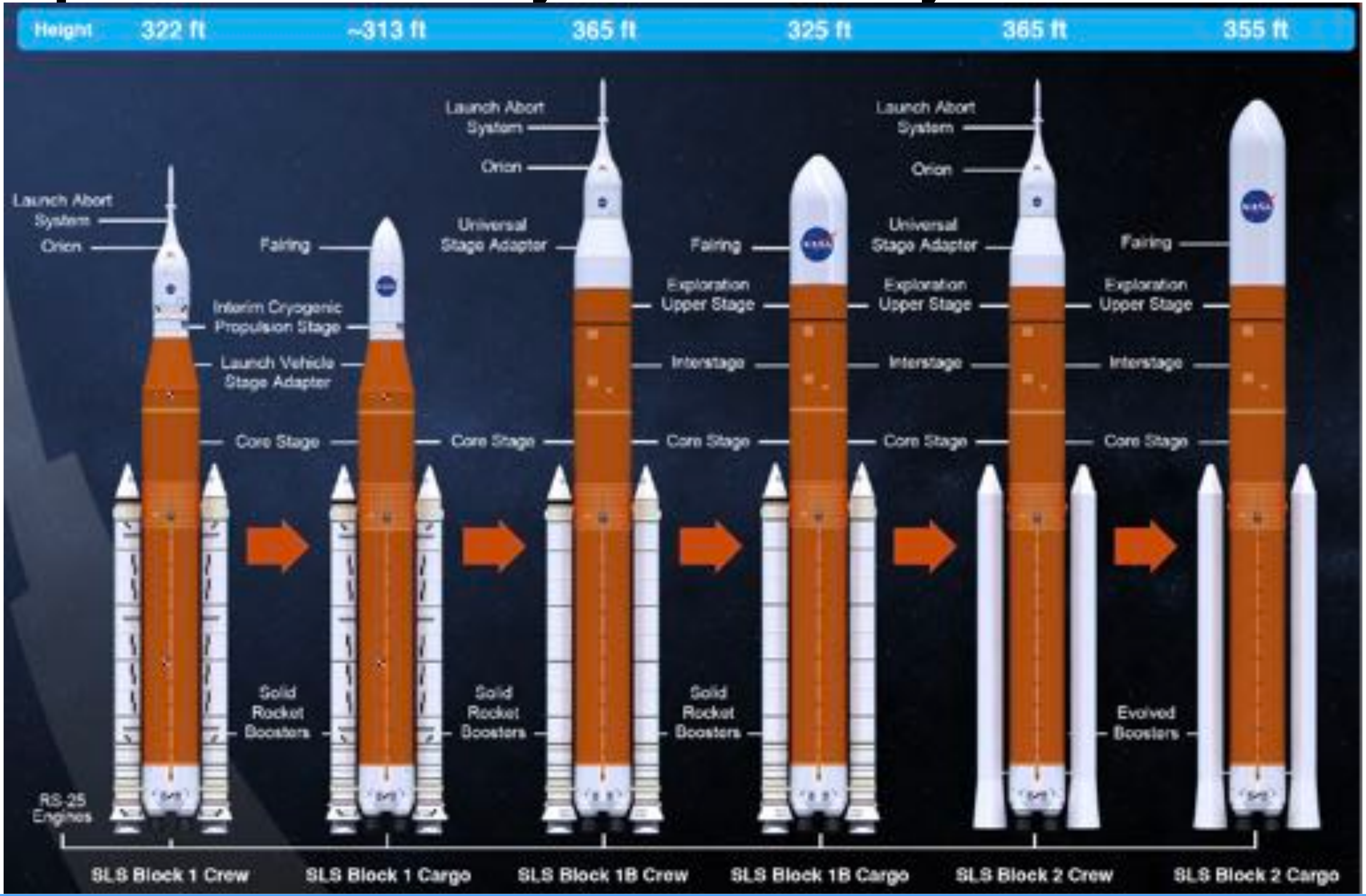
Supercomputing Dallas, November 2018

NASA Space Launch System

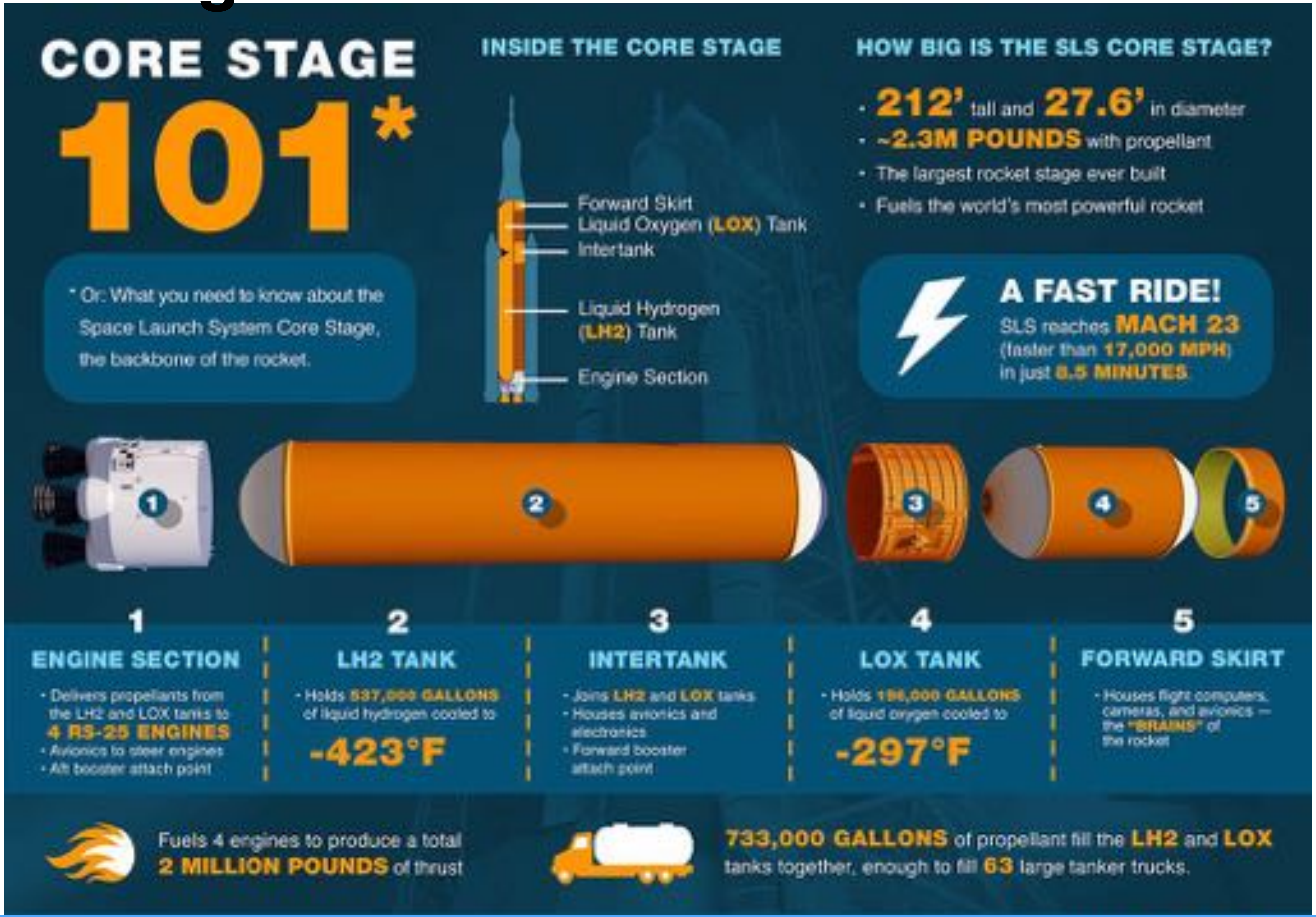
- NASA developed heavy-lift capability
- First rocket to transport astronauts beyond Earth orbit since Saturn V
- 70-metric ton payload capability
- Thrust:
  - 8.4 million pounds
  - 10% more than Saturn V
- Payload more than three times of the Space Shuttle

NASA Space Launch System Family

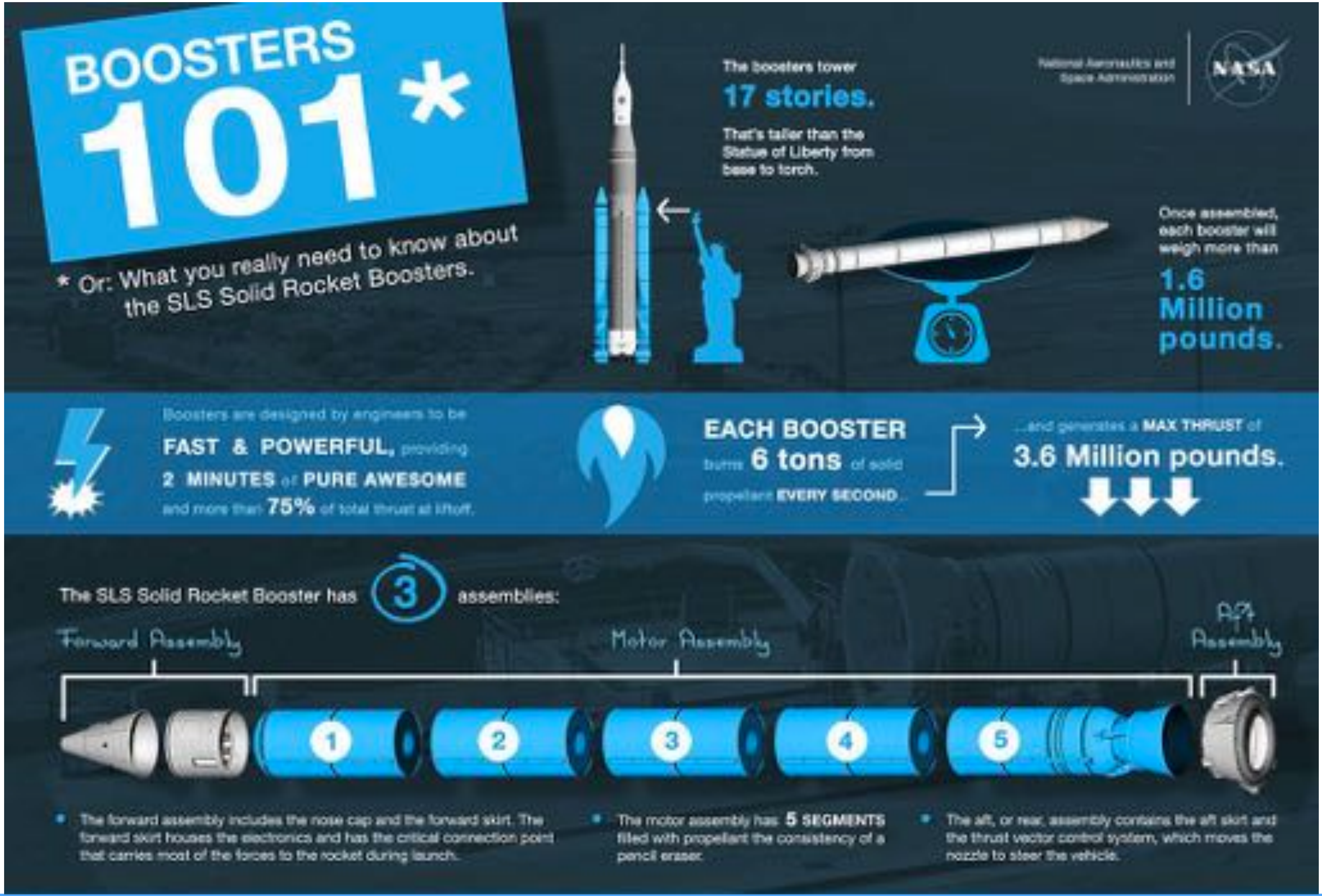
NASA Space Launch System Family



SLS Core Stage



SLS Boosters



SLS Exploration Mission-1

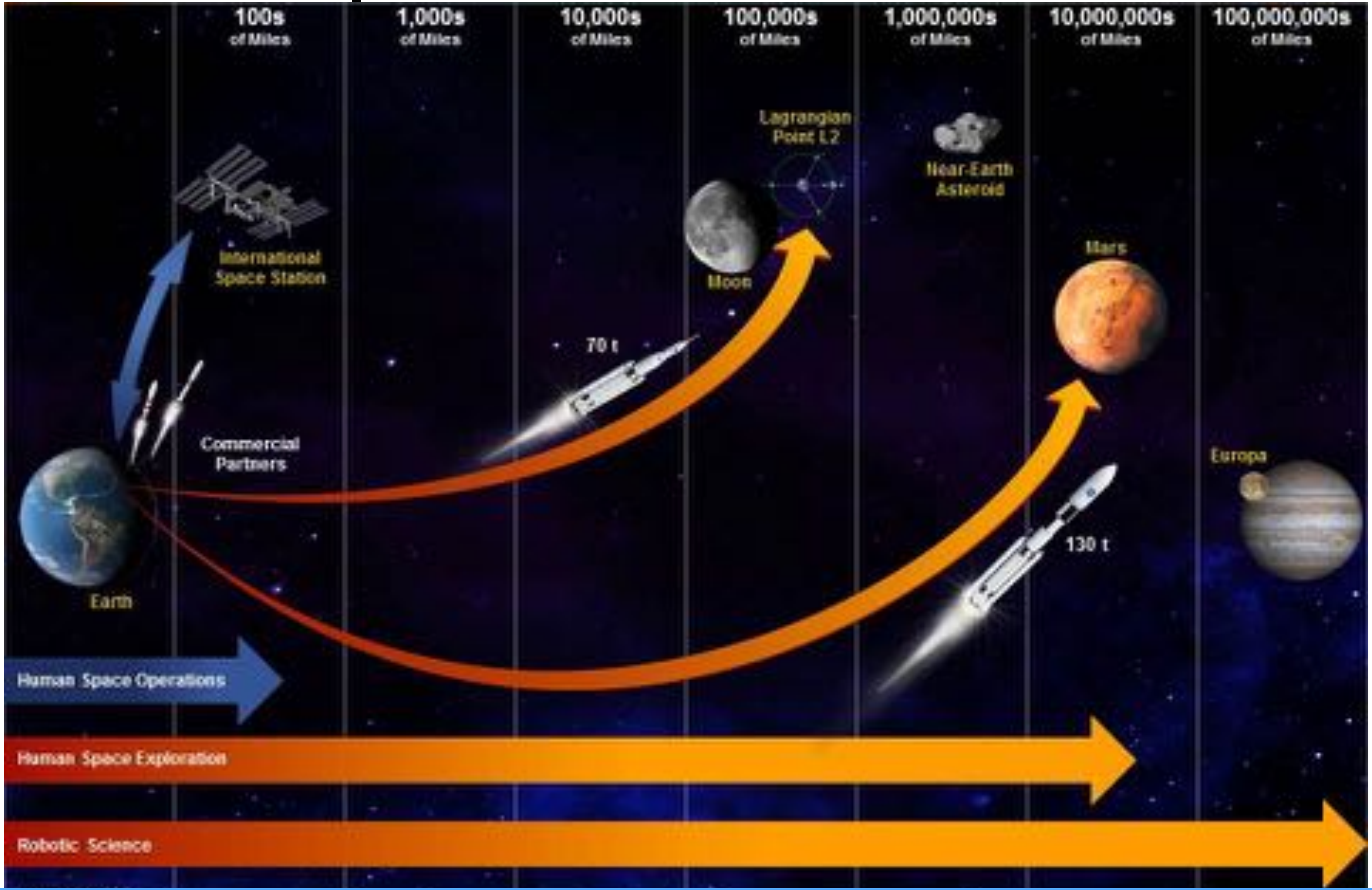
EXPLORATION MISSION 1

Narrated by Mission Manager, Mike Sarafin

SLS Exploration Mission 1

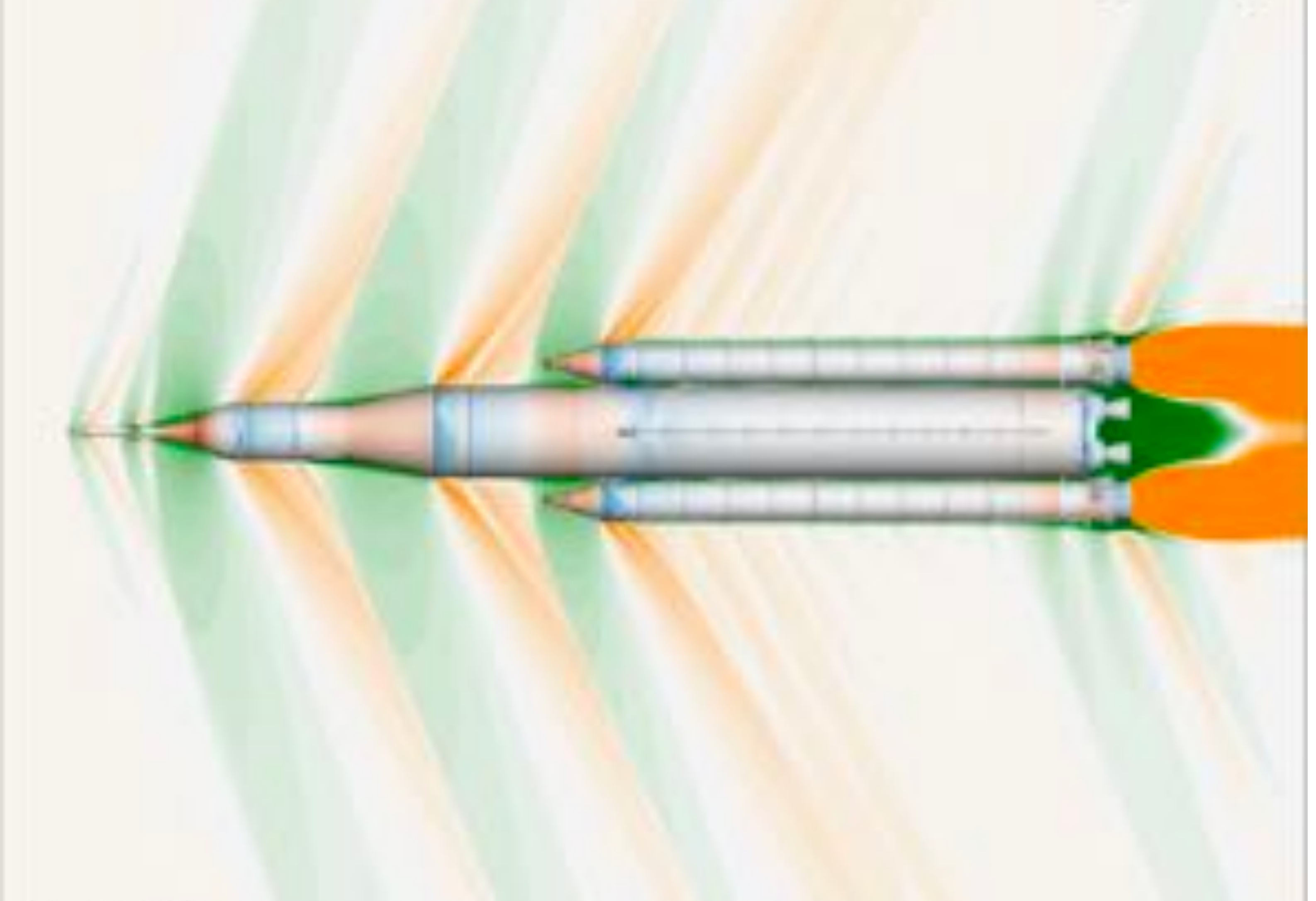
Total distance traveled: 1.3 million miles – Mission duration: 25.5 days – Re-entry speed: 24,500 mph (Mach 32) – 13 CubeSats deployed

SLS Future of Exploration



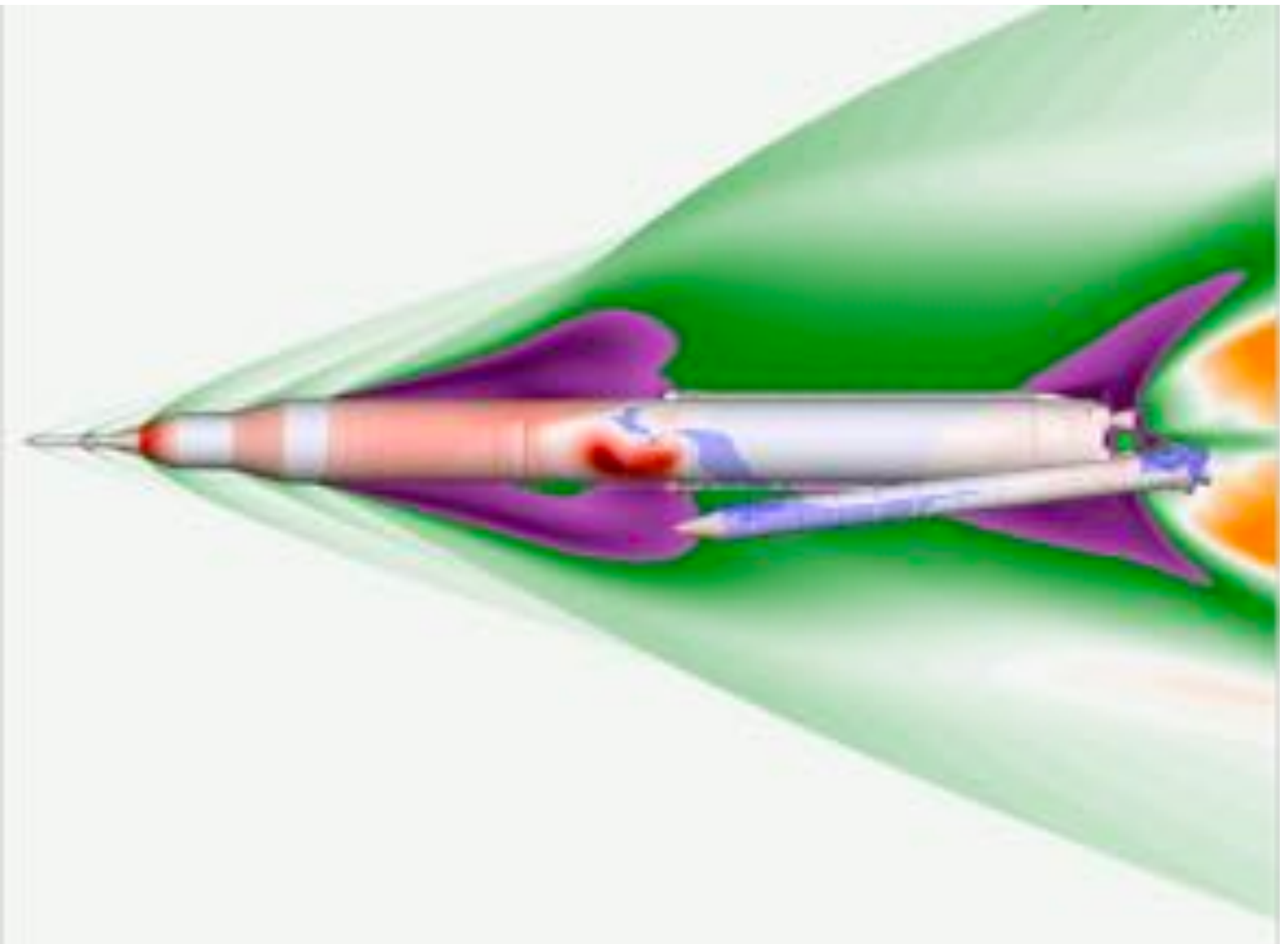
SLS Computational Fluid Dynamics Applications

Ground Winds



Ascent

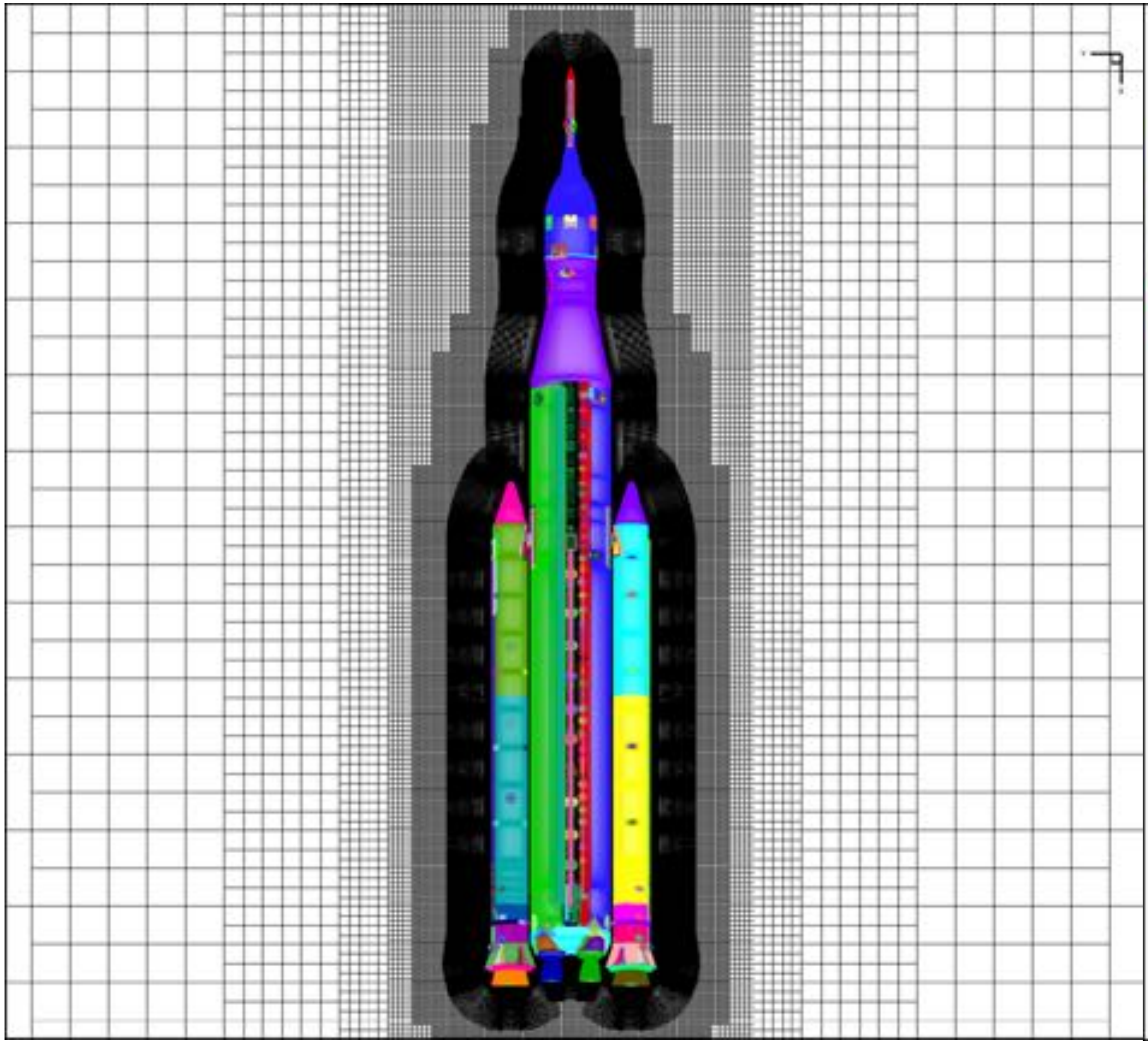
Launch Abort

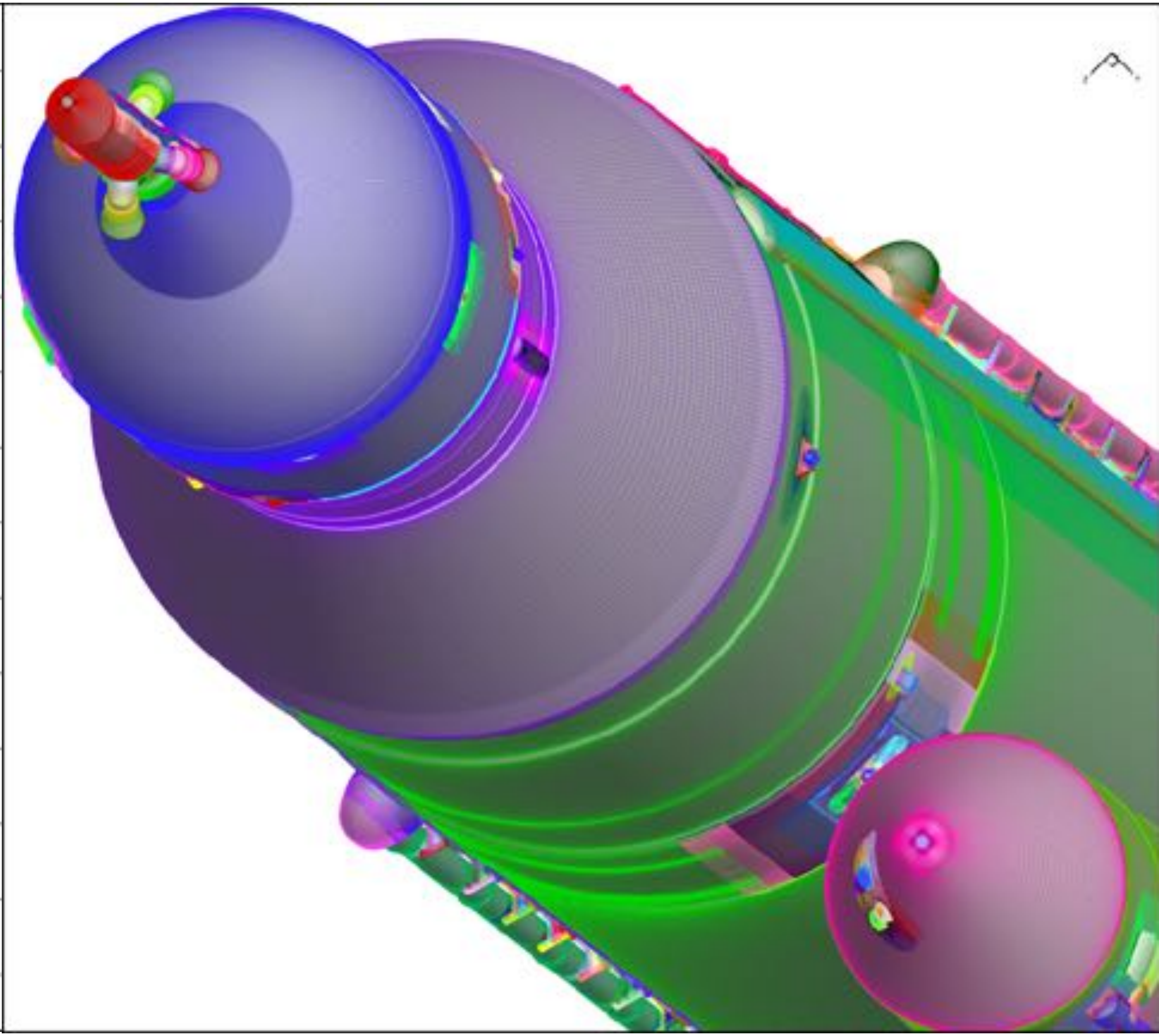


Booster Separation

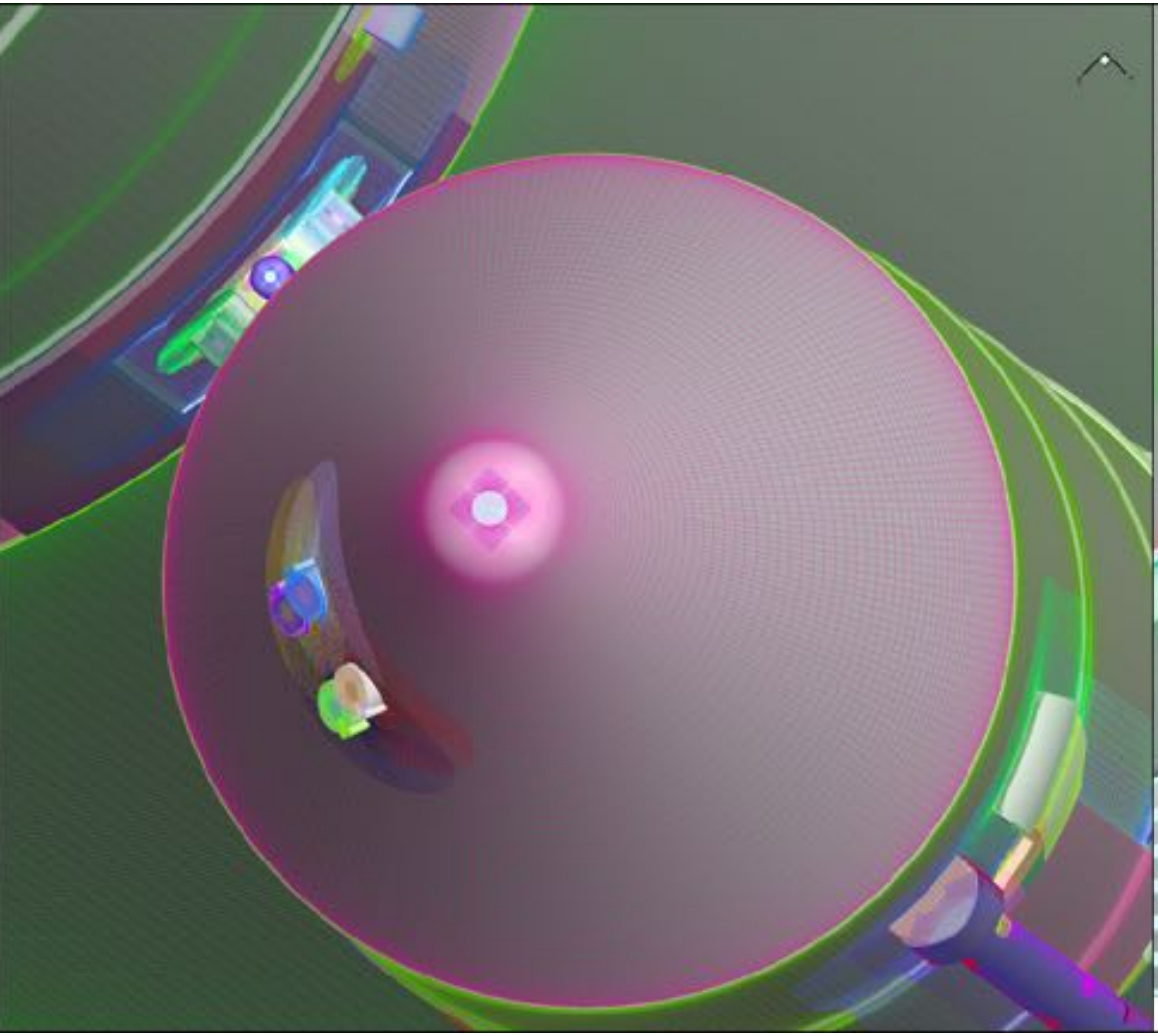
NAS Pleiades and Electra Supercomputers

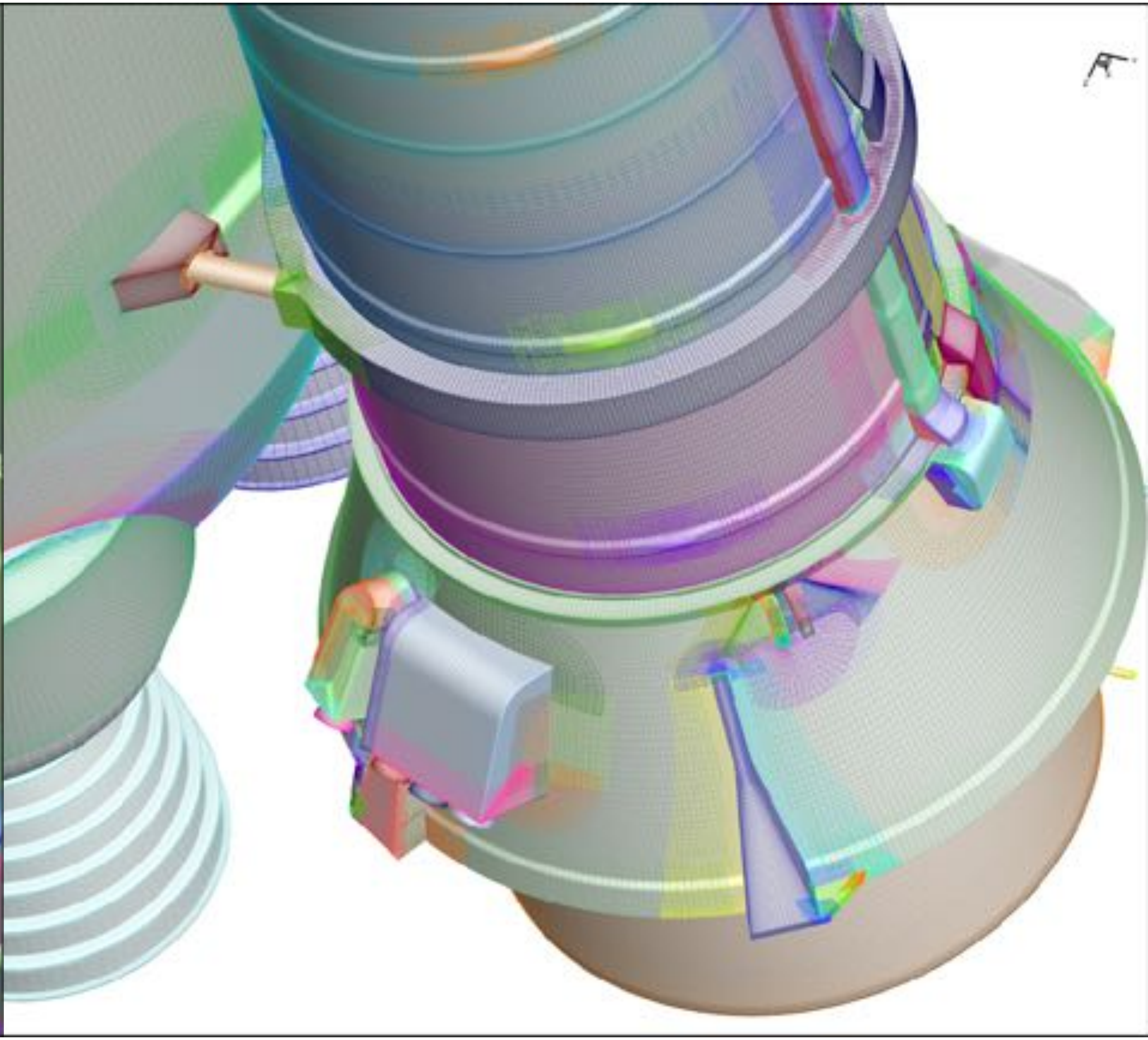
CFD Modeling SLS Geometry





CFD Modeling SLS Geometry

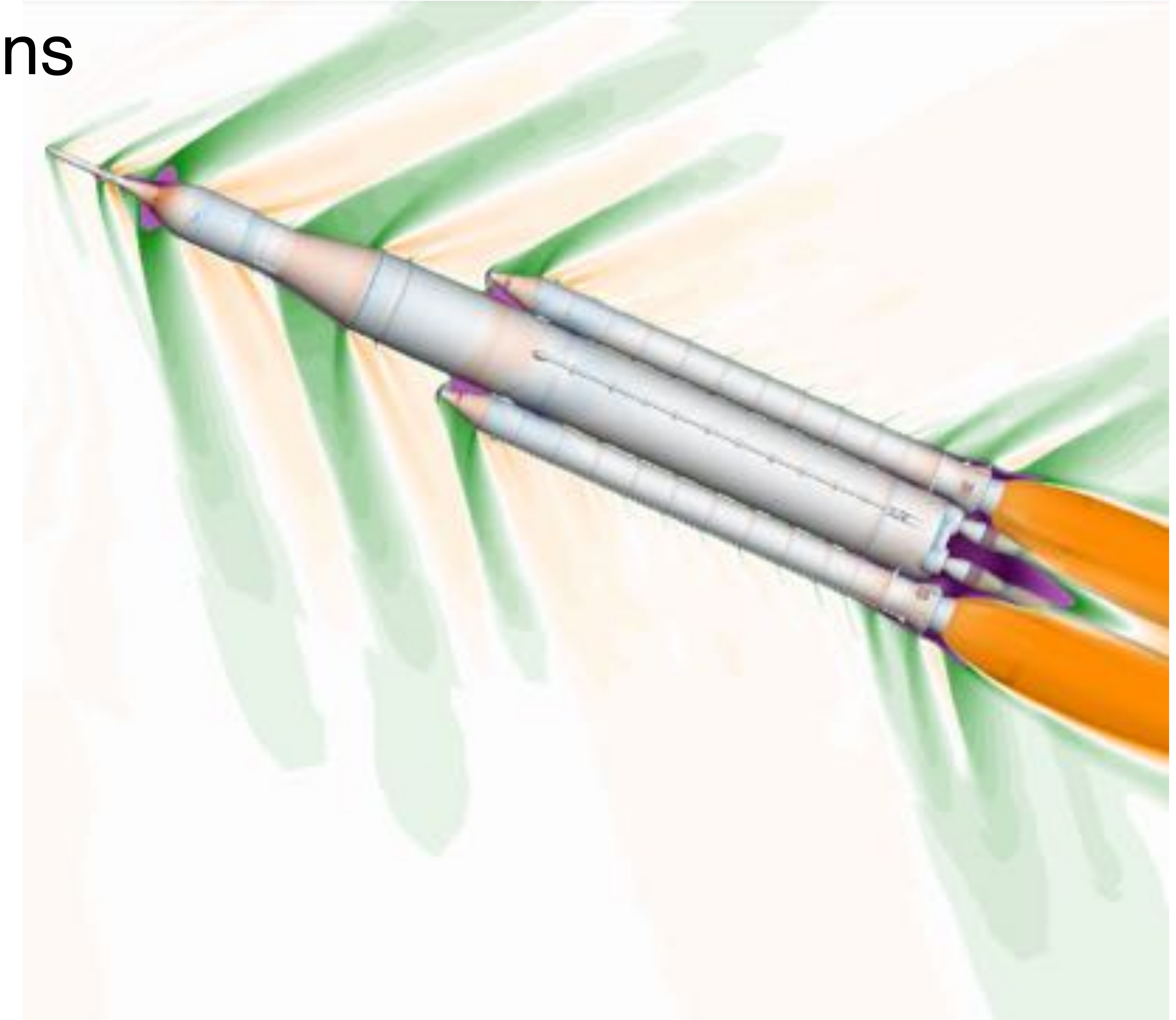




SLS CFD Ascent Database

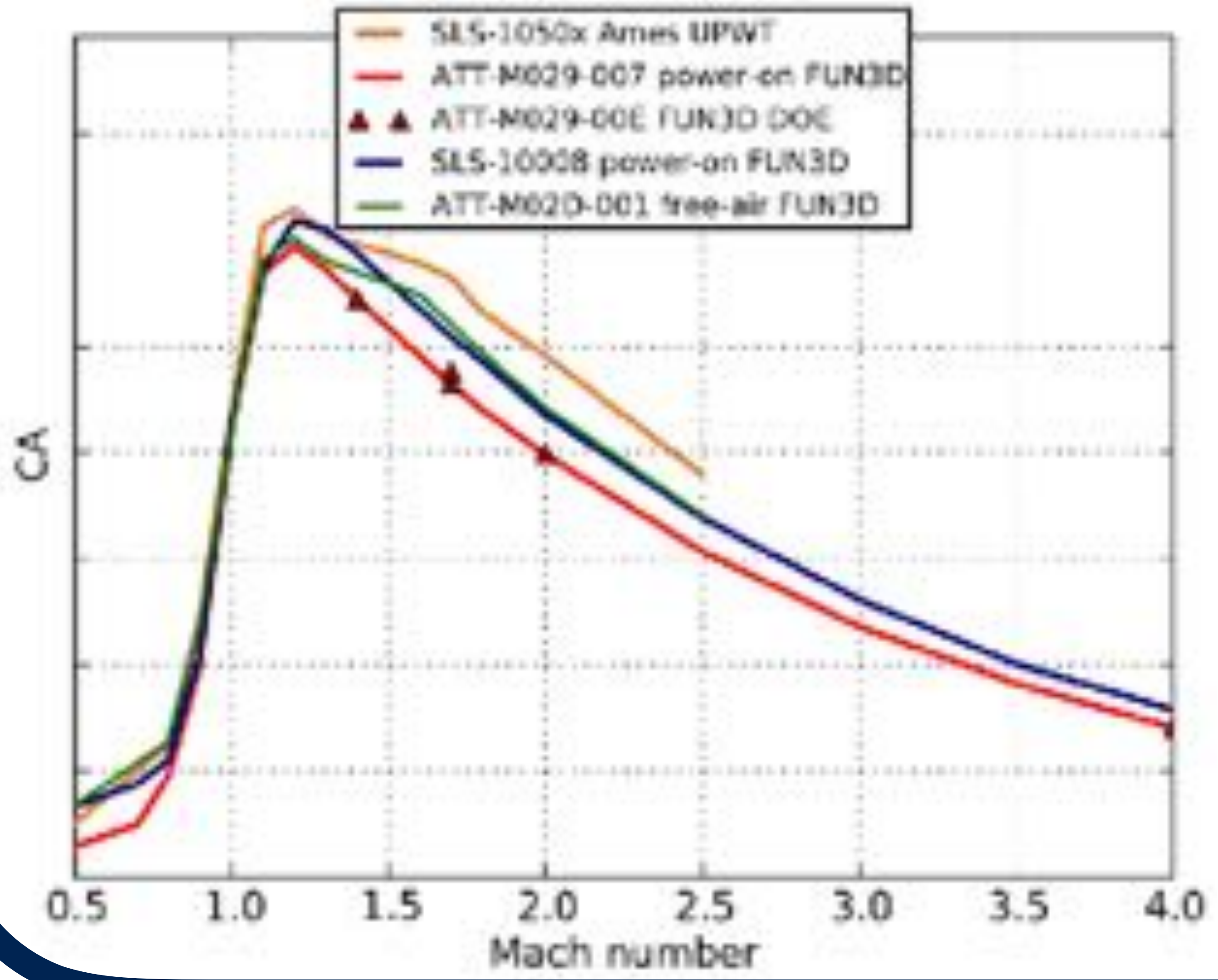
- Provide forces and moments on core and both boosters
- Complicated fluid dynamics: plume interactions
- Large data
  - Many independent parameters
  - Flight geometry & Wind-tunnel geometry
  - Static cases

- Computational Fluid Dynamics (CFD)
  - FUN3D viscous CFD solver
  - Overflow viscous CFD solver



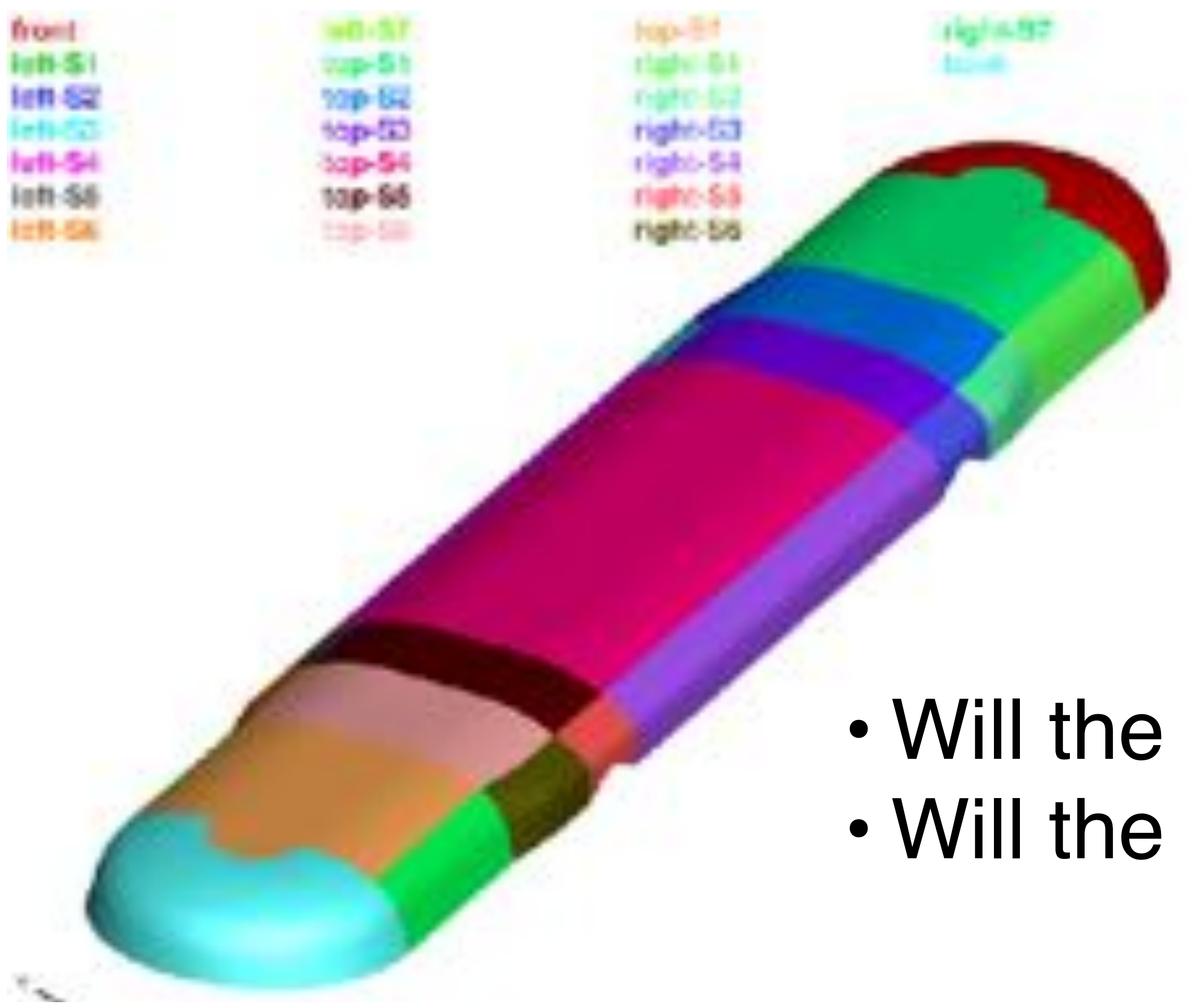
SLS CFD Ascent Analysis

Ascent Force & Moments



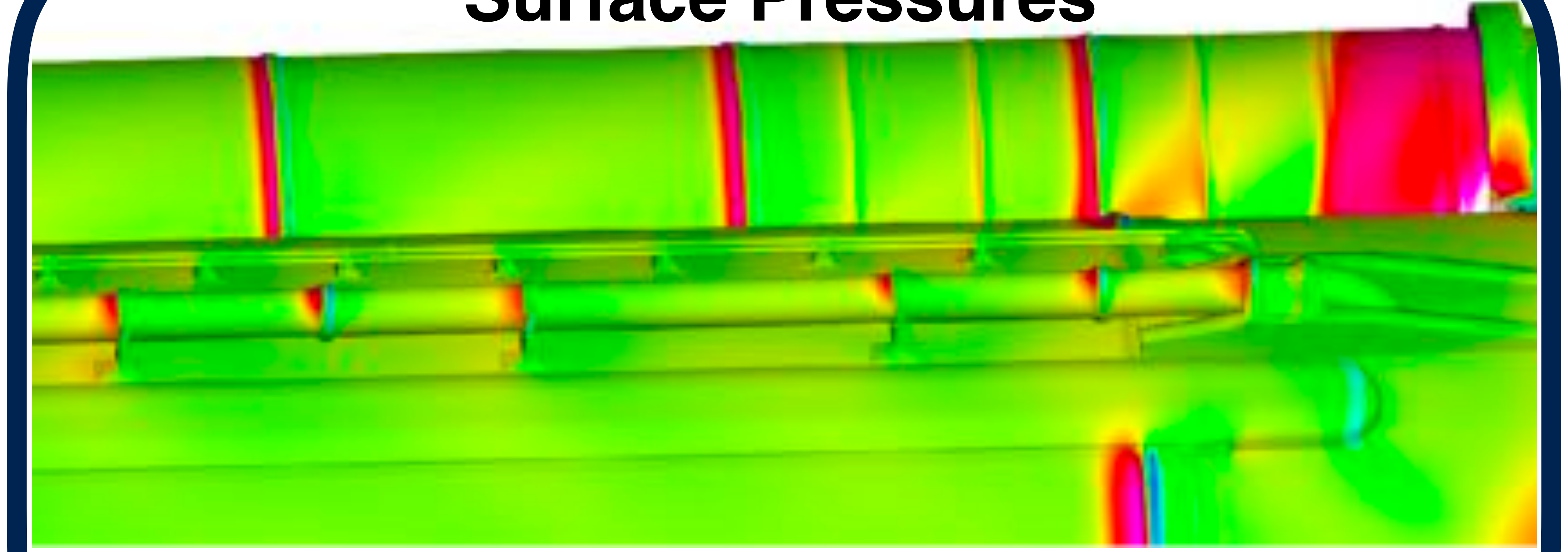
- How does the vehicle fly?
- CFD supplemental to Wind Tunnel

Protuberance Air Loads



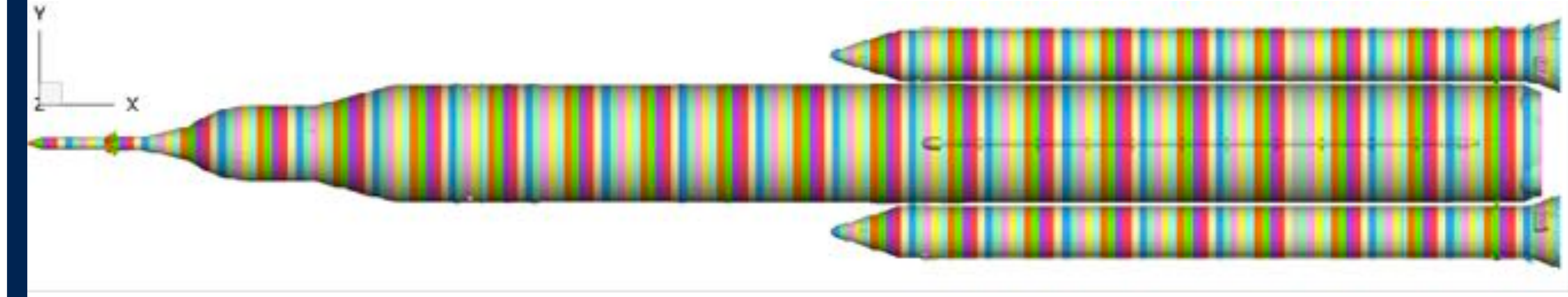
- Will the parts fly off?
- Will the parts crush in flight?

Surface Pressures



- Venting: any parts burst/crush?
- Other Considerations as well

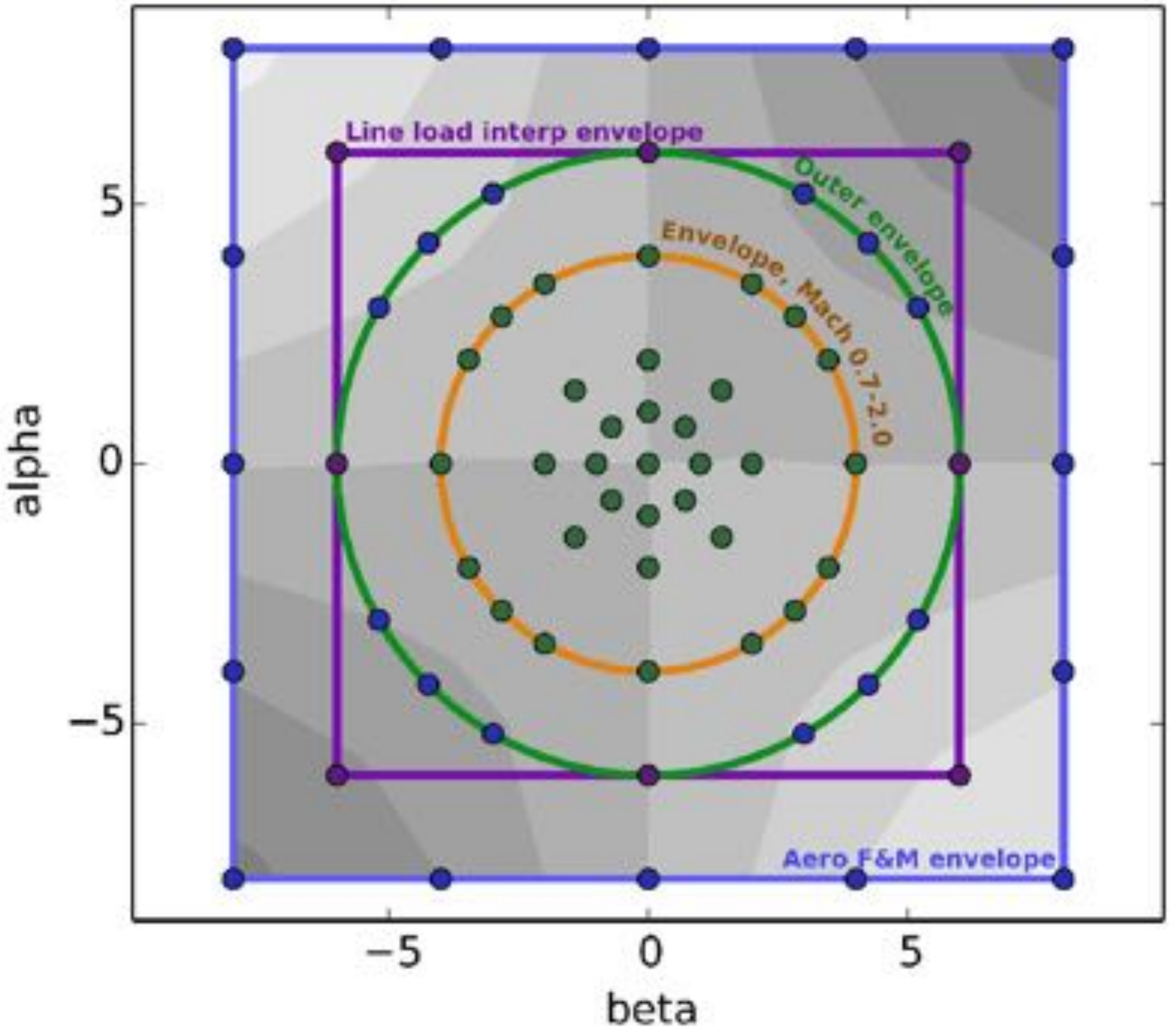
Line Loads

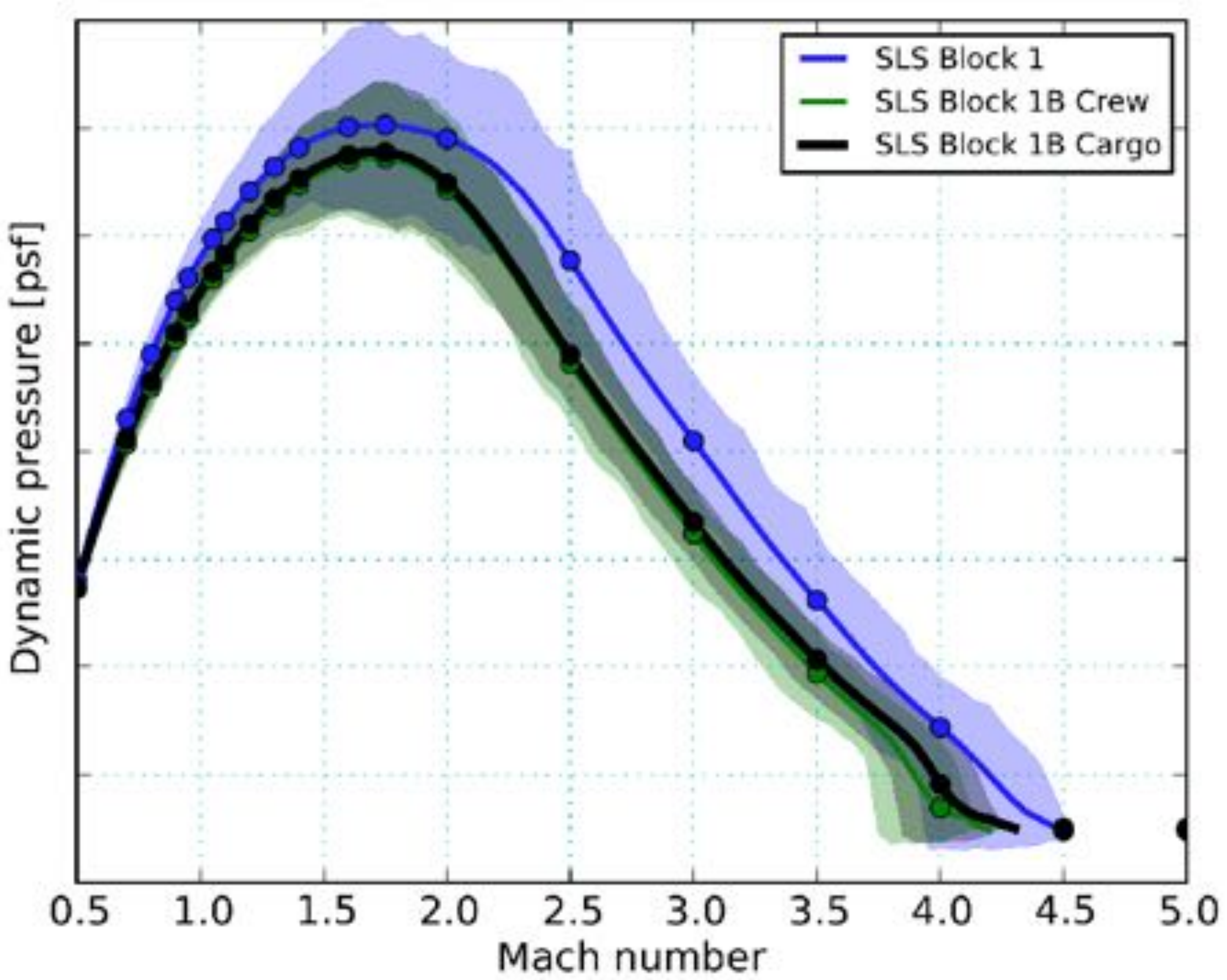


- How much does the vehicle bend?
- Does the vehicle break/buckle?

SLS Ascent Aerodynamics

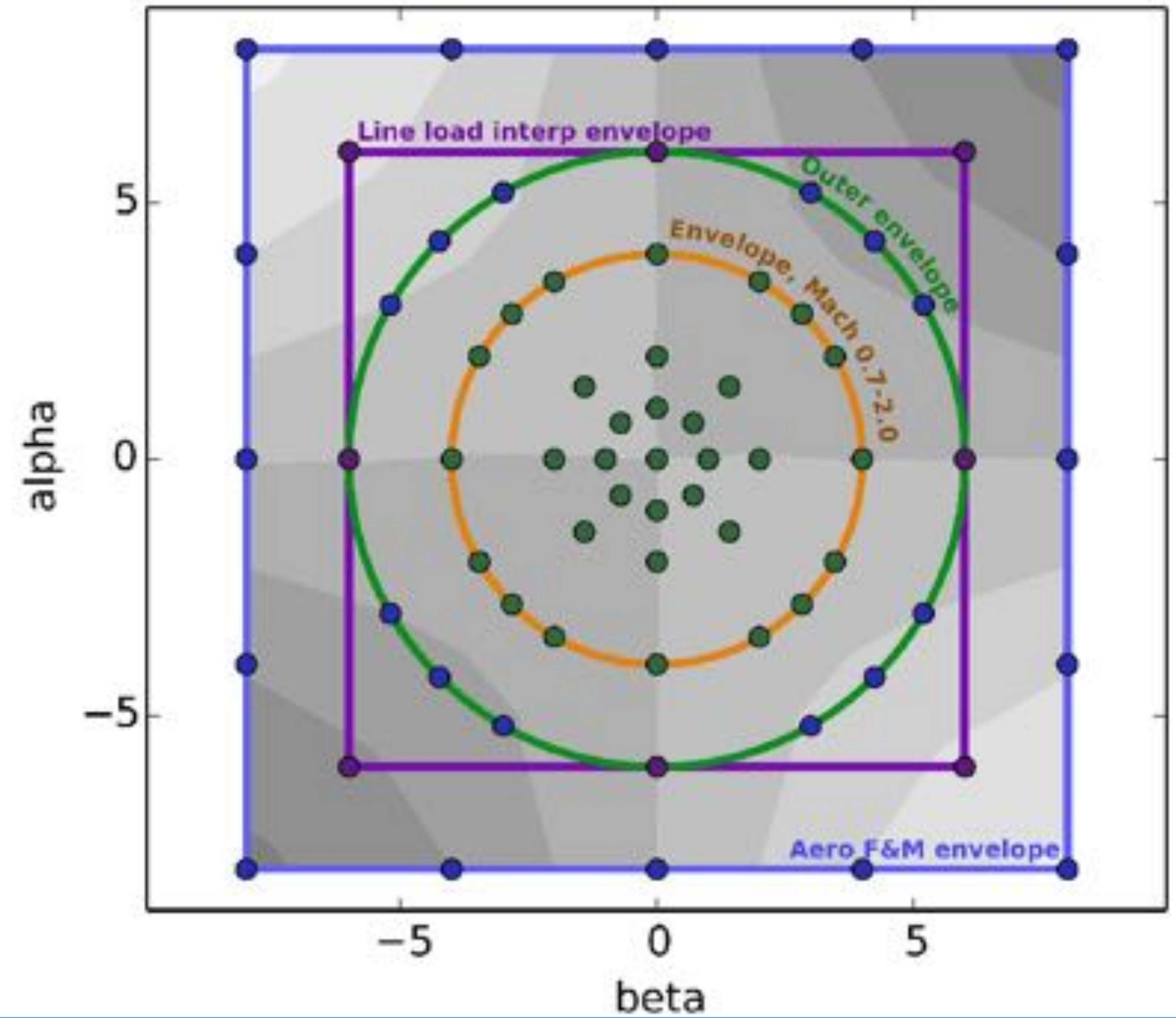
- Covers from just above tower, to booster separation
- Altitude ranges from just above sea level, to very high dynamic pressure, to near vacuum

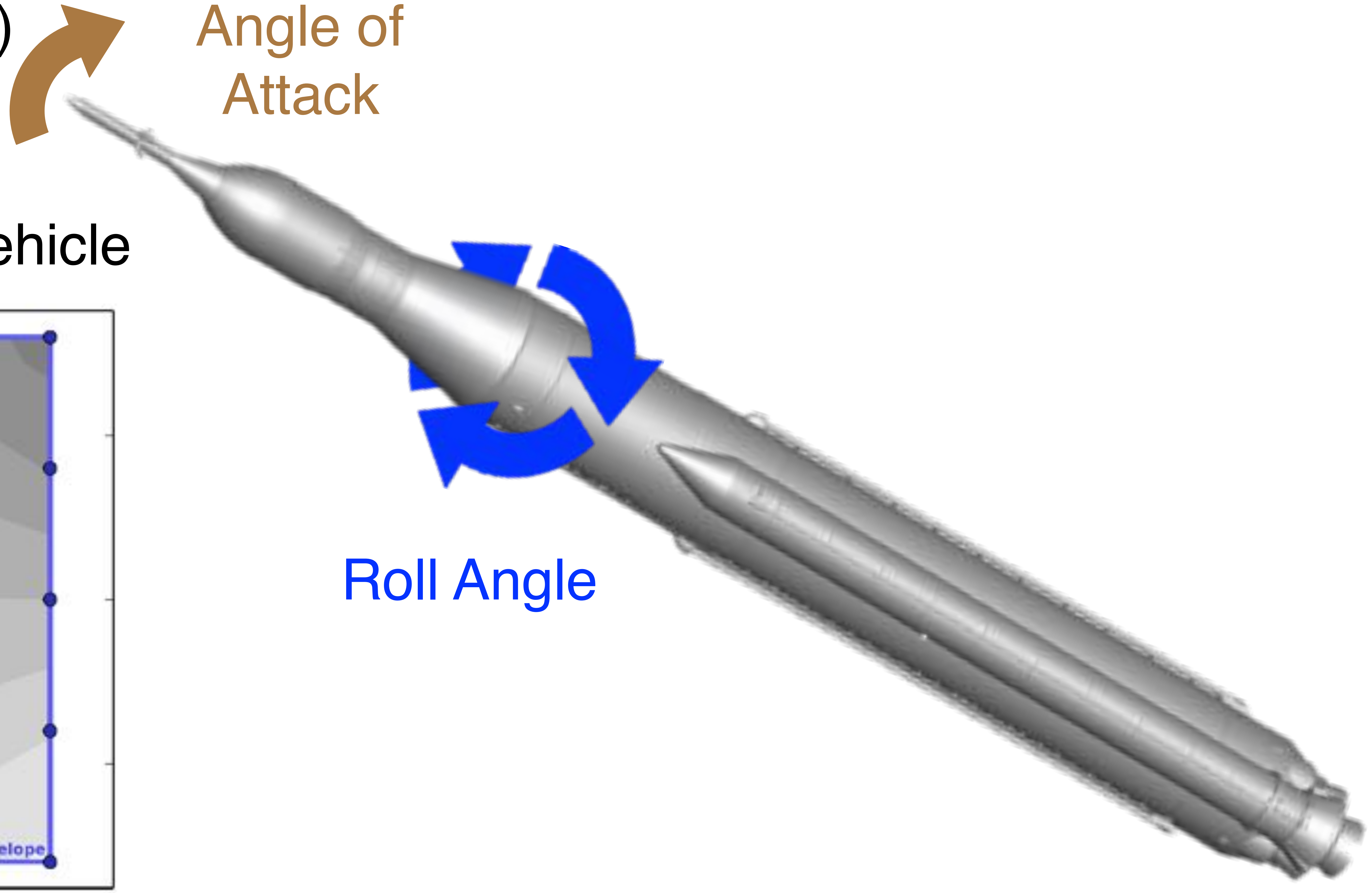




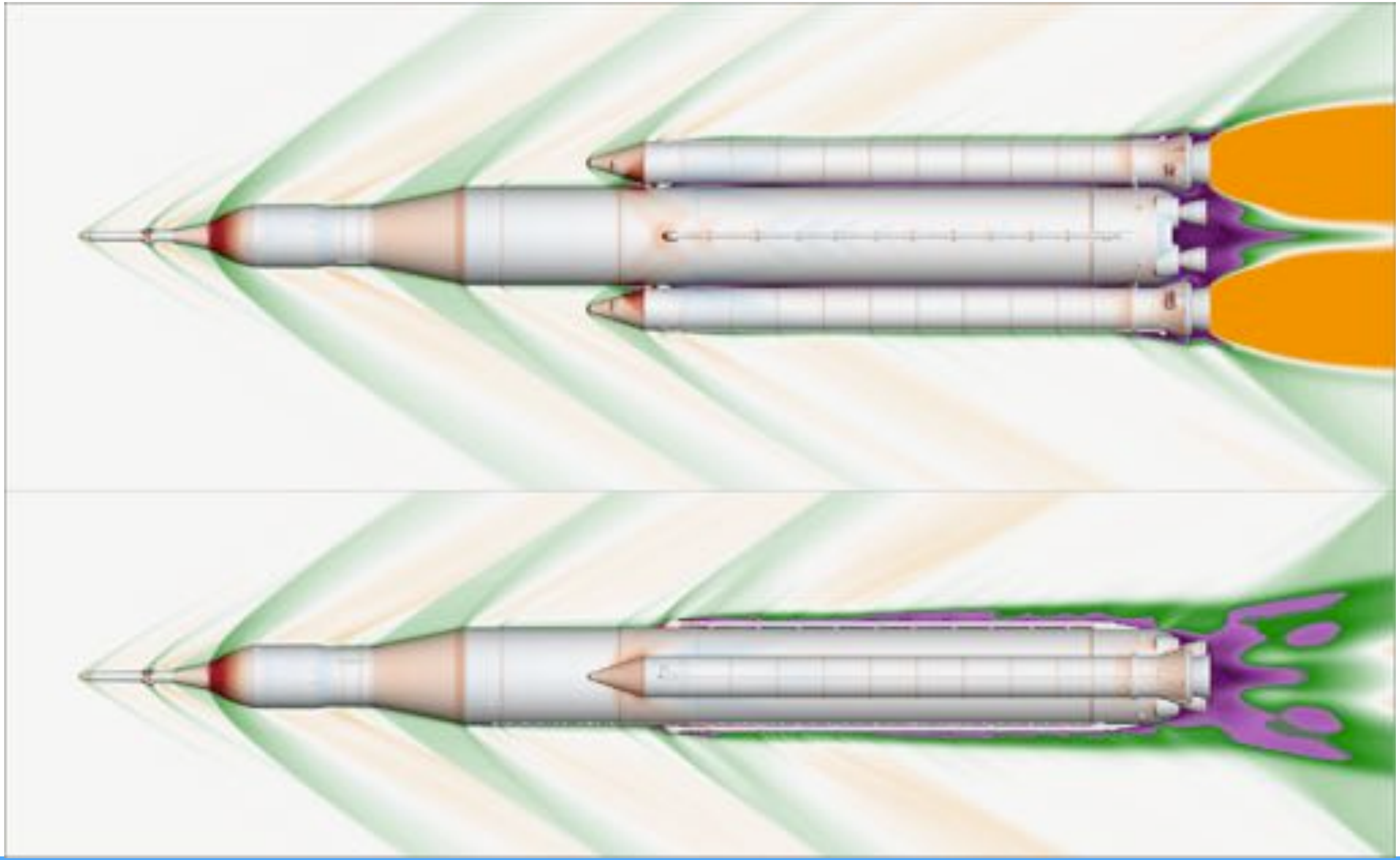
SLS Ascent Aerodynamics Database

- Three-Dimensional run matrix
  - Mach number (altitude)
  - Total angle of attack
  - Roll Angle
- 1300+ cases total per vehicle

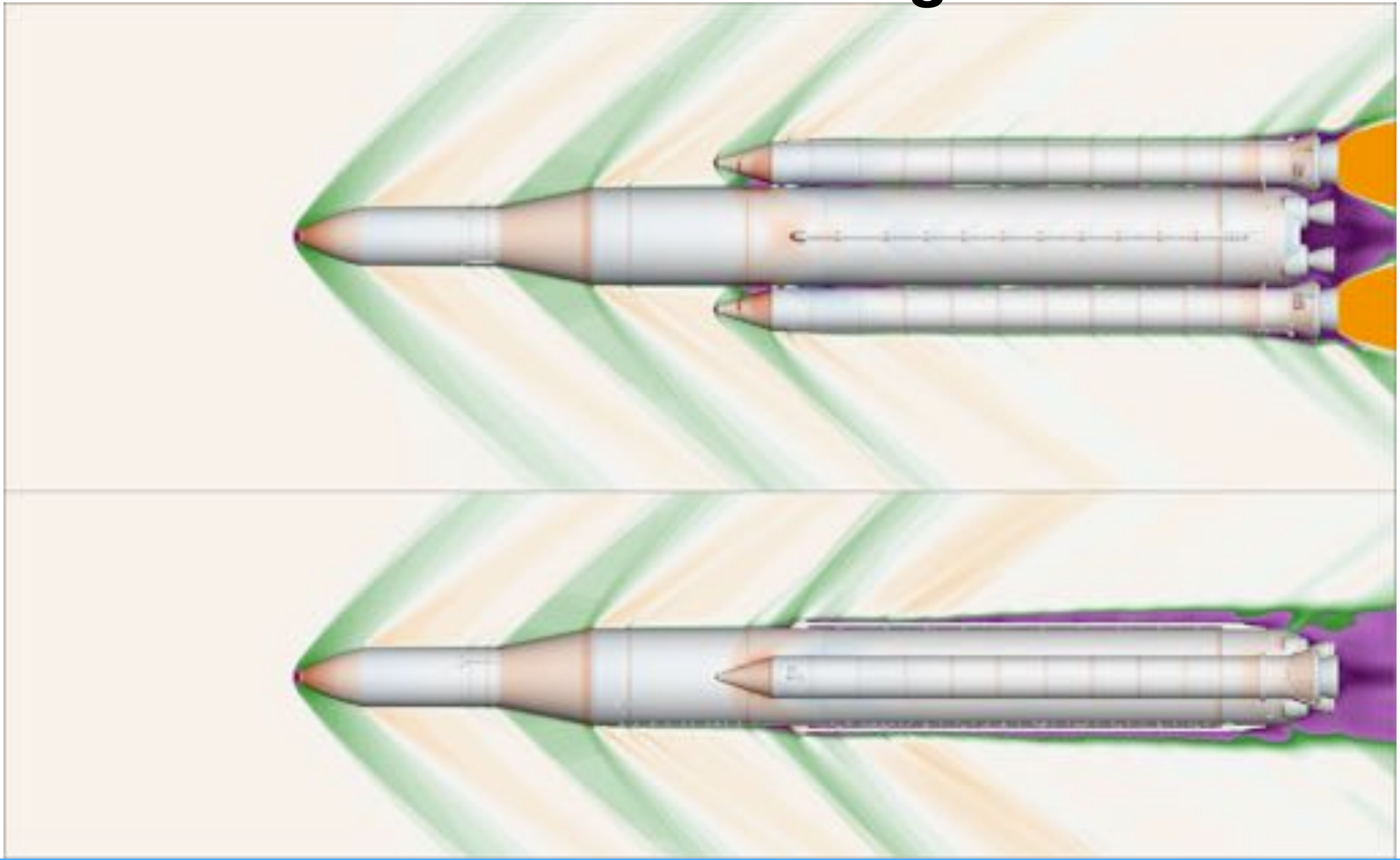




SLS Ascent Database: Block 1 Crew



SLS Ascent Database: Block 1 Cargo



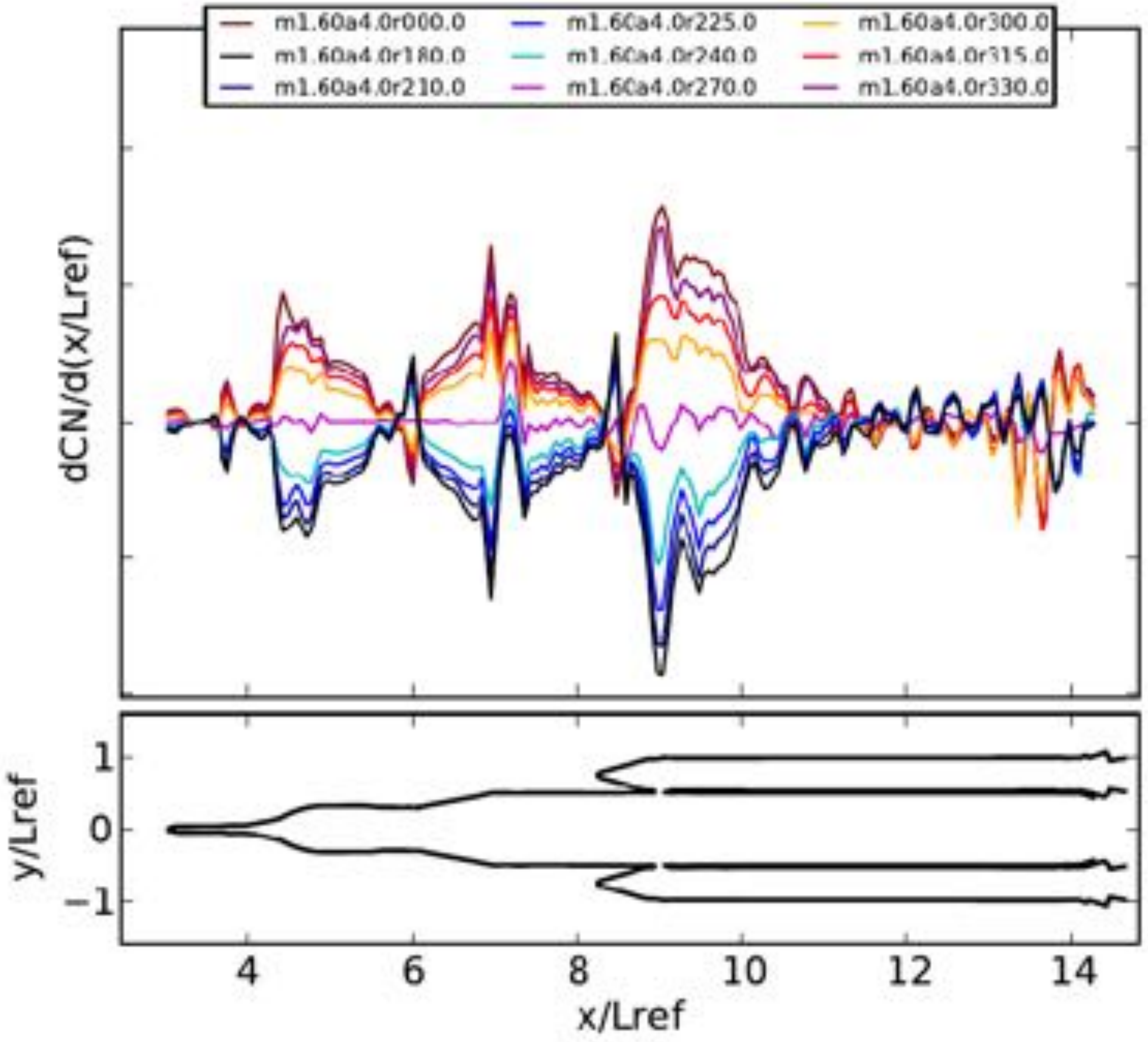
SLS Ascent Sectional Loads/Line Loads

- Divide vehicle into slices

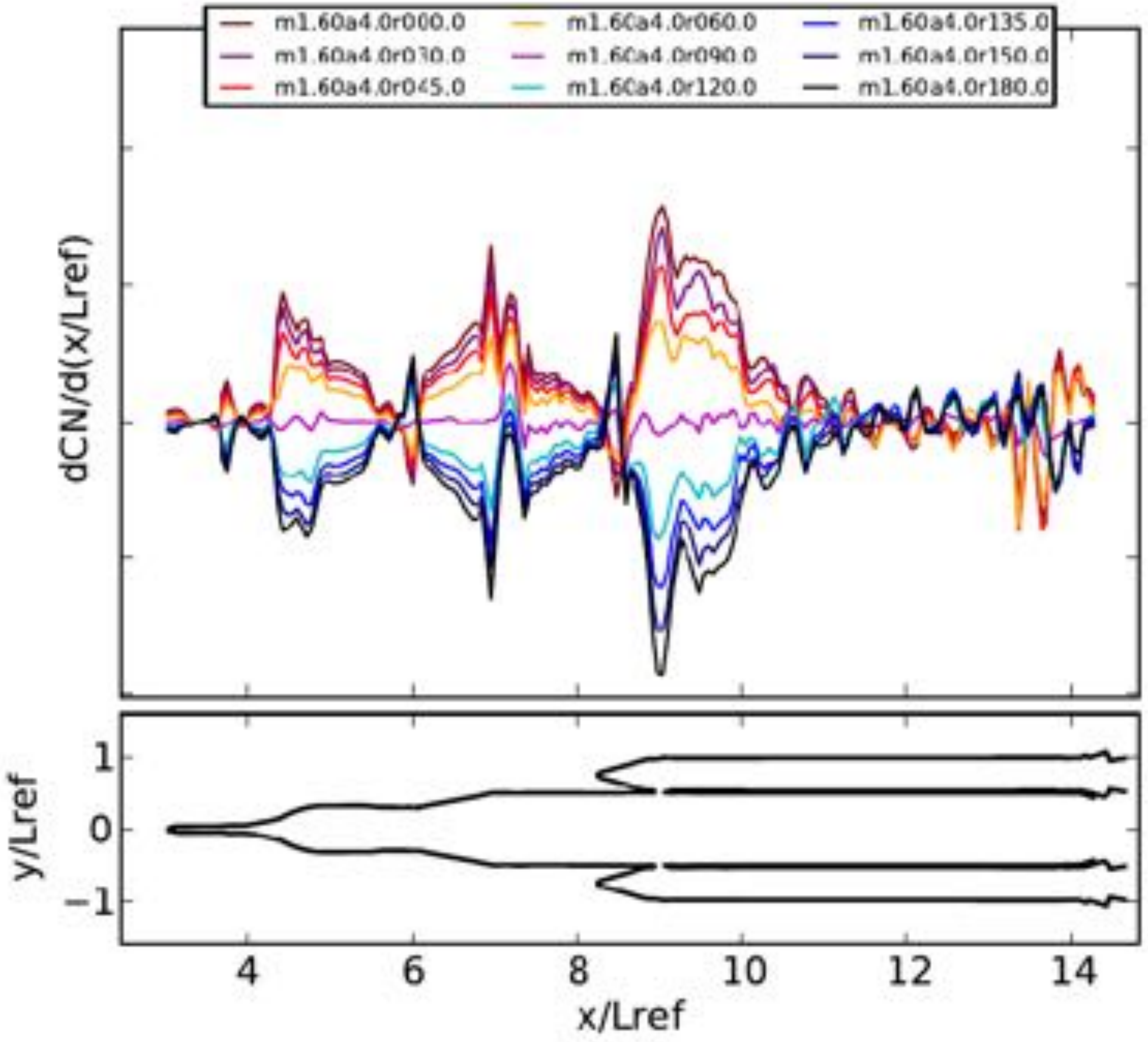
Block 1B Crew Configuration divided into 200 slices

- Calculate Load on each slice
- This is utilized by the structures group, vibrations, etc

SLS Ascent Sectional Loads/Line Loads



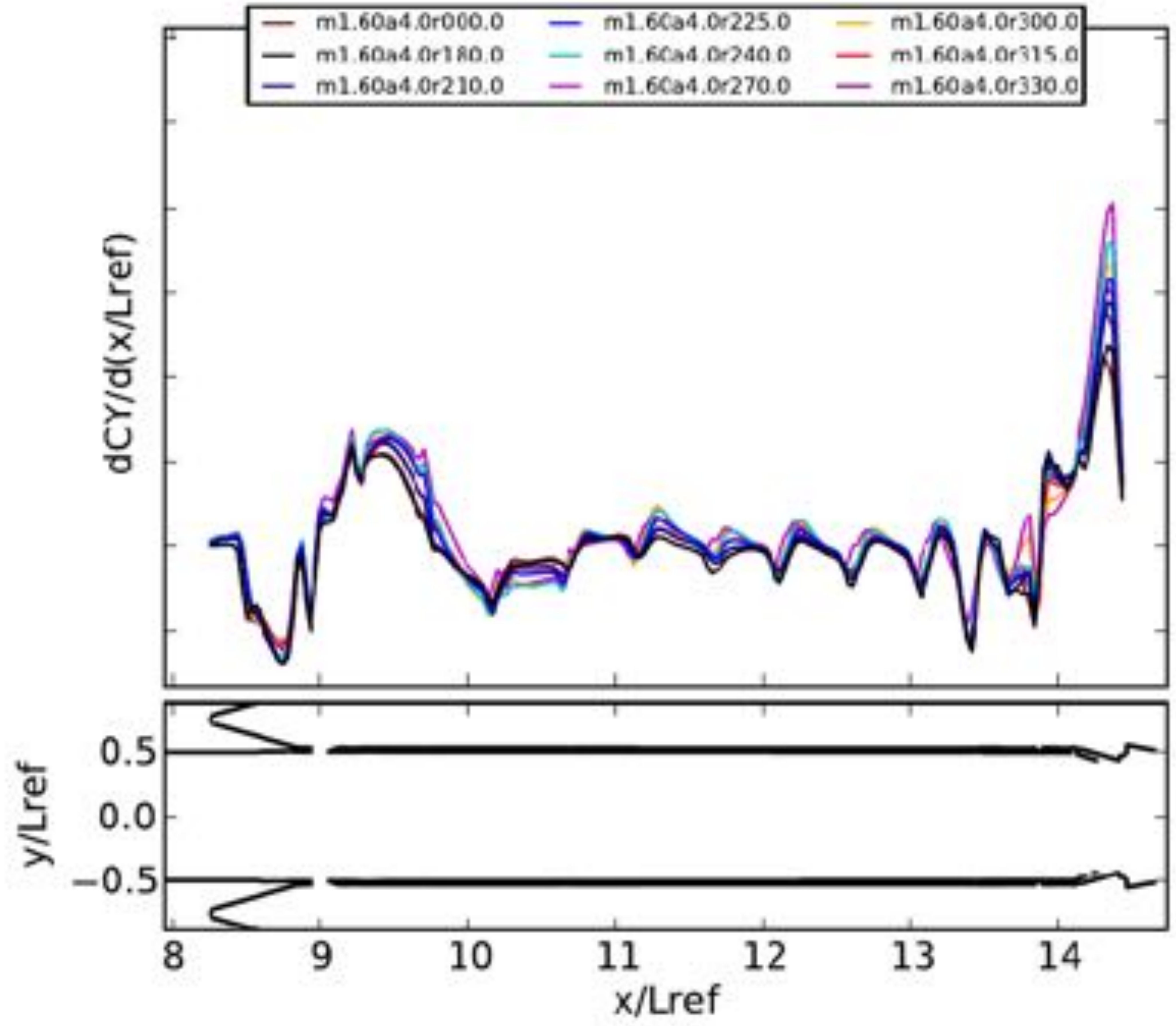
CORE/*CN, - Sideslip*



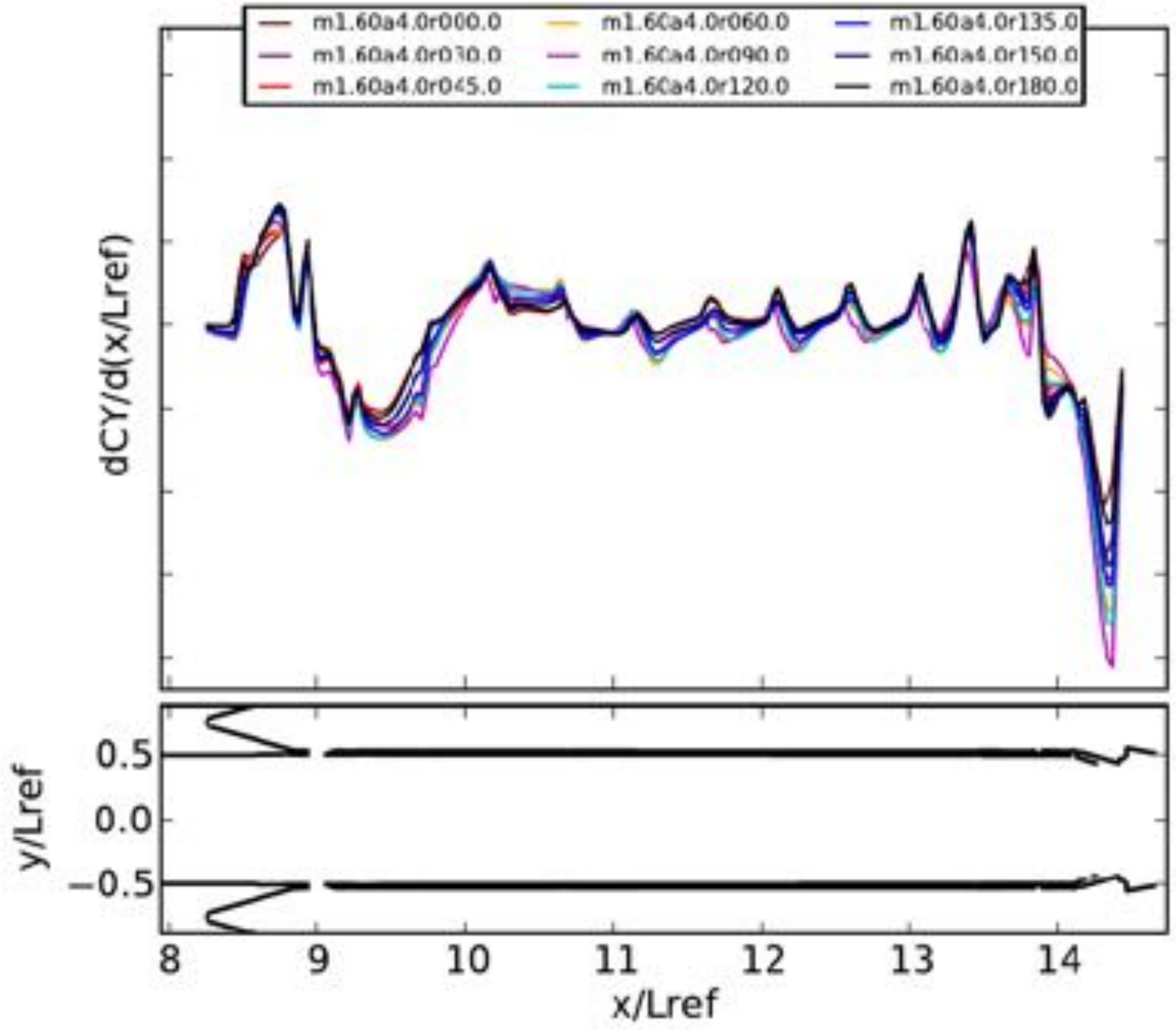
CORE/*CN, + Sideslip*

- Separate all the cases in half by sideslip angle
- Check for expected symmetries

SLS Ascent Sectional Loads/Line Loads



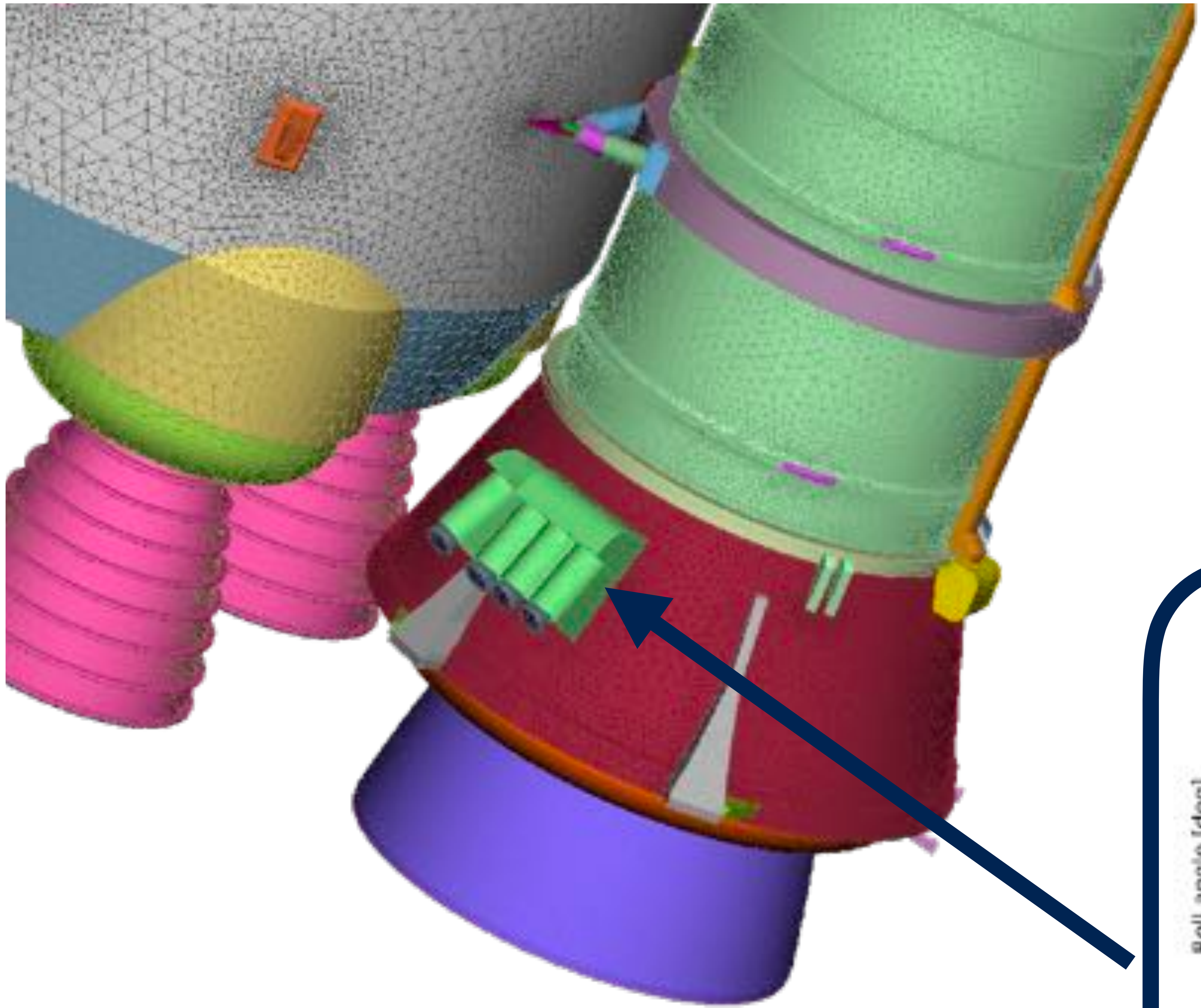
LSRB/*CY, - Sideslip*

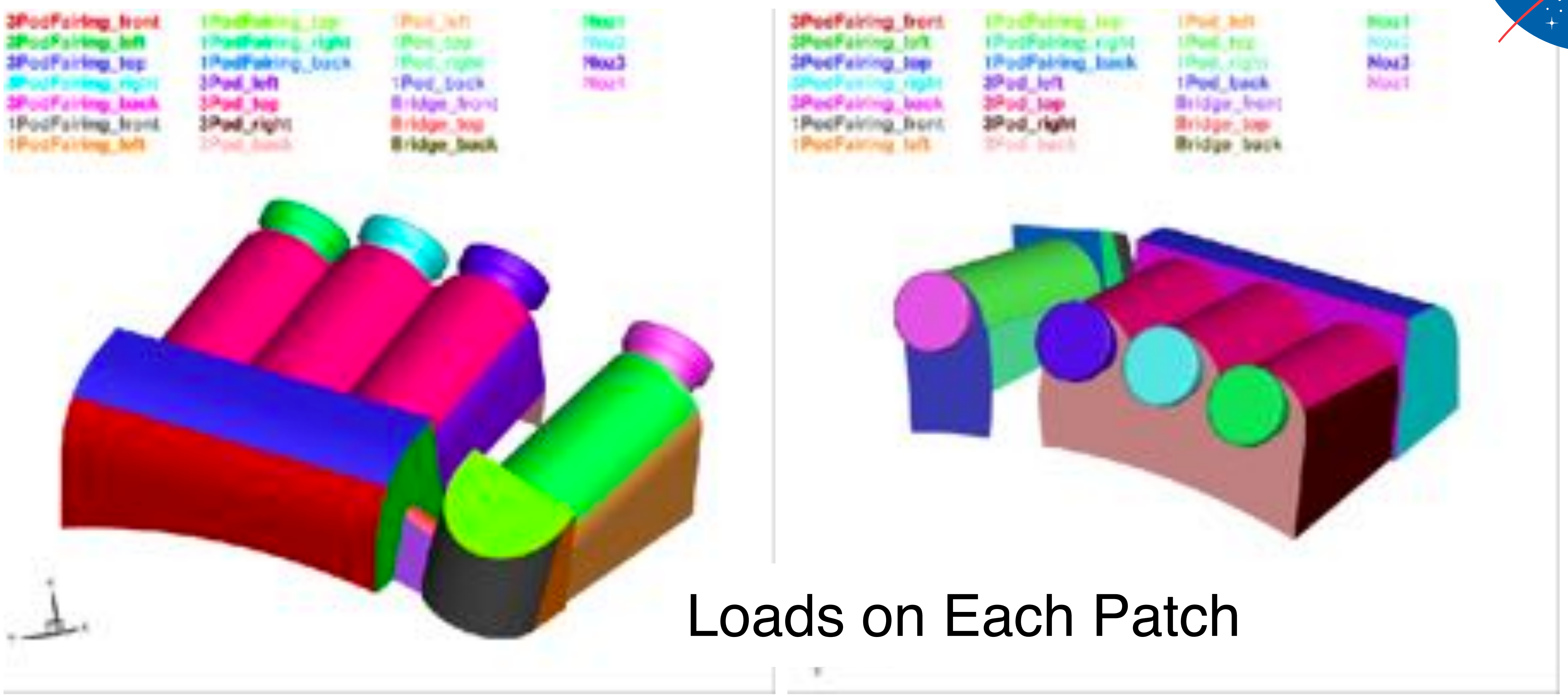


RSRB/*CY, + Sideslip*

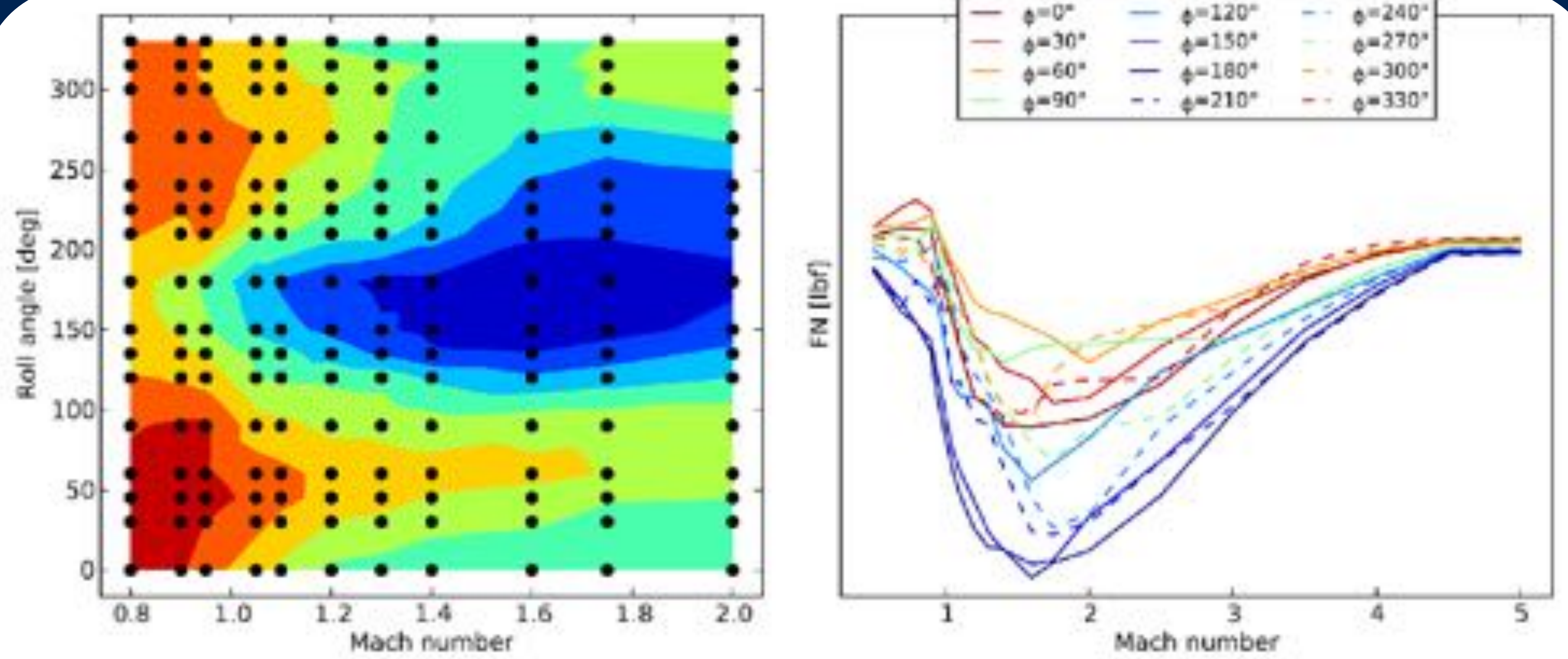
- Separate all the cases in half by sideslip angle
- Check for expected symmetries

SLS Ascent Protuberance Air Loads



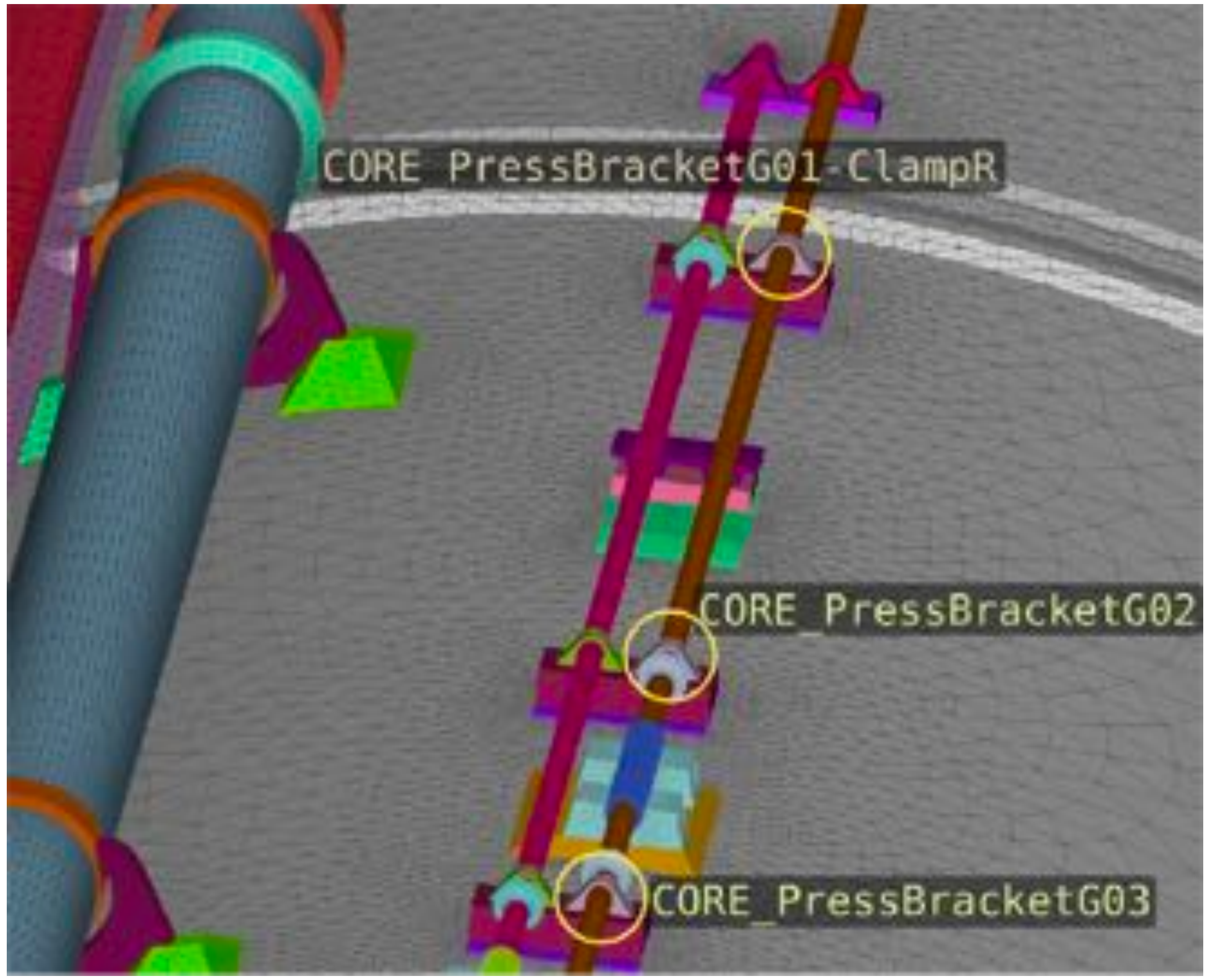


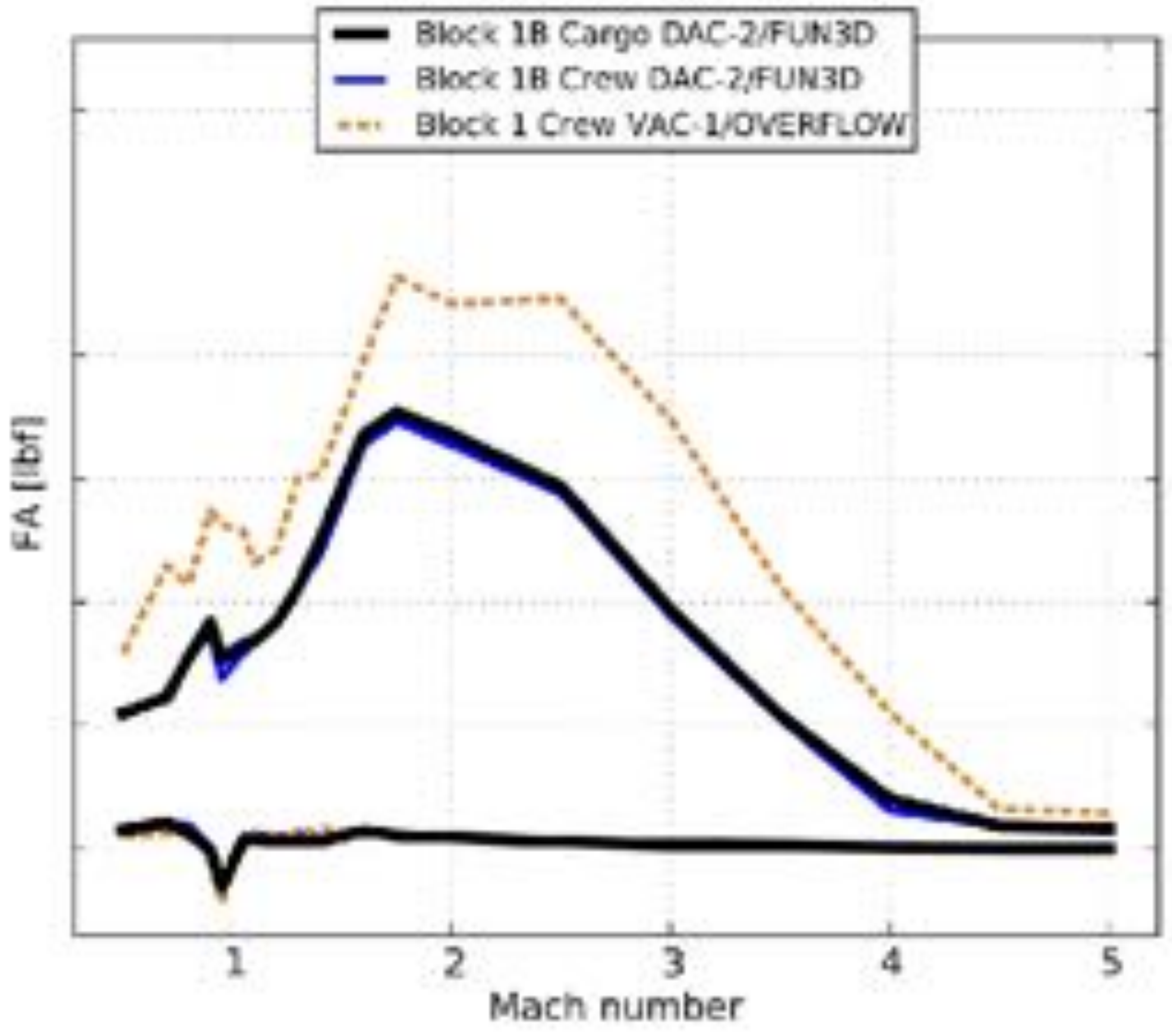
Loads on Each Patch

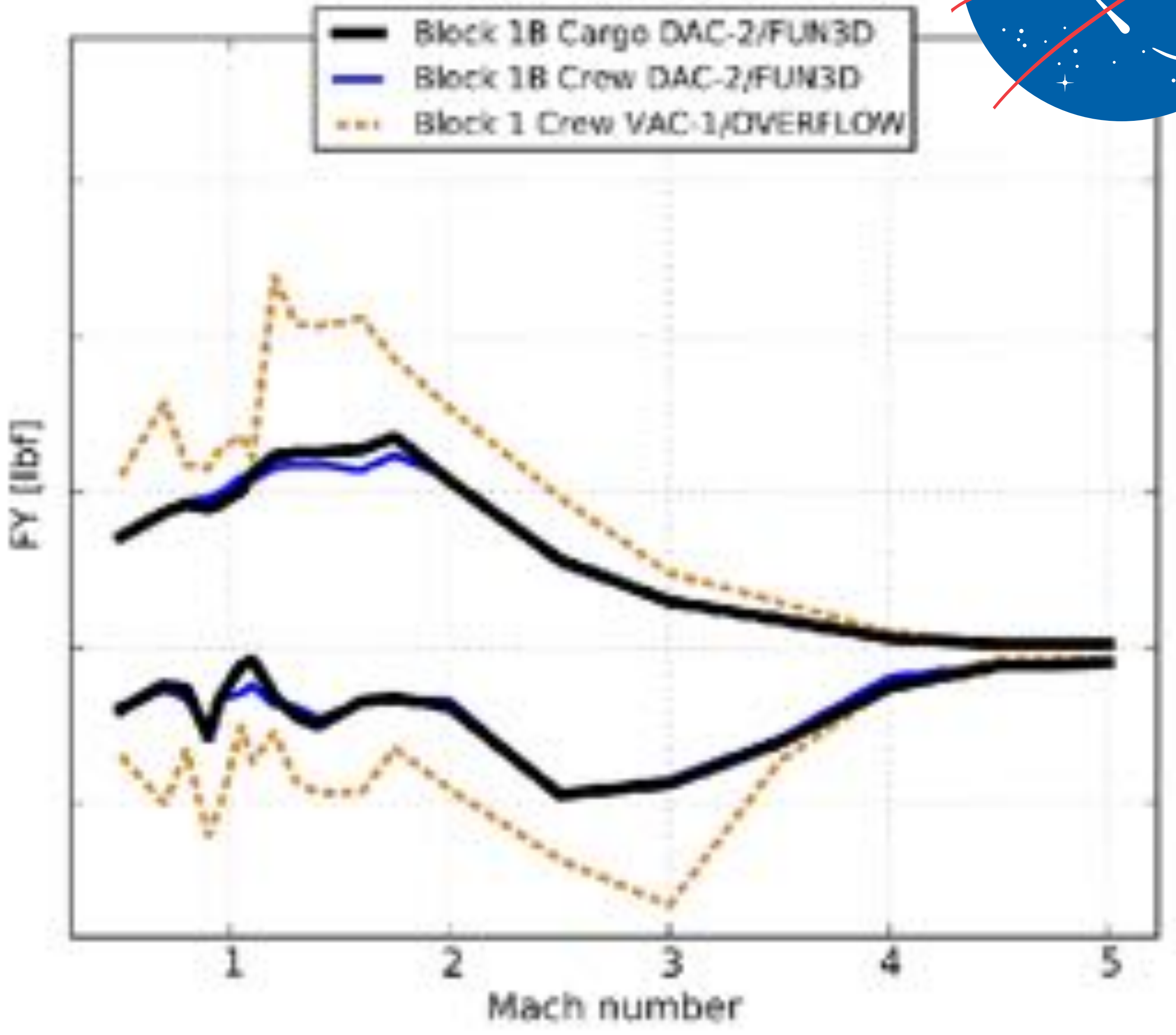


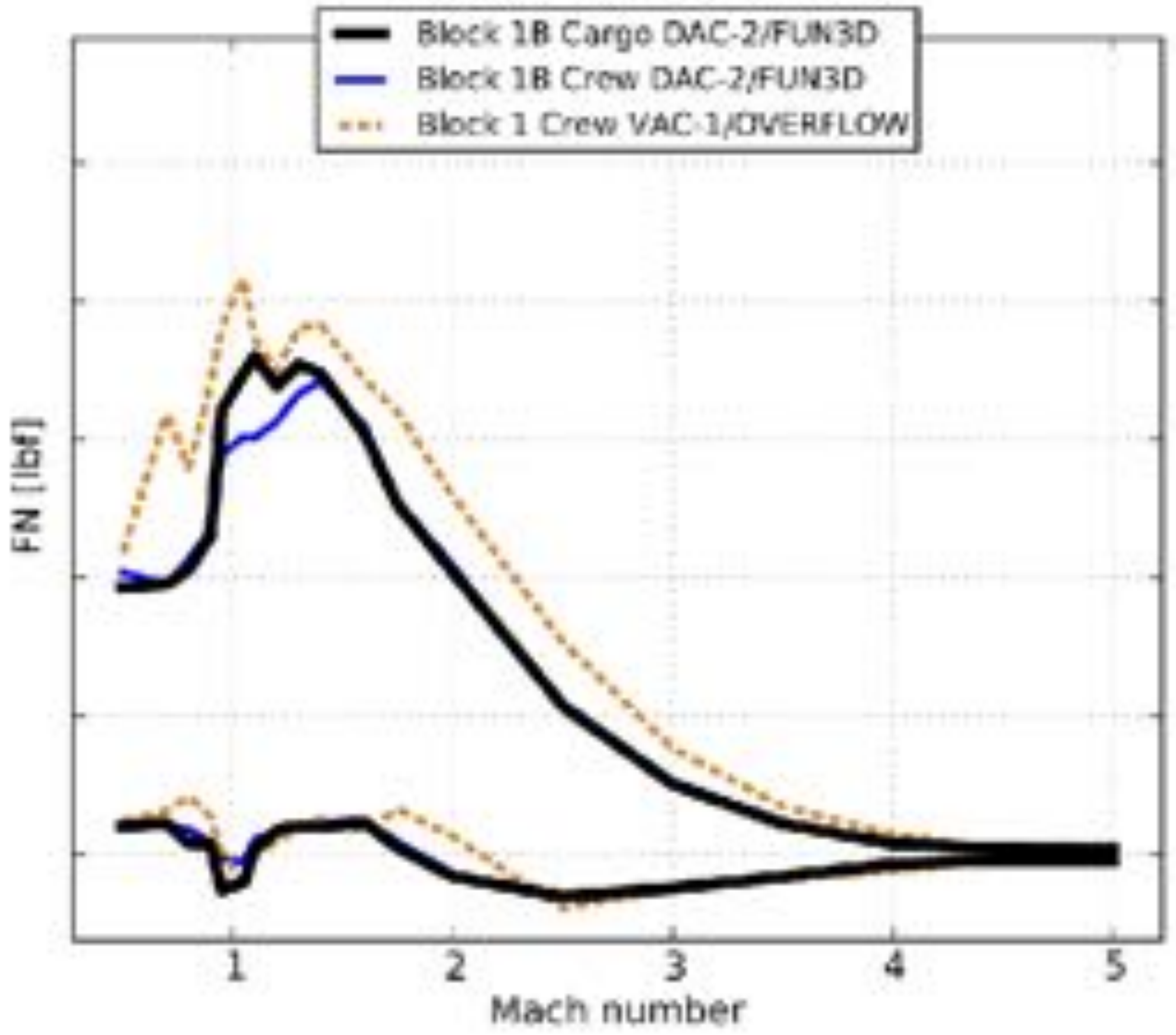
Plots to make sure loads makes sense

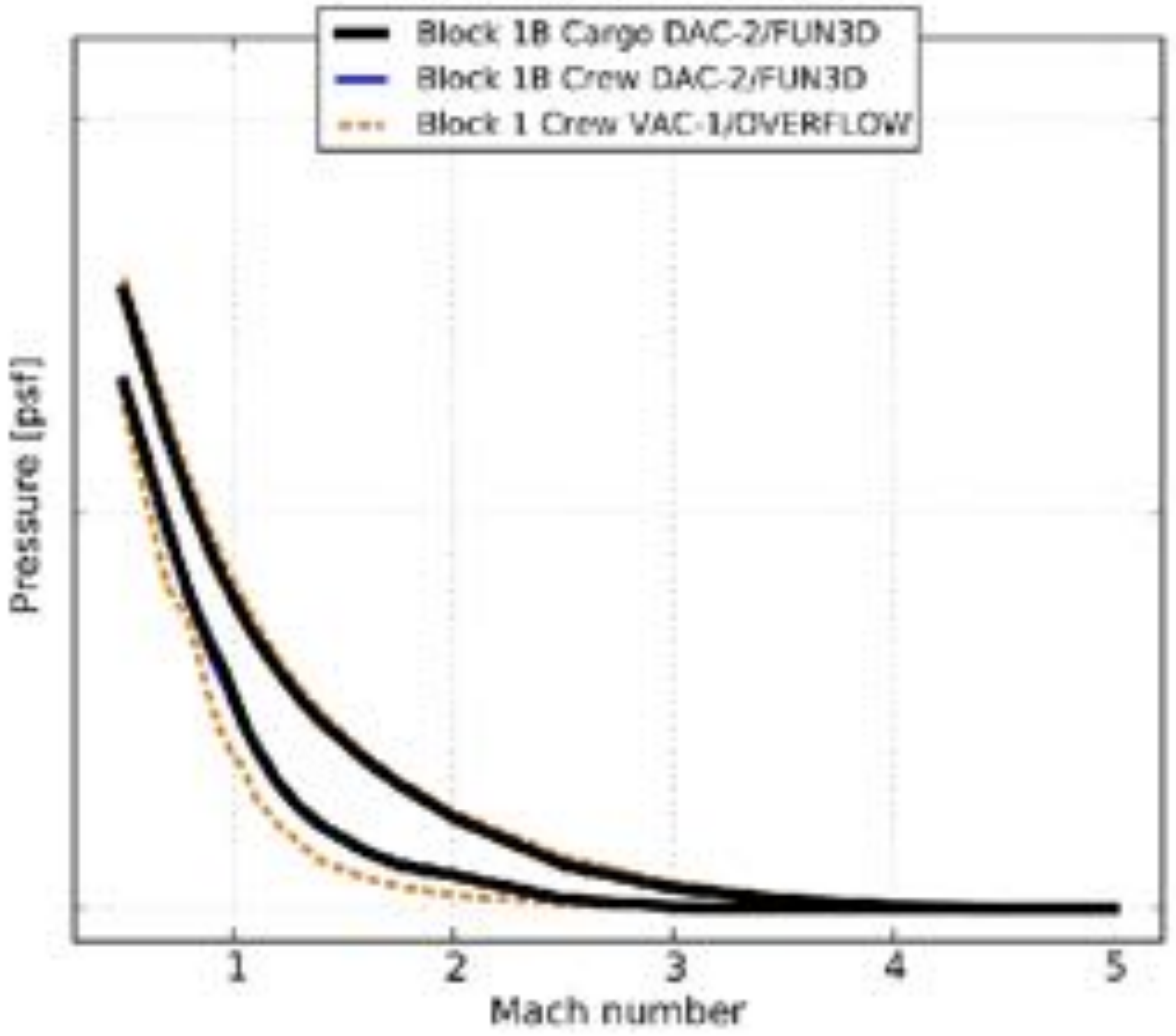
SLS Ascent Pressurization Line Bracket Plots







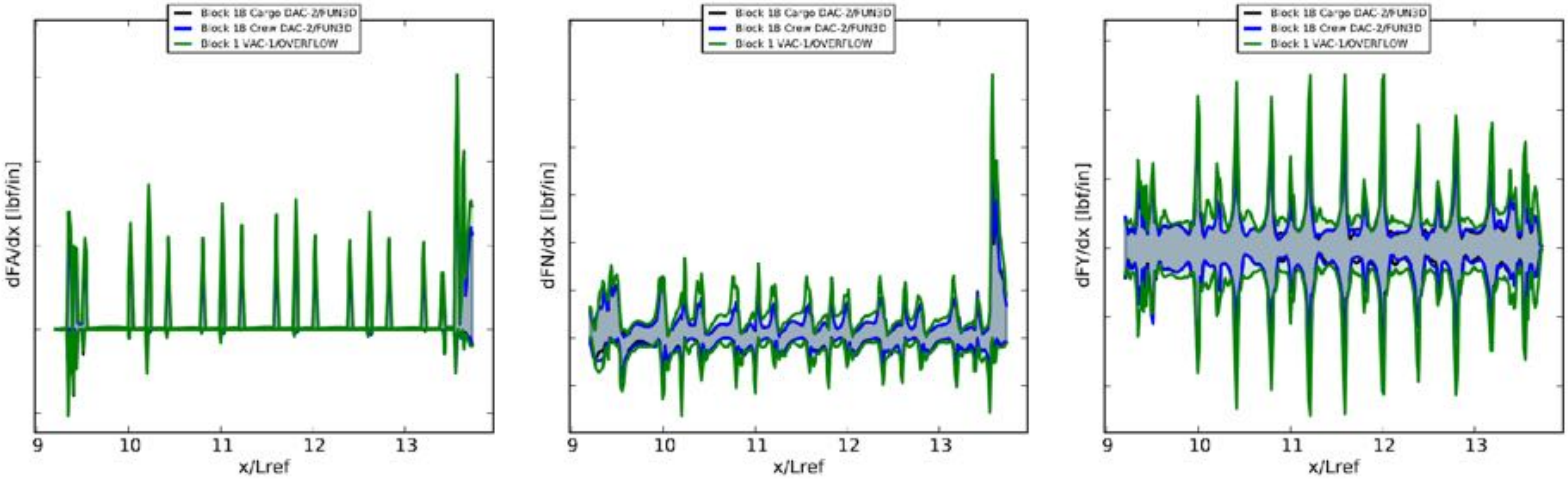




- Quantify differences in loads between each vehicle
- Check for anomalies

SLS Ascent Protuberance Line Loads

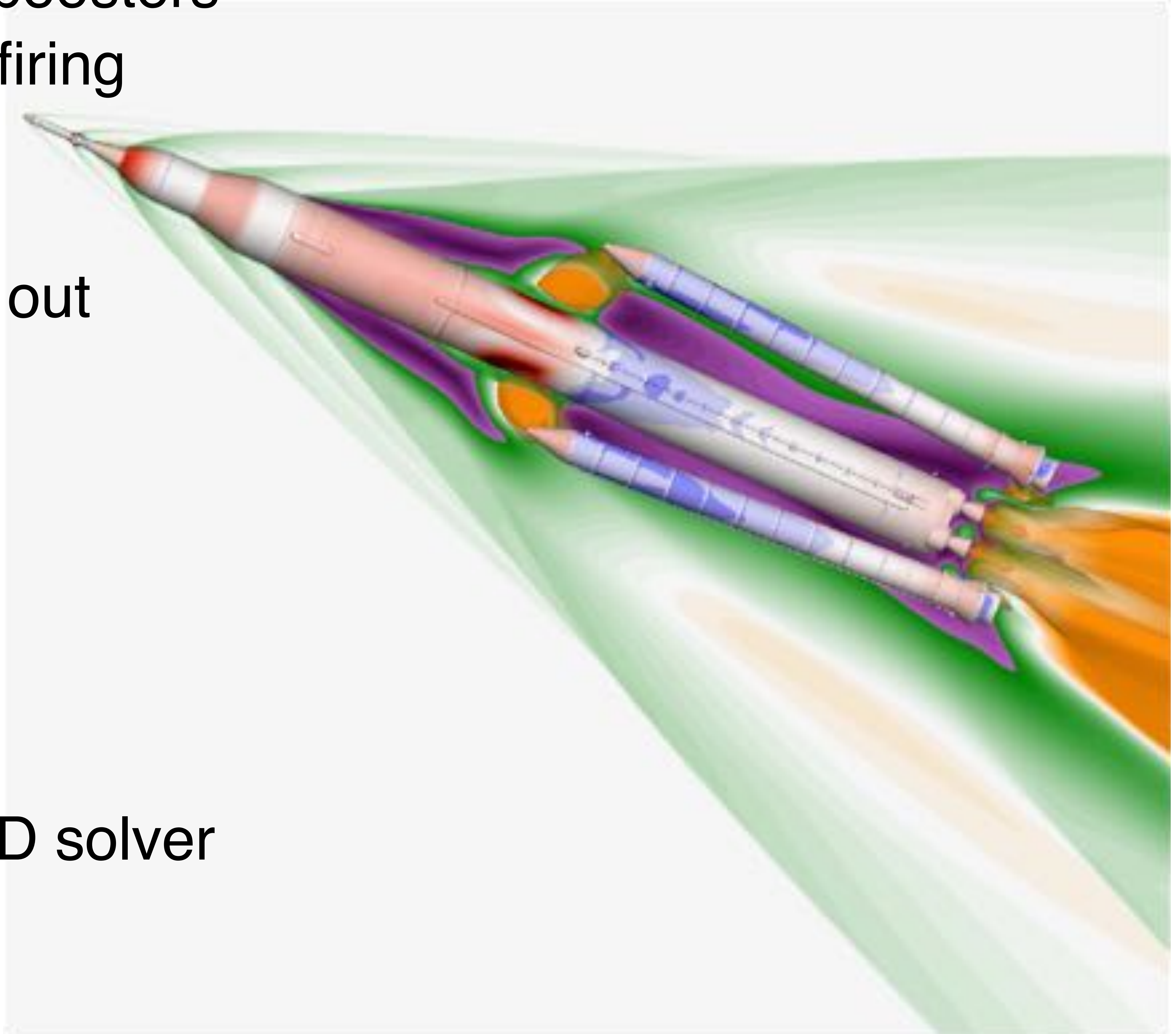
- Divide long slender protuberances into slices
- Example below: Liquid Oxygen feed lines



SLS CFD Booster Separation Database

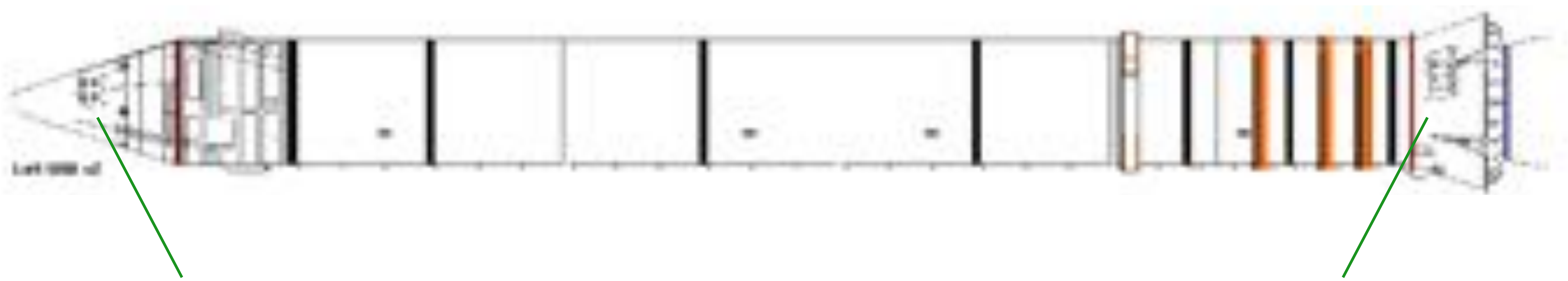
- Provide forces and moments on core and both boosters
- Complicated fluid dynamics: 14 engine plumes firing
- Large data
  - Many independent parameters
  - Off-nominal conditions: core engine out, BSM out
  - Flight geometry & Wind-tunnel geometry
  - Static and Dynamic cases

- Computational Fluid Dynamics (CFD)
  - FUN3D viscous CFD solver
  - Overflow viscous CFD solver
  - Overflow-D viscous dynamic moving body CFD solver



SLS Booster Separation Motors

- Separation system derived from Space Shuttle
- Boosters separate ~ 2 mins into flight
- 16 booster-separation motors (BSM) fire
  - 8 motors per booster (2 boosters)
  - 4 motors on the nose
  - 4 motors on the aft end
- 22,000 lbs of thrust each
- BSMs fire for about one second

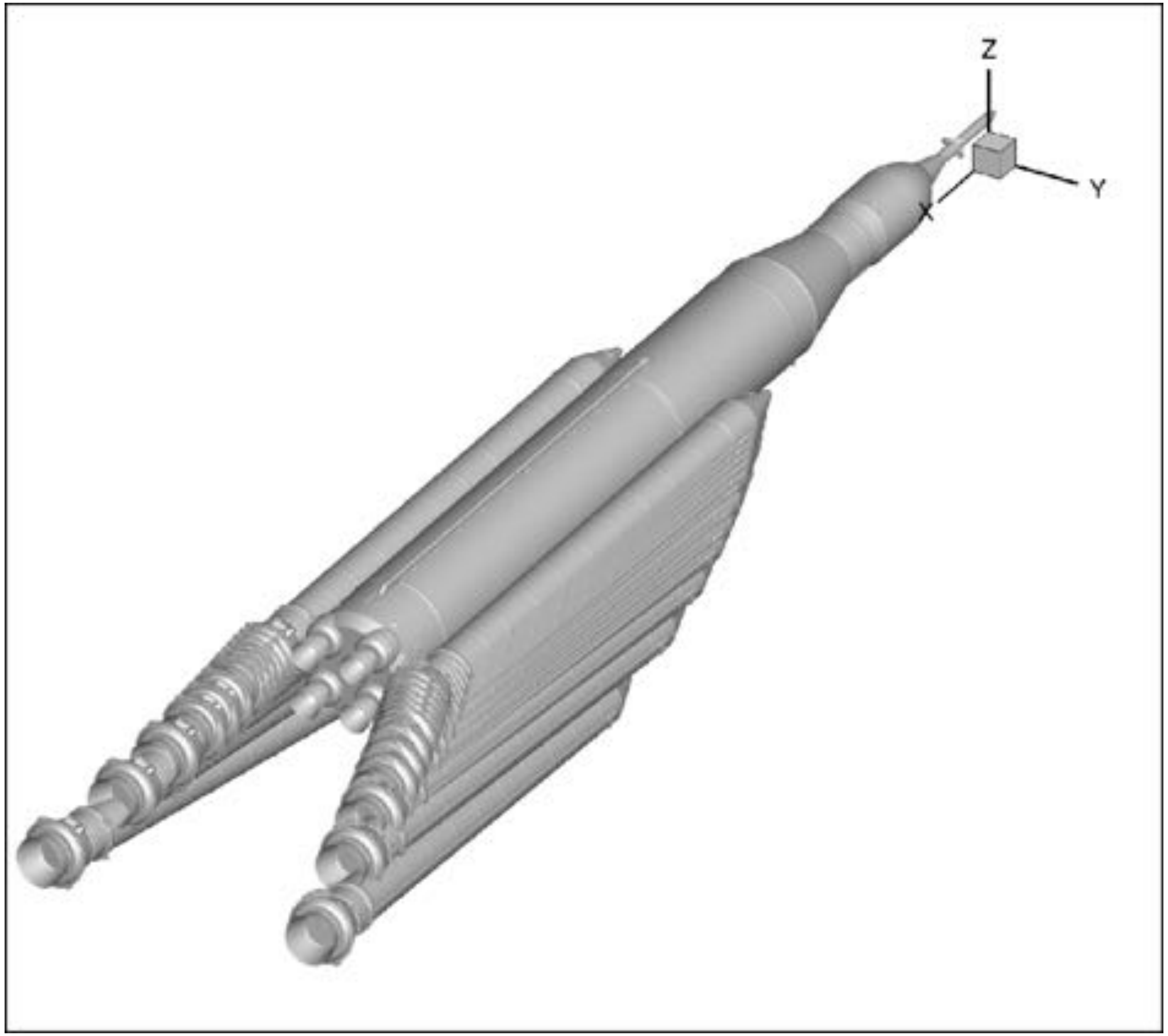


Forward BSMs

Aft BSMs

SLS Booster Separation Aerodynamics Database

- Eight-Dimensional run matrix
  - Translational variables - 3
  - Rotational variables - 2
  - Thrust of booster separation motors -1
  - Freestream conditions - 2

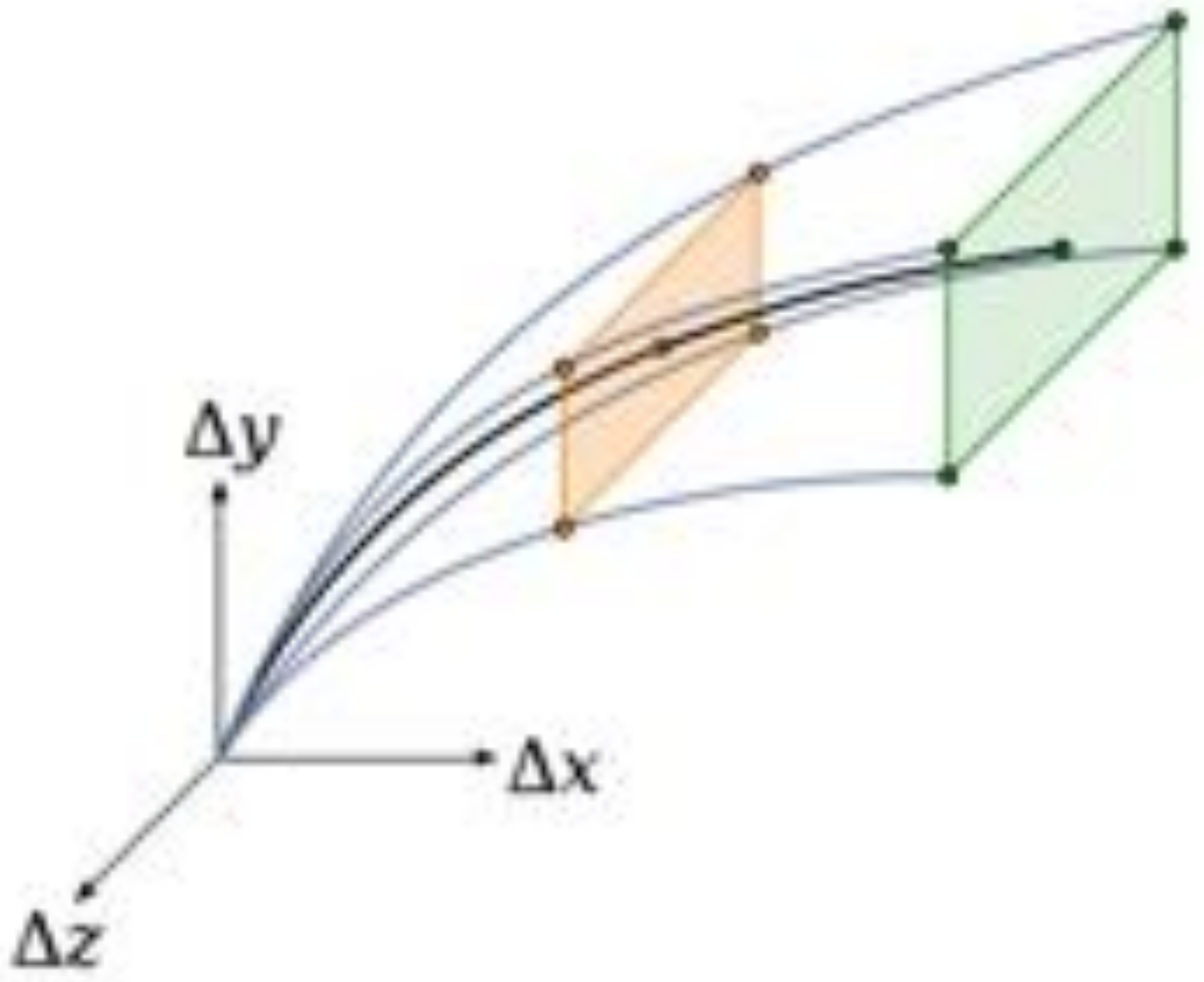


SLS Booster Separation Aerodynamics Database

- Eight-Dimensional run matrix
  - Translational variables - 3
  - Rotational variables - 2
  - Thrust of booster separation motors -1
  - Freestream conditions - 2
- 7-dimensional rectangular run matrix for each dx value

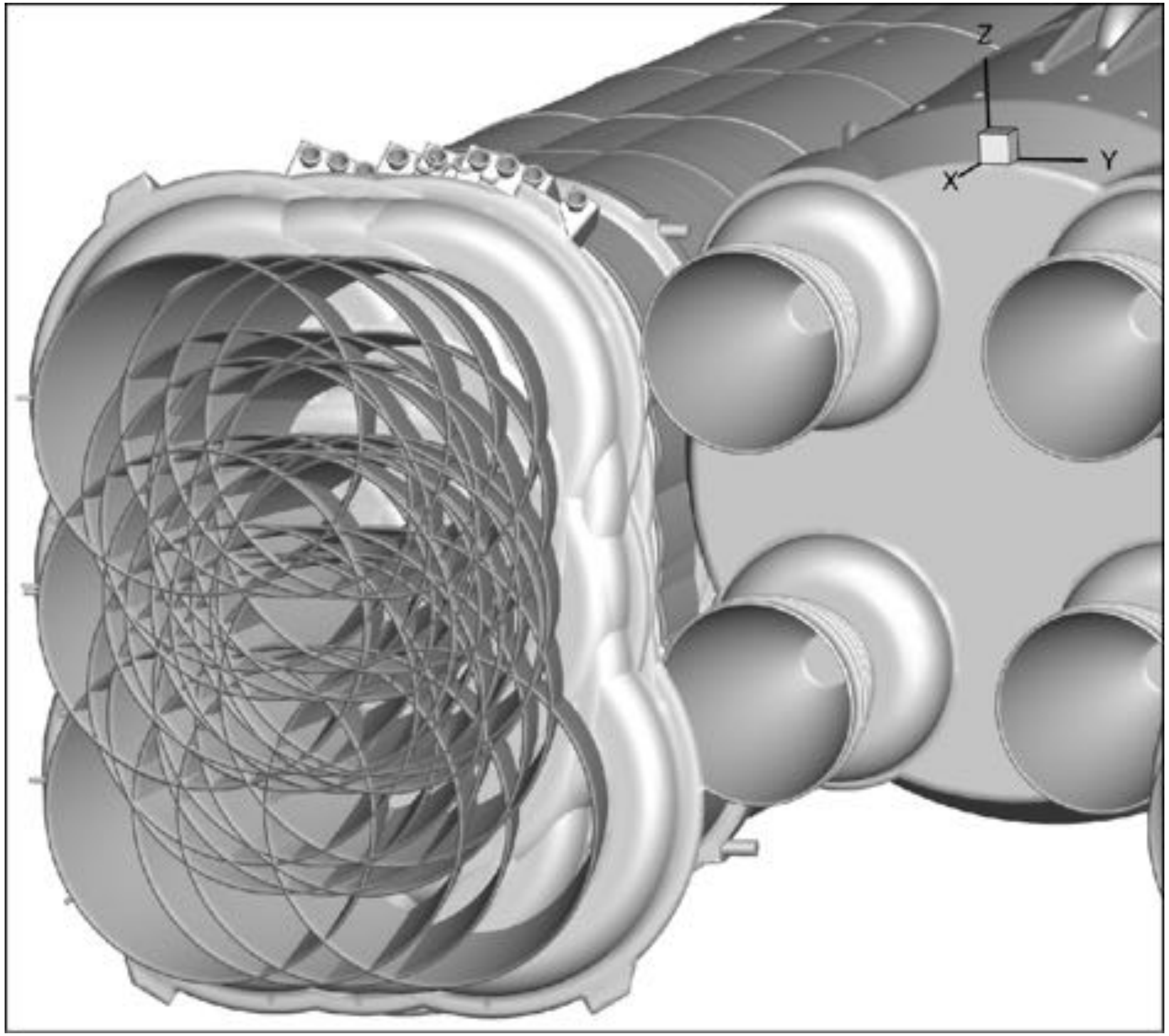
SLS Booster Separation Aerodynamics Database

- Eight-Dimensional run matrix
  - Translational variables - 3
  - Rotational variables - 2
  - Thrust of booster separation motors -1
  - Freestream conditions - 2
- 7-dimensional rectangular run matrix for each dx value
- Pyramid-shaped run matrix



SLS Booster Separation Aerodynamics Database

- Eight-Dimensional run matrix
  - Translational variables - 3
  - Rotational variables - 2
  - Thrust of booster separation motors -1
  - Freestream conditions - 2
- 7-dimensional rectangular run matrix for each dx value
- Pyramid-shaped run matrix
- 22,000+ runs required



SLS Block 1B Crew Booster Separation

Booster Proximity: Attached • • • • • • • • Separated

Background slice purple-green-white-orange color contours represent low to high velocities
Vehicle surface blue-white-red color contours represent low to high pressures

SLS Block 1B Crew Booster Separation

Booster Proximity: Attached • • • • • • • • Separated

Background slice purple-green-white-orange color contours represent low to high velocities
Vehicle surface blue-white-red color contours represent low to high pressures

SLS Block 1B Crew Booster Separation

Booster Proximity: Attached • • • • • • • • Separated

Background slice purple-green-white-orange color contours represent low to high velocities
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SLS Block 1B Crew Booster Separation

Booster Proximity: Attached • • • • • • • • Separated

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SLS Block 1B Crew Booster Separation

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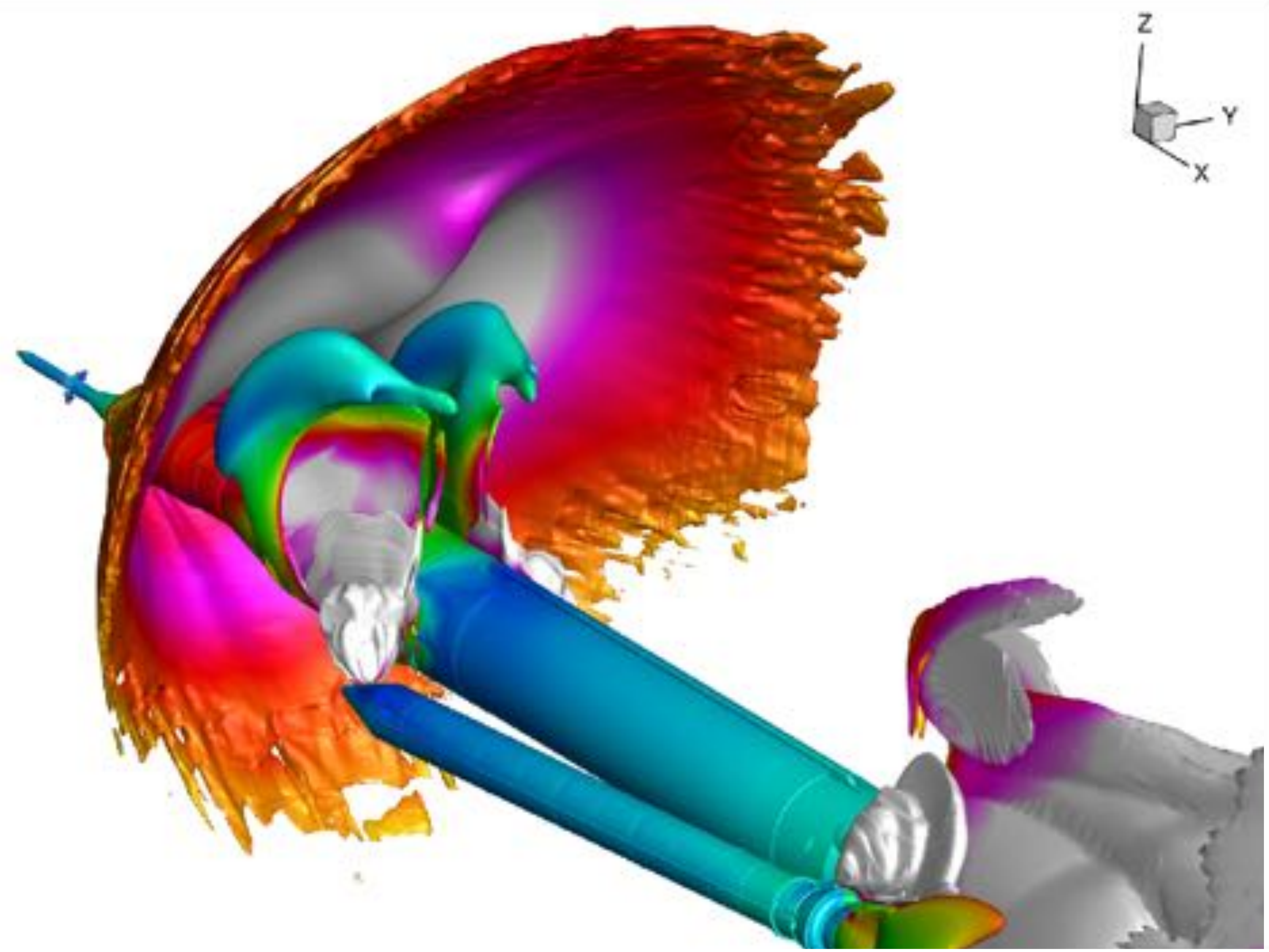
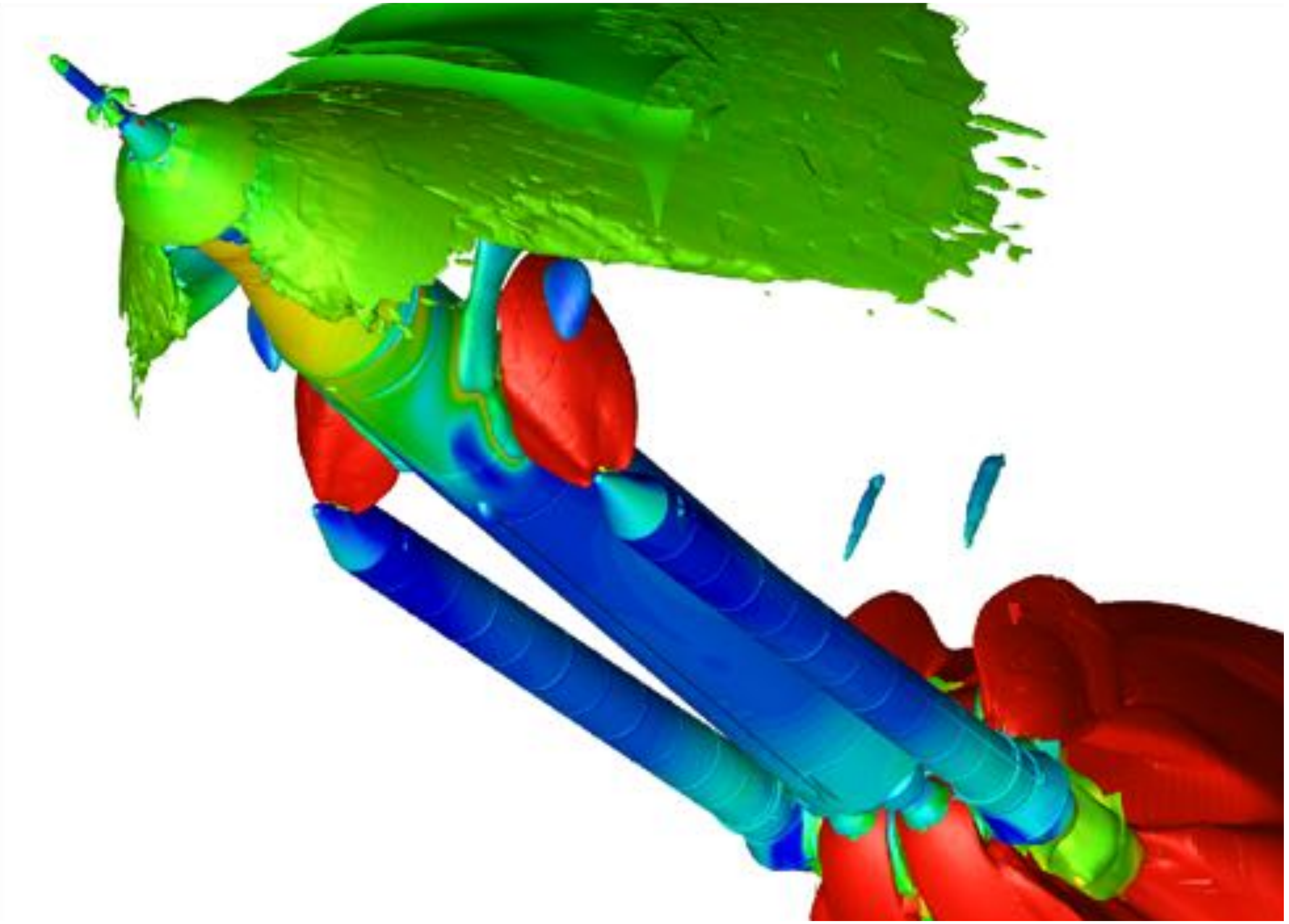
SLS Block 1B Crew Booster Separation

Booster Proximity: Attached • • • • • • • • Separated

Background slice purple-green-white-orange color contours represent low to high velocities
Vehicle surface blue-white-red color contours represent low to high pressures

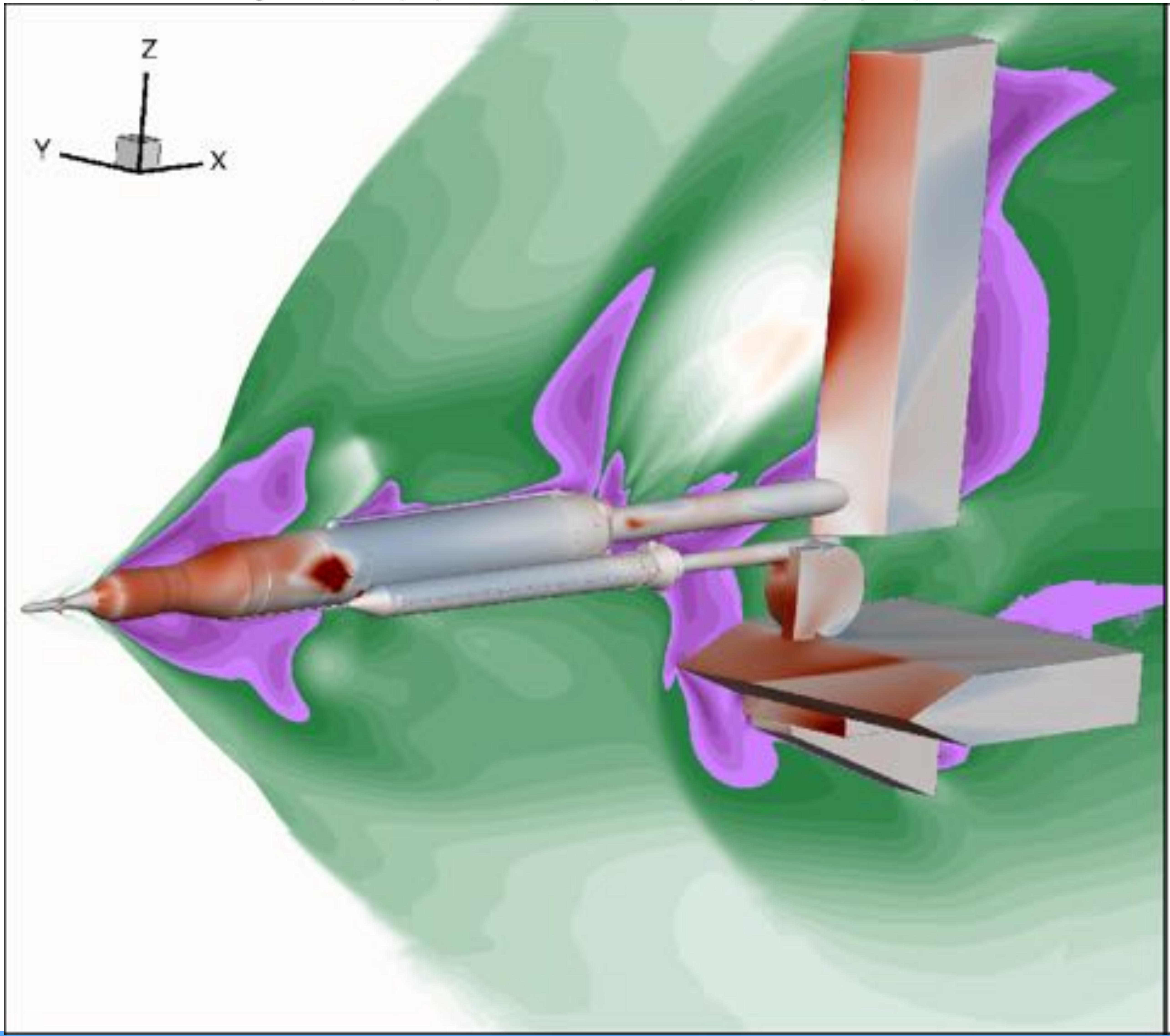
SLS Booster Separation (visualizations)



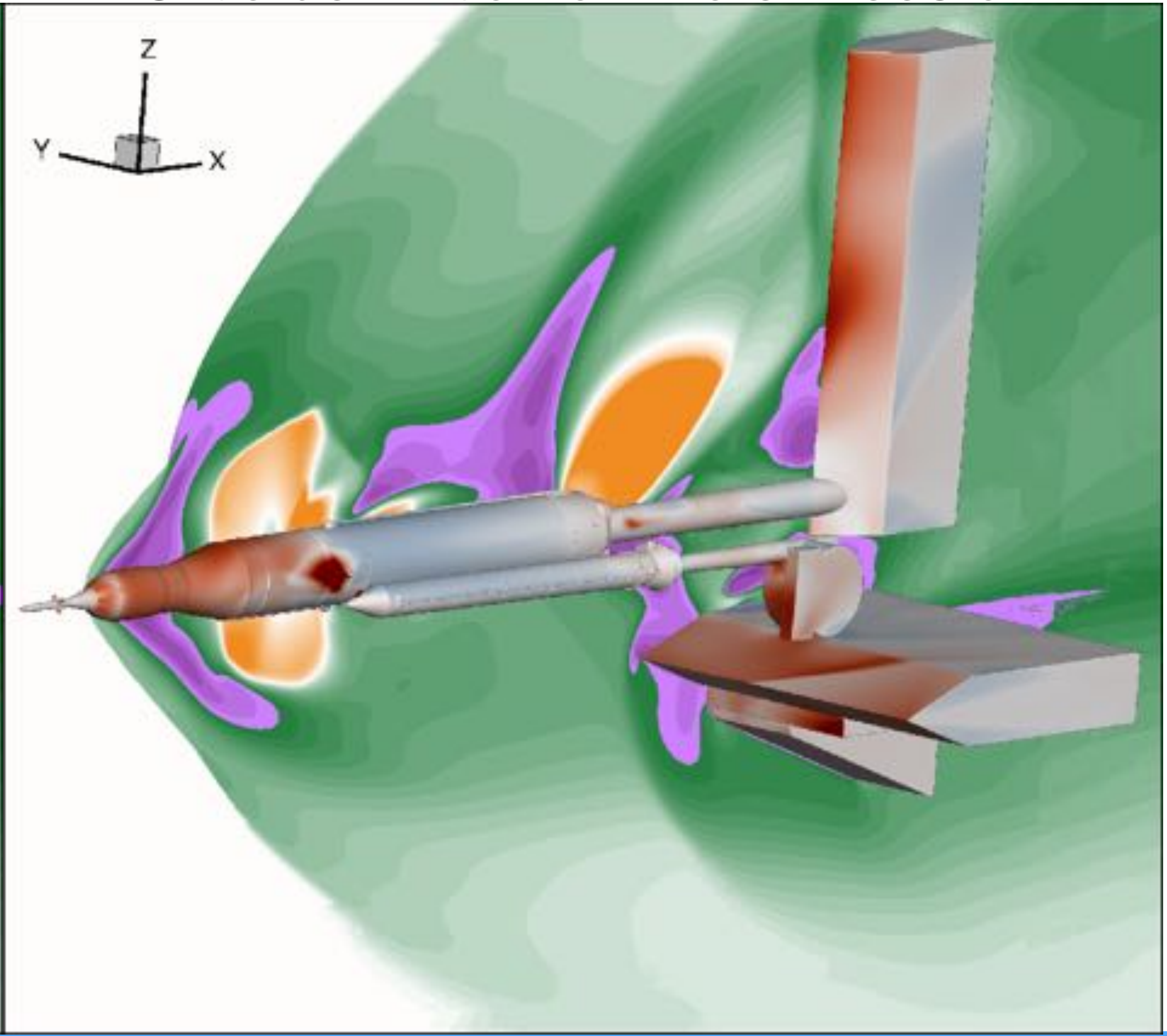


SLS Wind Tunnel Flow Visualization (Overflow)

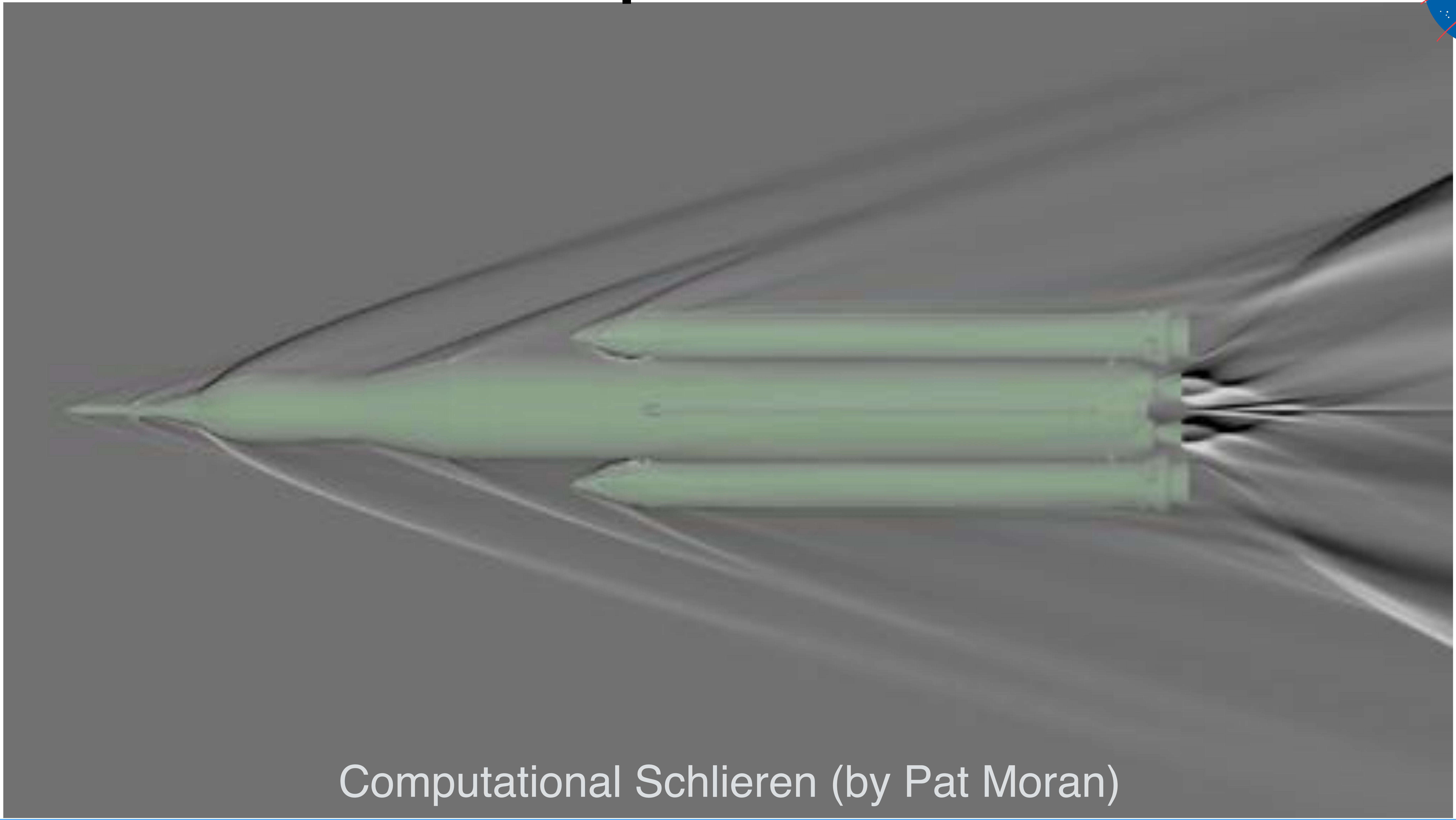
Slice down center of Core



Slice down center-line of Booster



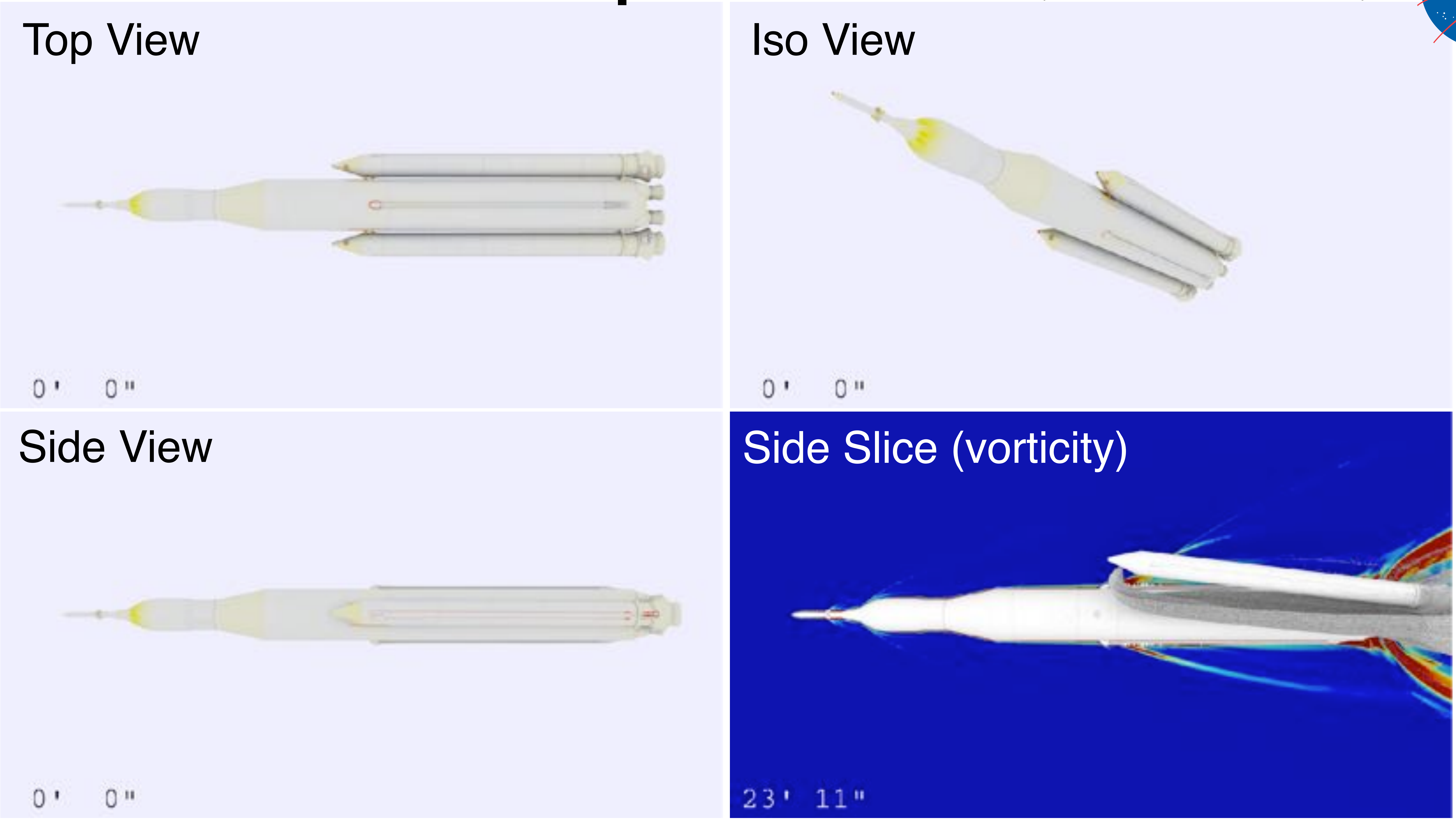
SLS Block 1 Booster Separation



Computational Schlieren (by Pat Moran)

SLS Block 1 Booster Separation

Particles Colored by BSM Nozzle
(Pat Moran, Tim Sandstrom)



Conclusions

- NAS Pleiades Supercomputer enabled the creation of many CFD-based databases
  - Created sets of aerodynamic databases for 4 configurations
  - Over 125 Million core-hours over just the last year
  - Over 8000 FUN3D cases per database
  - Over 1100 Overflow cases per database
  - Over 2.0 Million core-hours for moving body simulation to validate static-database method

- Successfully developed very complex aerodynamic databases
  - Most complex databases using CFD data in SLS program
  - Used extensively throughout the design process of the SLS rocket family

Thanks for stopping by!

Particles Colored by BSM Nozzle