



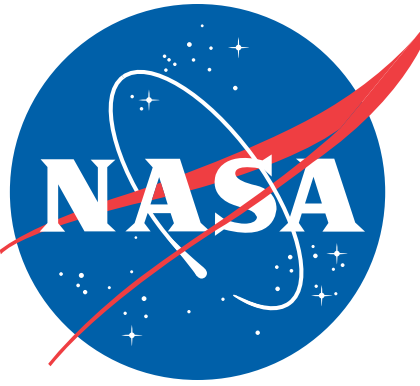
# Aerodynamic Databases for the Space Launch System

SLS Aerodynamics Group:  
Stuart Rogers, Derek Dalle, Henry Lee,  
Jamie Meeroff, Jeff Onufer, Thomas Pulliam

Computational Aerosciences Branch  
NASA Ames Research Center

Supercomputing Dallas, November 2018

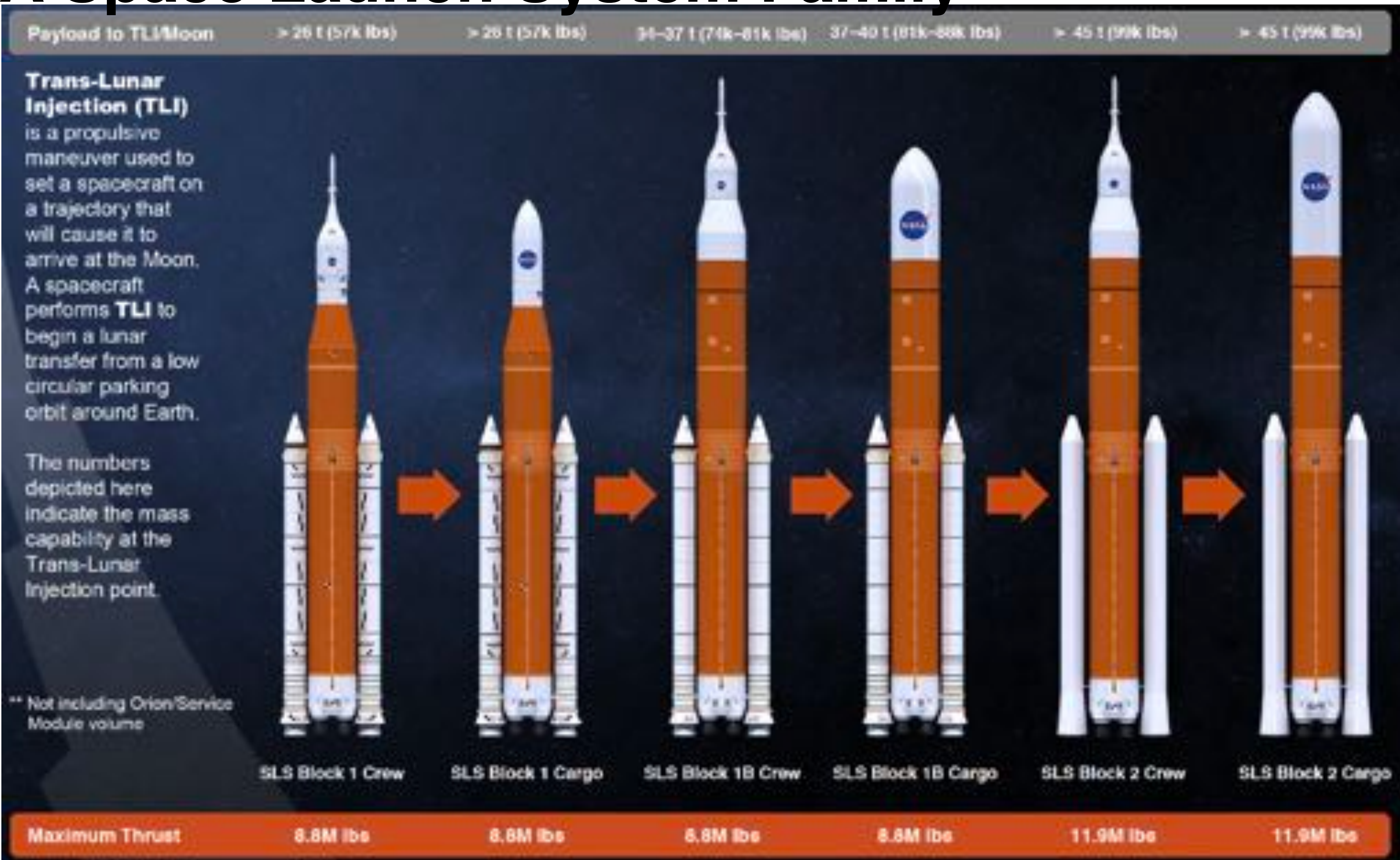
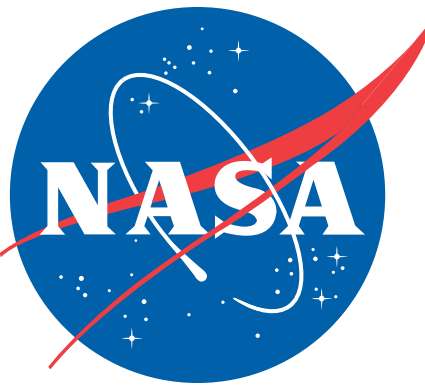
# NASA Space Launch System



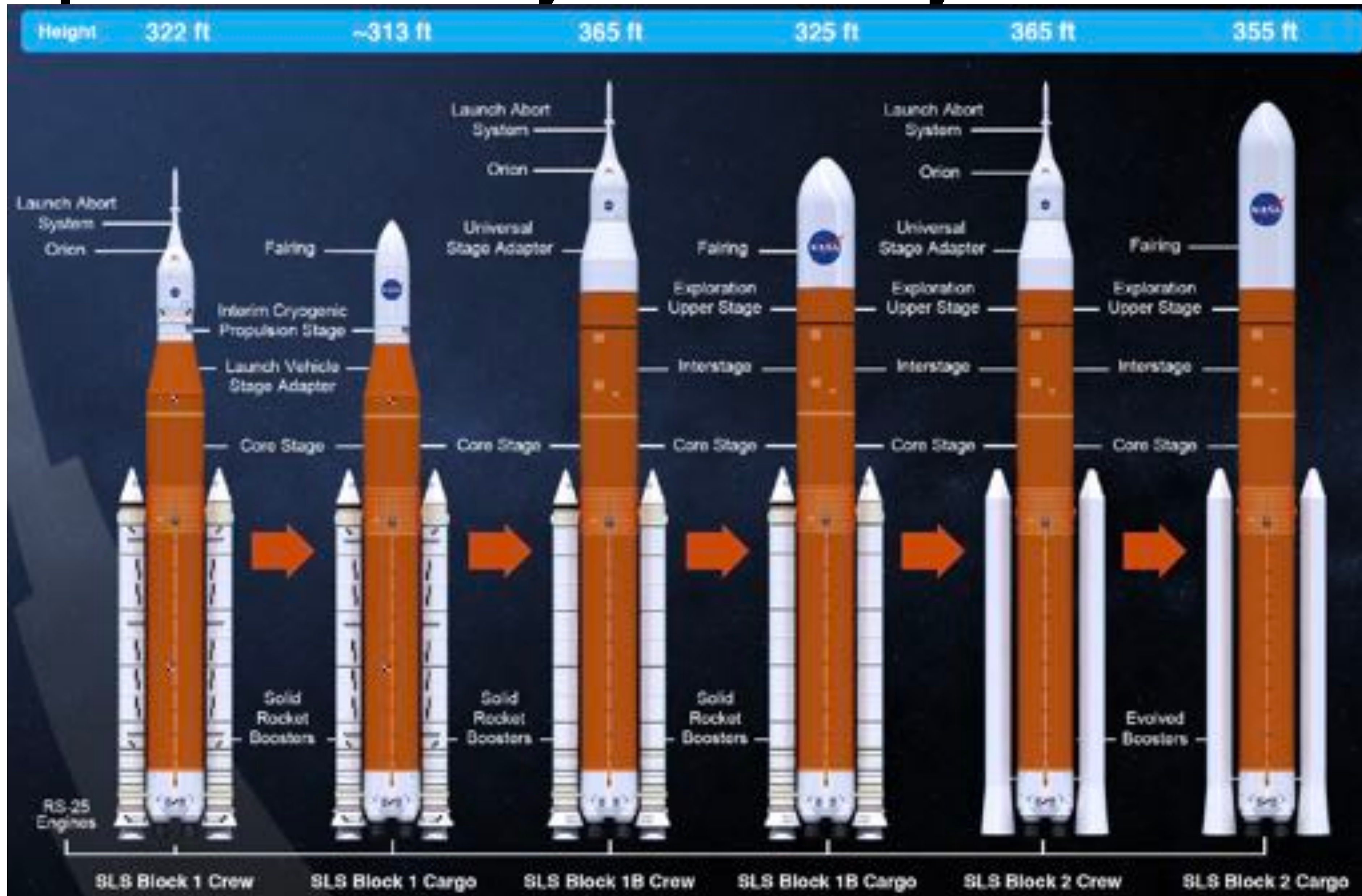
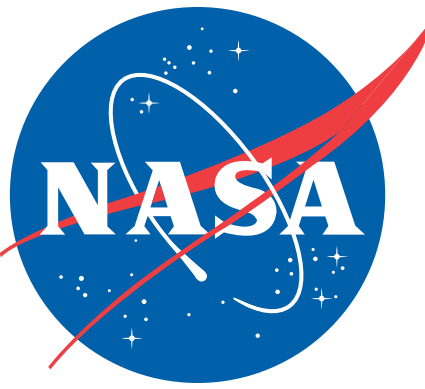
- NASA developed heavy-lift capability
- First rocket to transport astronauts beyond Earth orbit since Saturn V
- 70-metric ton payload capability
- Thrust:
  - 8.4 million pounds
  - 10% more than Saturn V
- Payload more than three times of the Space Shuttle



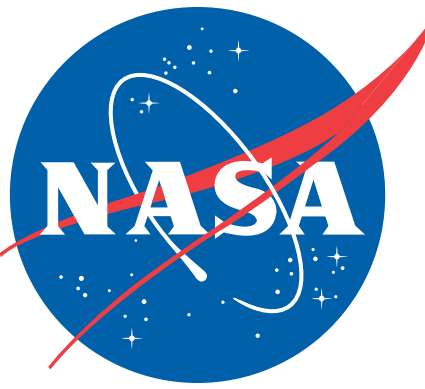
# NASA Space Launch System Family



# NASA Space Launch System Family



# SLS Core Stage



## CORE STAGE

# 101\*

\* Or: What you need to know about the Space Launch System Core Stage, the backbone of the rocket.

### INSIDE THE CORE STAGE

### HOW BIG IS THE SLS CORE STAGE?

- **212'** tall and **27.6'** in diameter
- **~2.3M POUNDS** with propellant
- The largest rocket stage ever built
- Fuels the world's most powerful rocket

### A FAST RIDE!

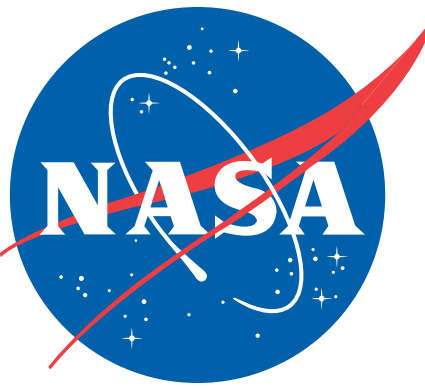
SLS reaches **MACH 23** (faster than **17,000 MPH**) in just **6.5 MINUTES**.

- 1 ENGINE SECTION**
  - Delivers propellants from the LH2 and LOX tanks to **4 RS-25 ENGINES**
  - Avionics to steer engines
  - All booster attach point
- 2 LH2 TANK**
  - Holds **537,000 GALLONS** of liquid hydrogen cooled to **-423°F**
- 3 INTERTANK**
  - Joins **LH2** and **LOX** tanks.
  - Houses avionics and electronics
  - Forward booster attach point
- 4 LOX TANK**
  - Holds **196,000 GALLONS** of liquid oxygen cooled to **-297°F**
- 5 FORWARD SKIRT**
  - Houses flight computers, cameras, and avionics — the **"BRAINS"** of the rocket

Fuels 4 engines to produce a total **2 MILLION POUNDS** of thrust

**733,000 GALLONS** of propellant fill the **LH2** and **LOX** tanks together, enough to fill **63** large tanker trucks.

# SLS Boosters



## BOOSTERS 101\*

\* Or: What you really need to know about the SLS Solid Rocket Boosters.

The boosters tower **17 stories.**  
That's taller than the Statue of Liberty from base to torch.

Once assembled, each booster will weigh more than **1.6 Million pounds.**

Boosters are designed by engineers to be **FAST & POWERFUL**, providing **2 MINUTES** of **PURE AWESOME** and more than **75%** of total thrust at liftoff.

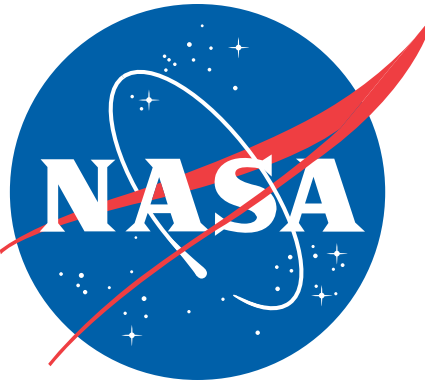
**EACH BOOSTER** burns **6 tons** of solid propellant **EVERY SECOND**...  
...and generates a **MAX THRUST** of **3.6 Million pounds.**

The SLS Solid Rocket Booster has **3** assemblies:

- Forward Assembly**
- Motor Assembly**
- Aft Assembly**

- The forward assembly includes the nose cap and the forward skirt. The forward skirt houses the electronics and has the critical connection point that carries most of the forces to the rocket during launch.
- The motor assembly has **5 SEGMENTS** filled with propellant the consistency of a pencil eraser.
- The aft, or rear, assembly contains the aft skirt and the thrust vector control system, which moves the nozzle to steer the vehicle.

# SLS Exploration Mission-1

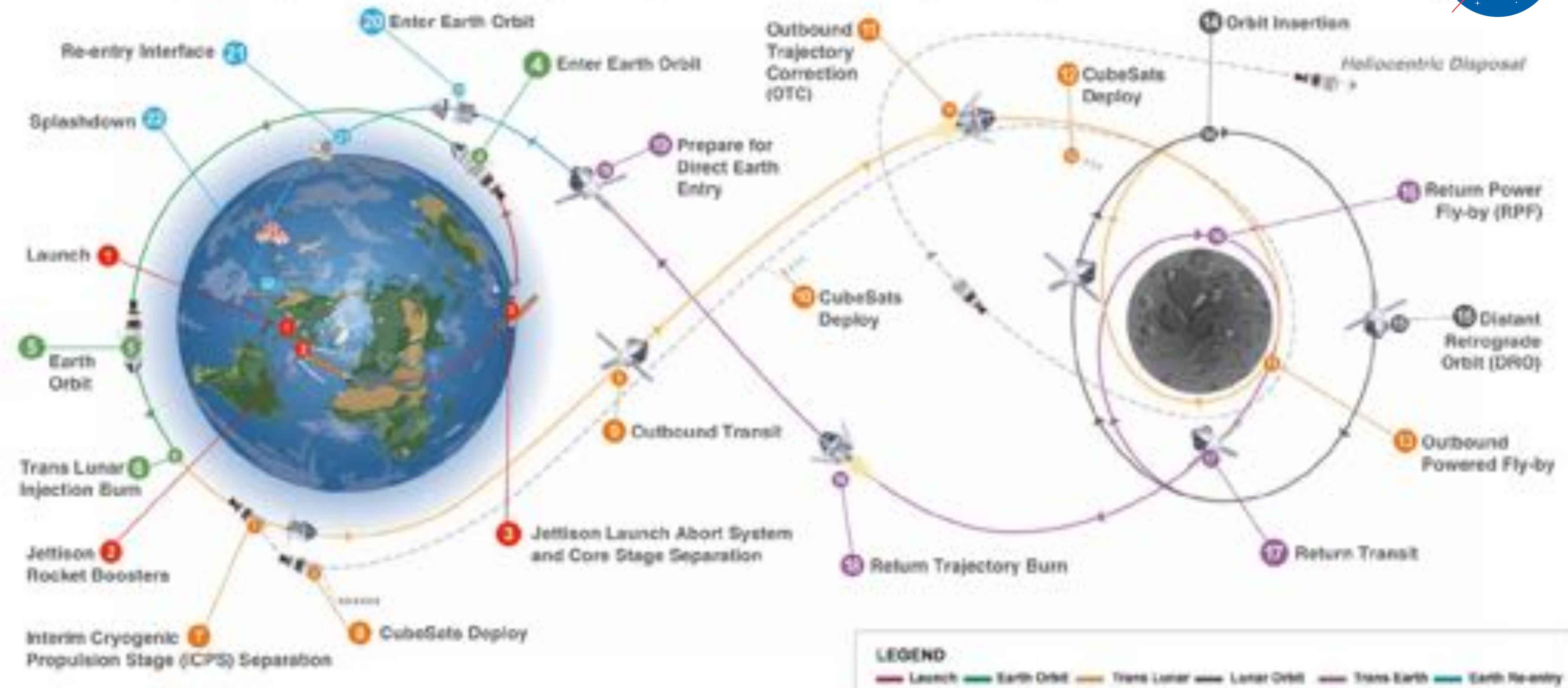
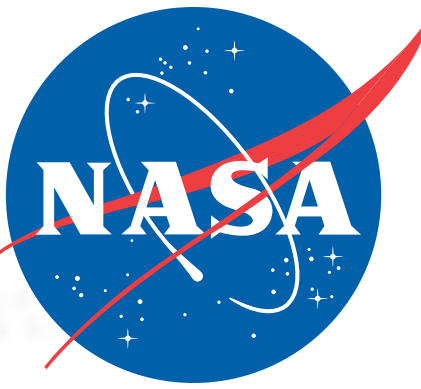


EXPLORATION MISSION 1



Narrated by Mission Manager, Mike Sarafin

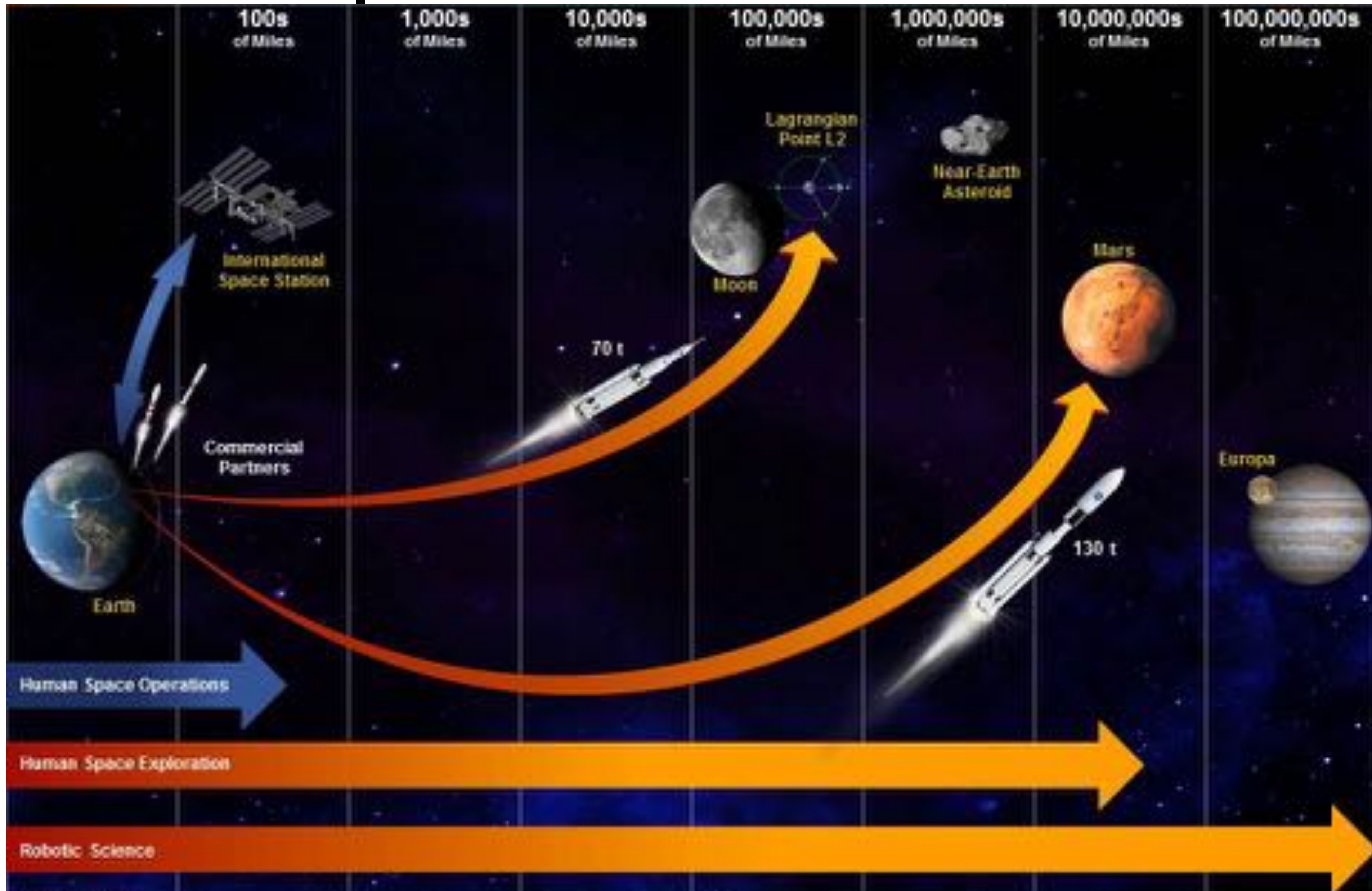
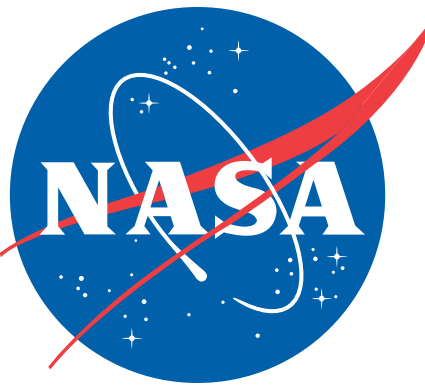
# SLS Exploration Mission 1



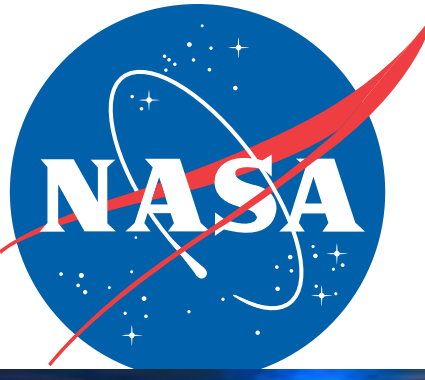
Total distance traveled: 1.3 million miles – Mission duration: 25.5 days – Re-entry speed: 24,500 mph (Mach 32) – 13 CubeSats deployed



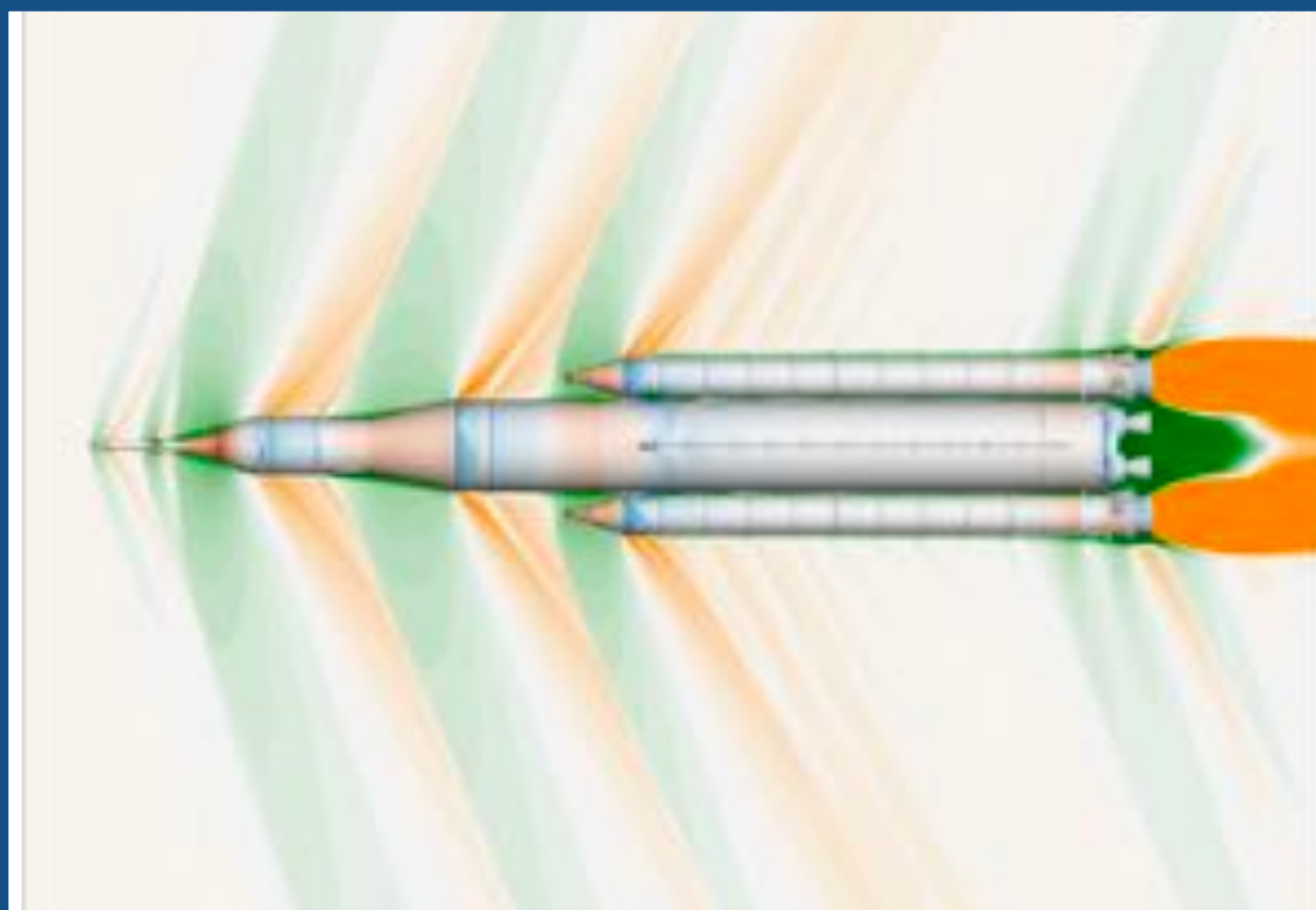
# SLS Future of Exploration



# SLS Computational Fluid Dynamics Applications



Ground Winds



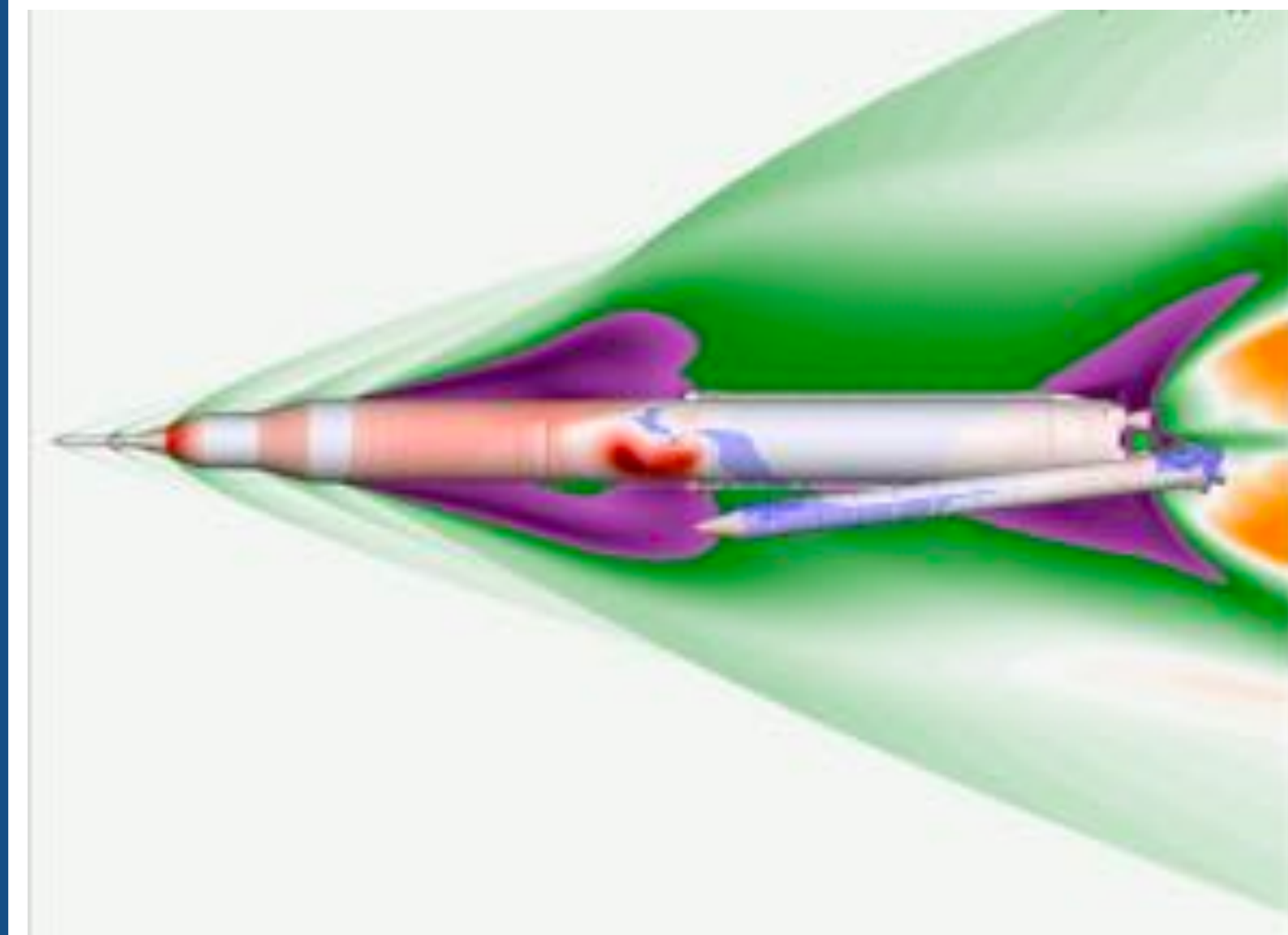
Ascent



NAS Pleiades and Electra Supercomputers



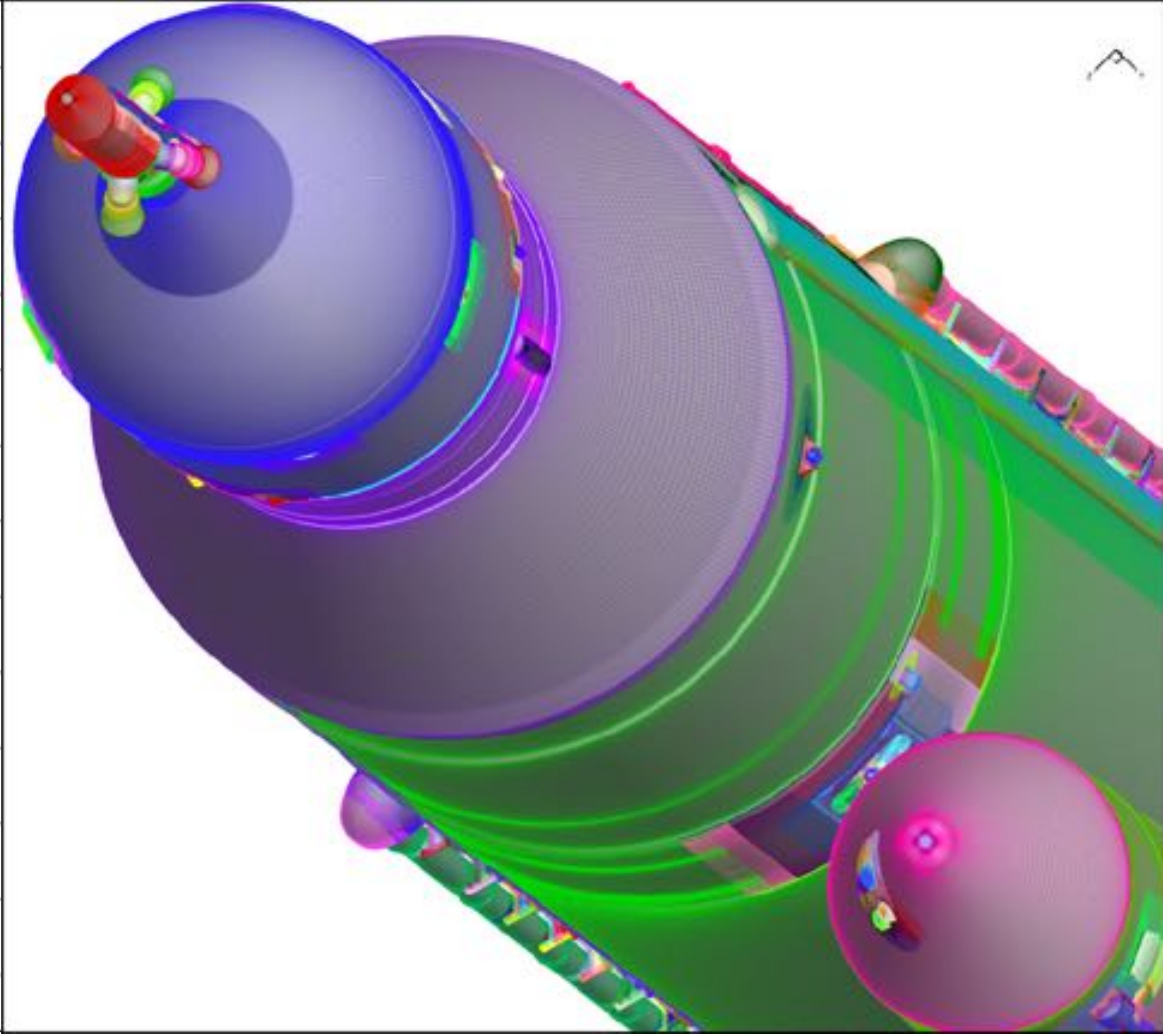
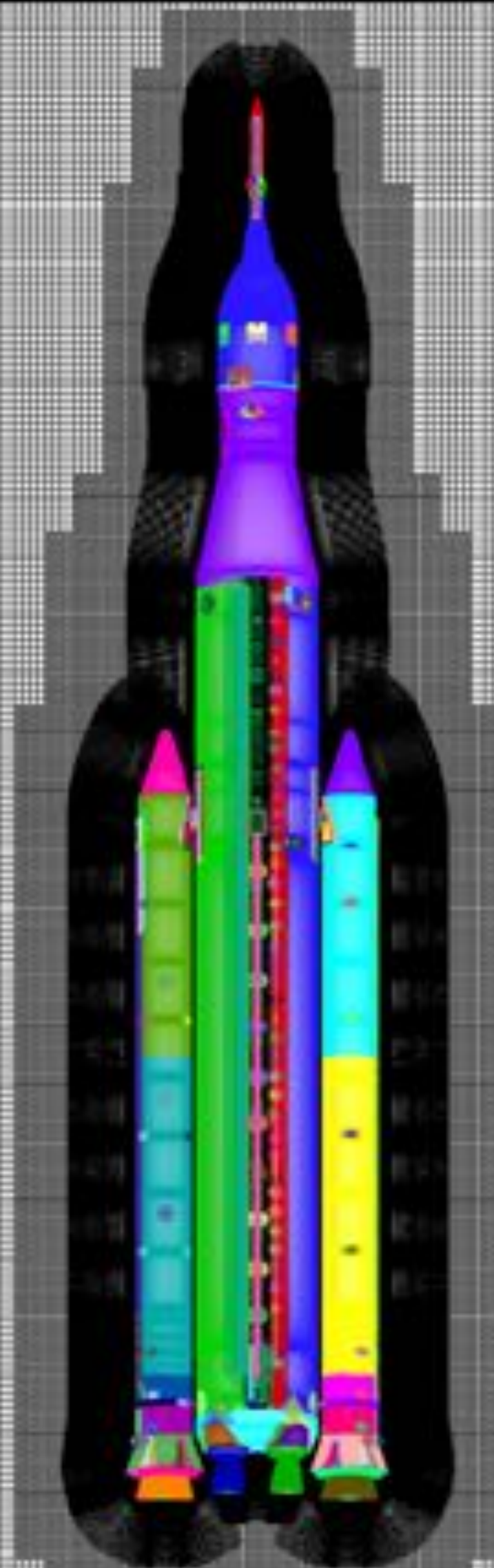
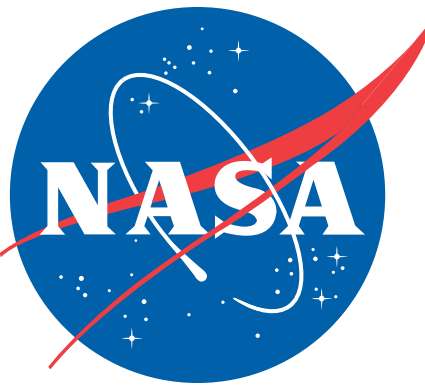
Launch Abort



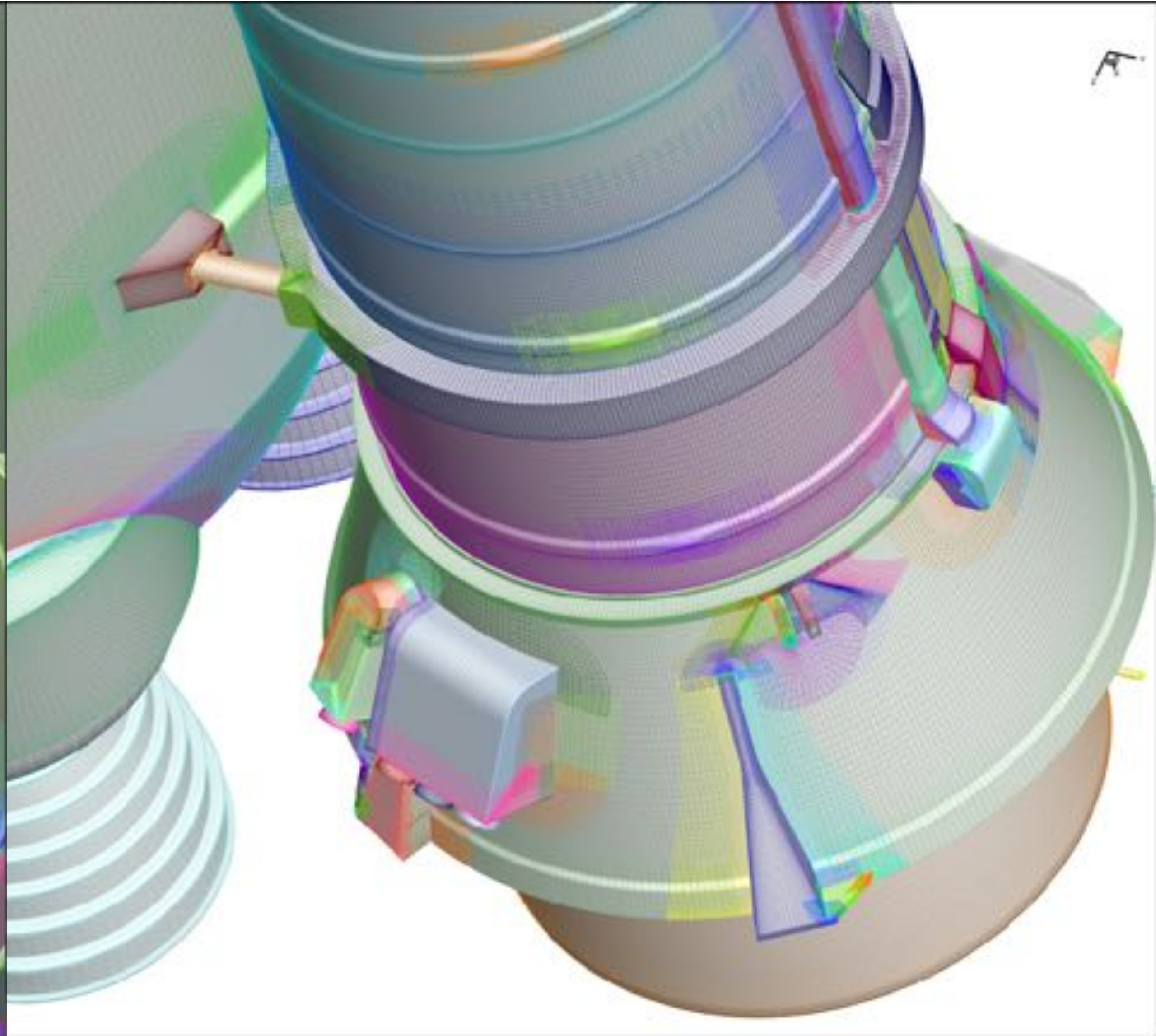
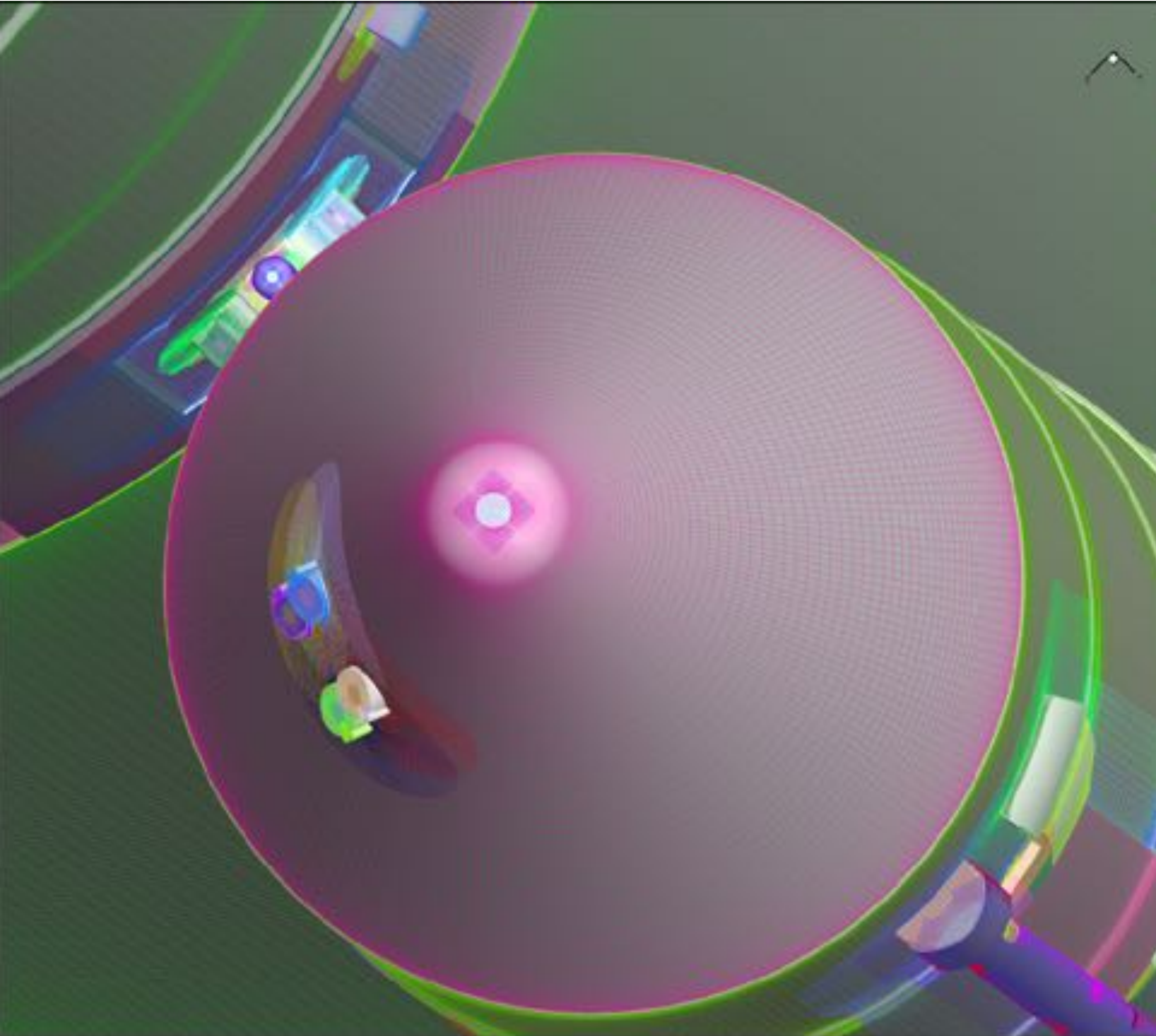
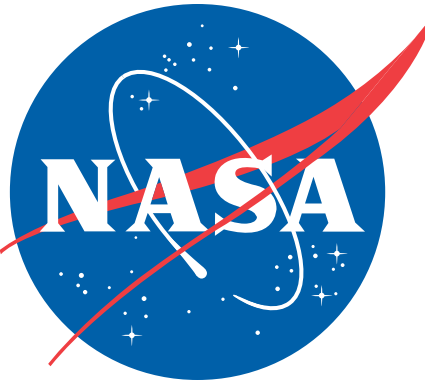
Booster Separation



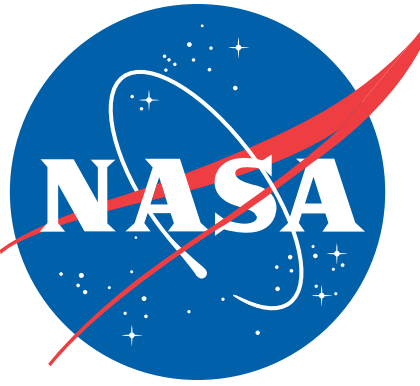
# CFD Modeling SLS Geometry



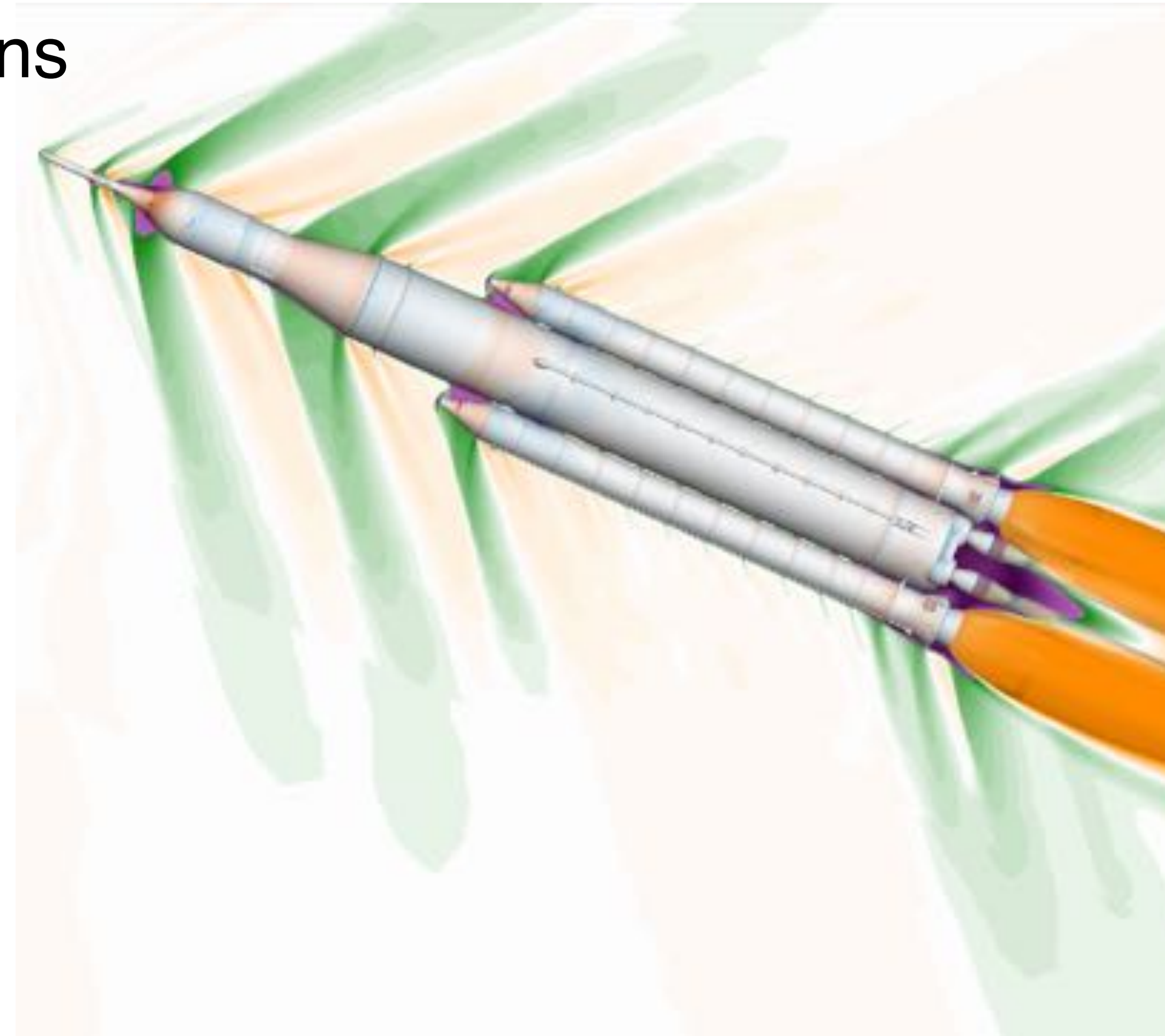
# CFD Modeling SLS Geometry



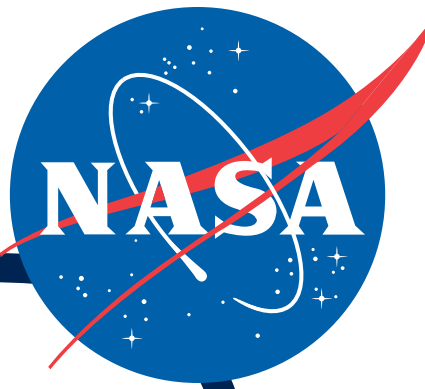
# SLS CFD Ascent Database



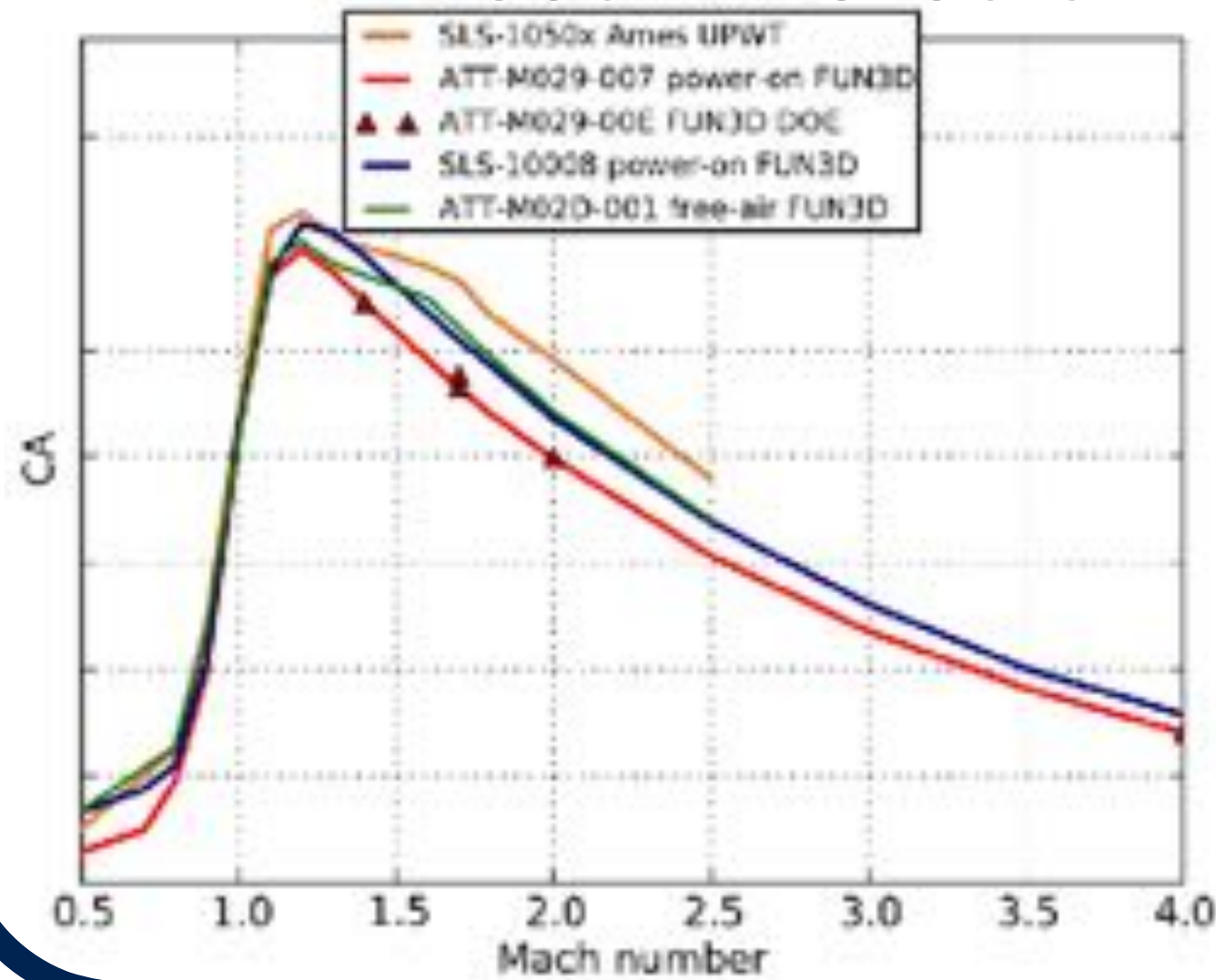
- Provide forces and moments on core and both boosters
- Complicated fluid dynamics: plume interactions
- Large data
  - Many independent parameters
  - Flight geometry & Wind-tunnel geometry
  - Static cases
- Computational Fluid Dynamics (CFD)
  - FUN3D viscous CFD solver
  - Overflow viscous CFD solver



# SLS CFD Ascent Analysis

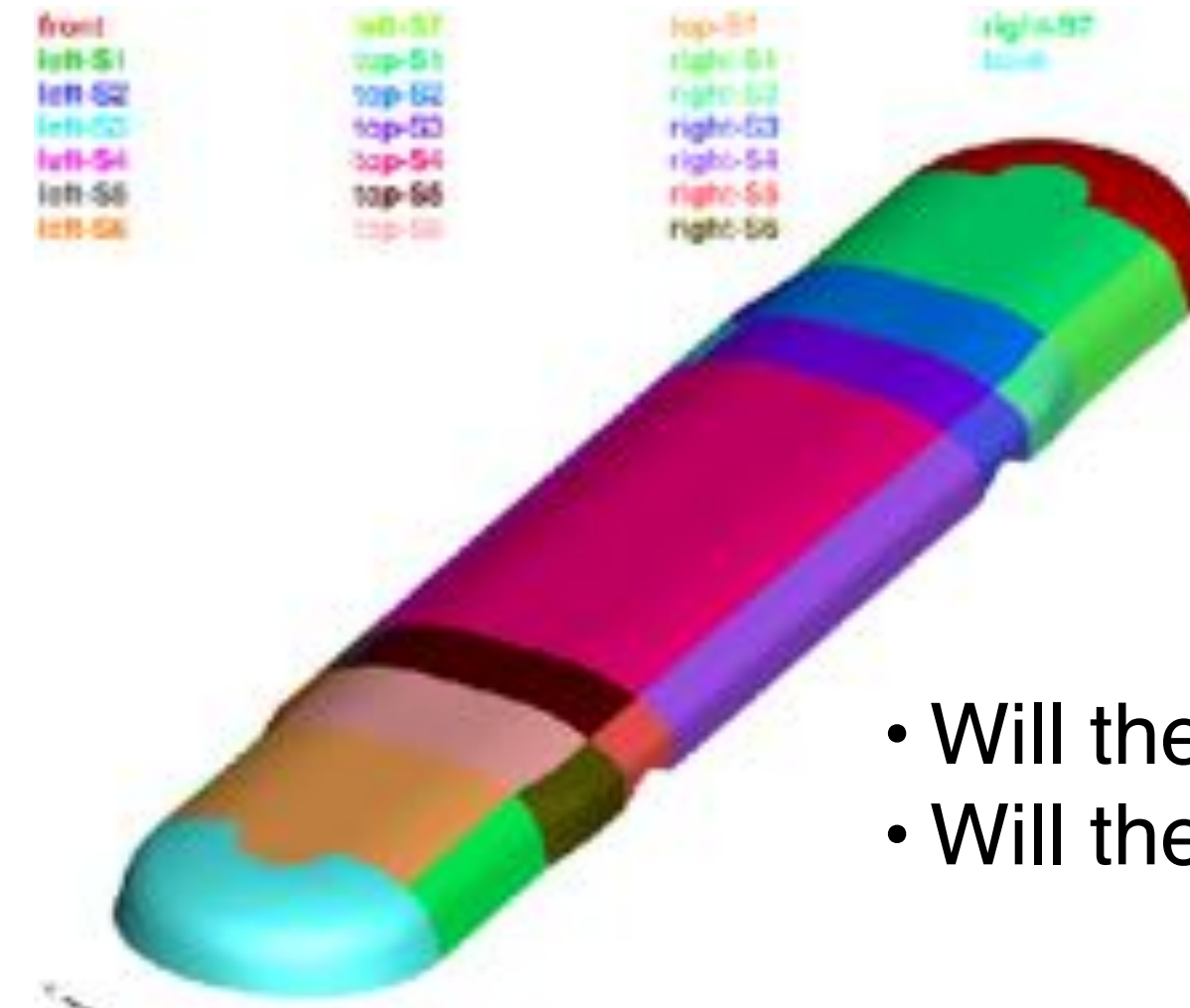


## Ascent Force & Moments



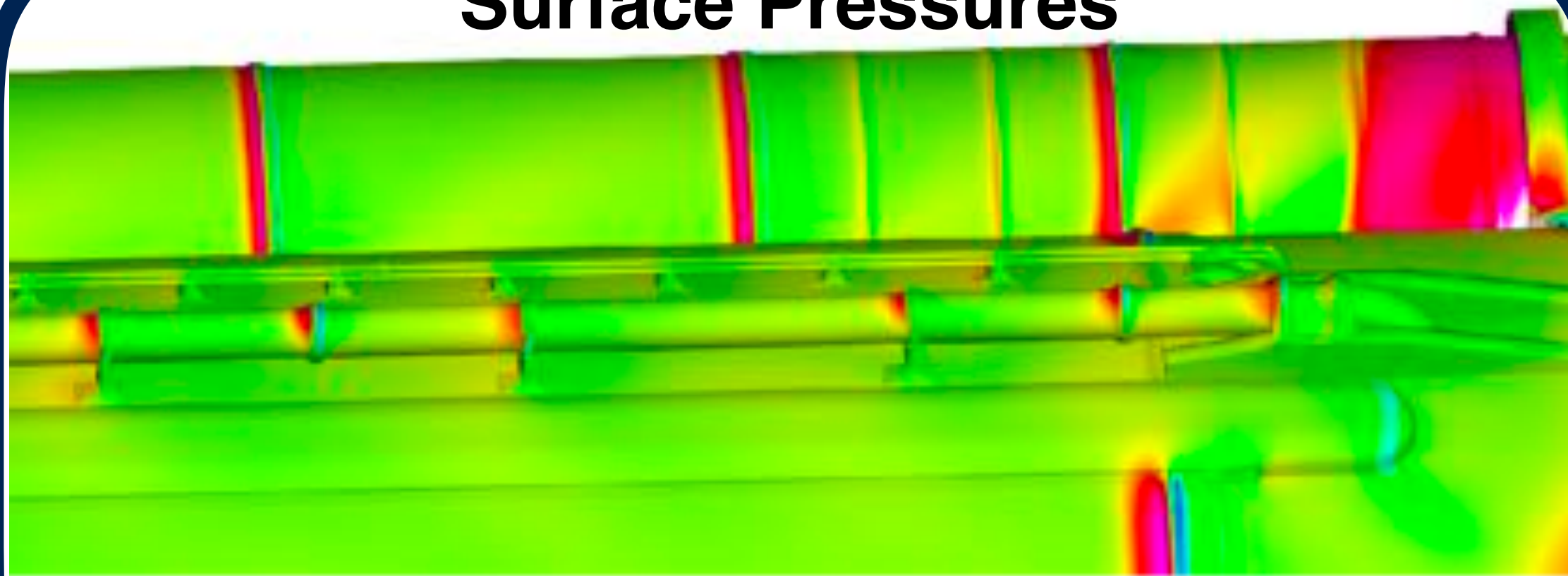
- How does the vehicle fly?
- CFD supplemental to Wind Tunnel

## Protuberance Air Loads



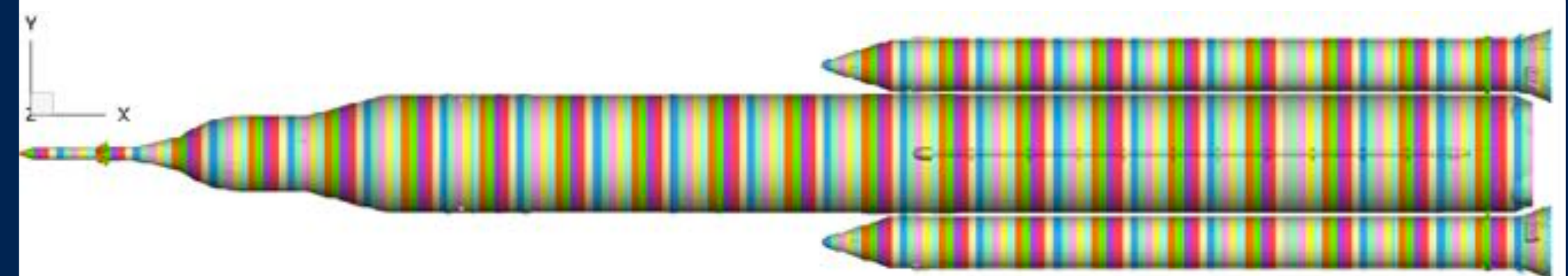
- Will the parts fly off?
- Will the parts crush in flight?

## Surface Pressures



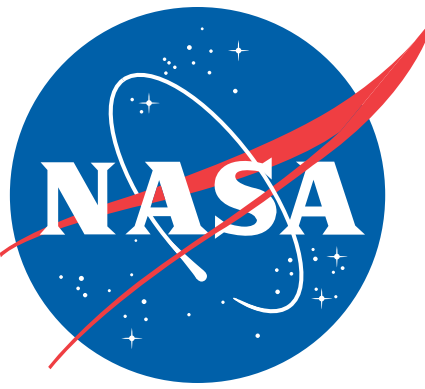
- Venting: any parts burst/crush?
- Other Considerations as well

## Line Loads

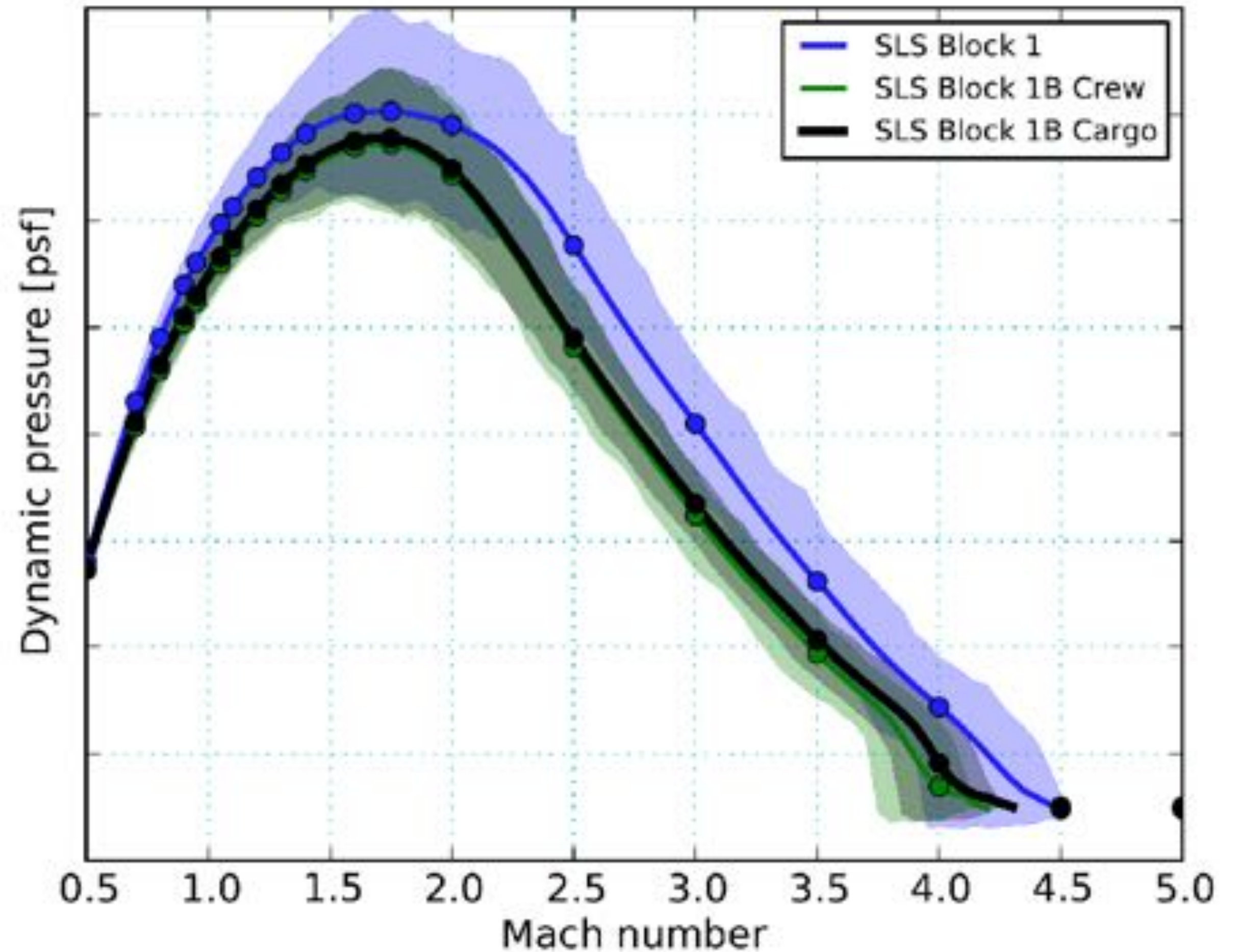
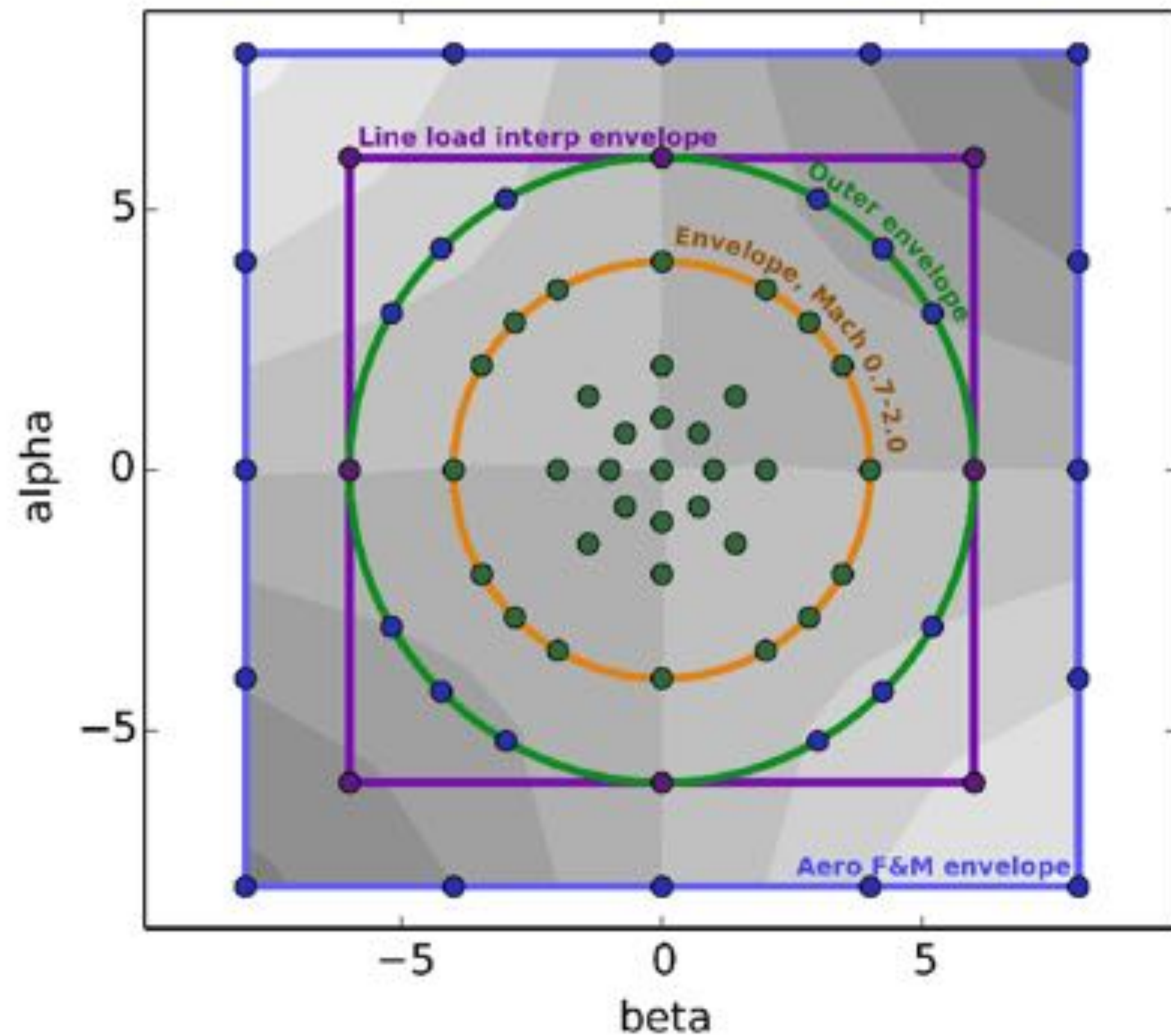


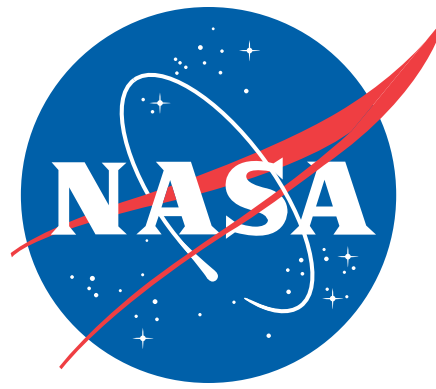
- How much does the vehicle bend?
- Does the vehicle break/buckle?

# 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



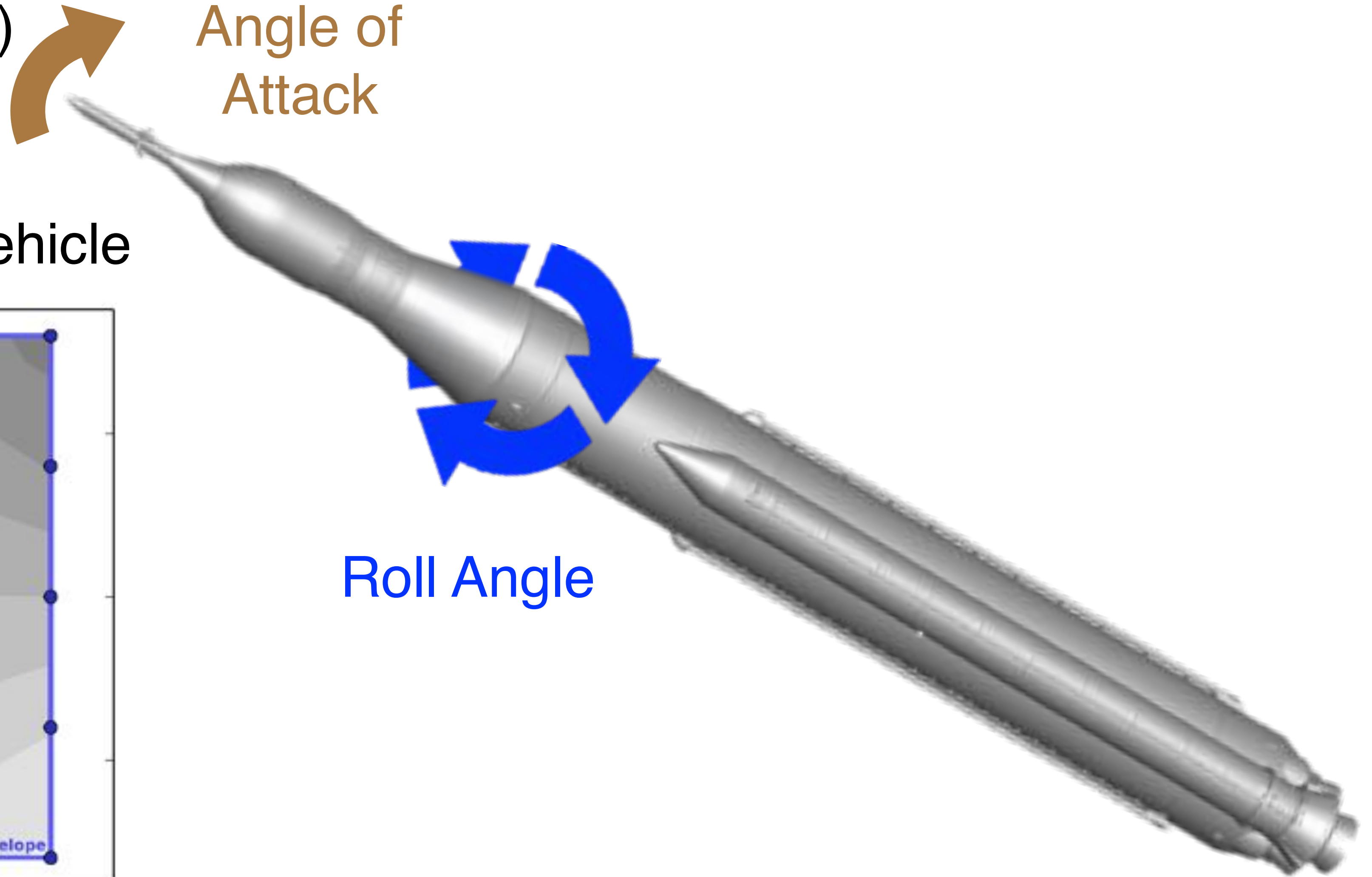
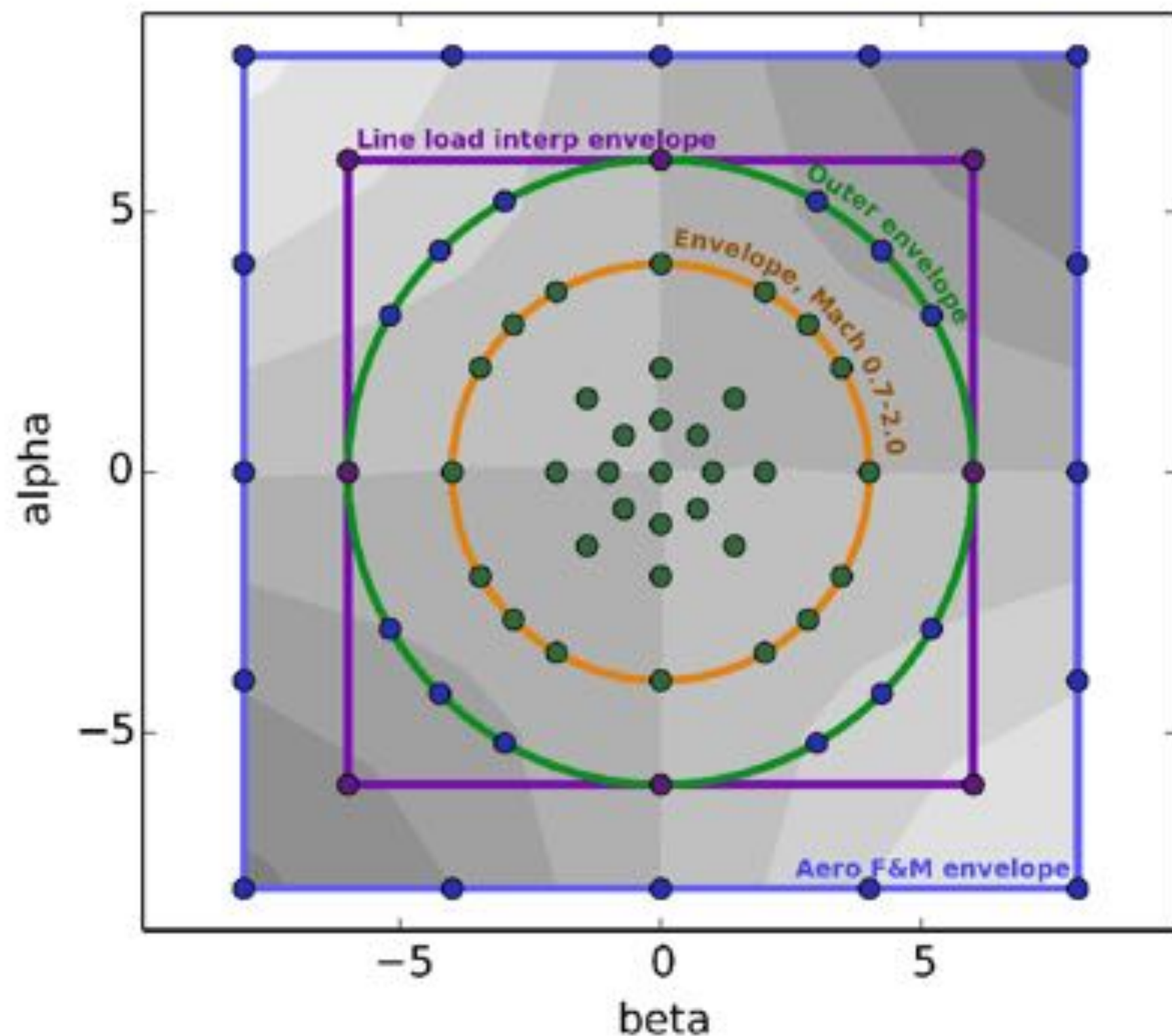


# SLS Ascent Aerodynamics Database

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

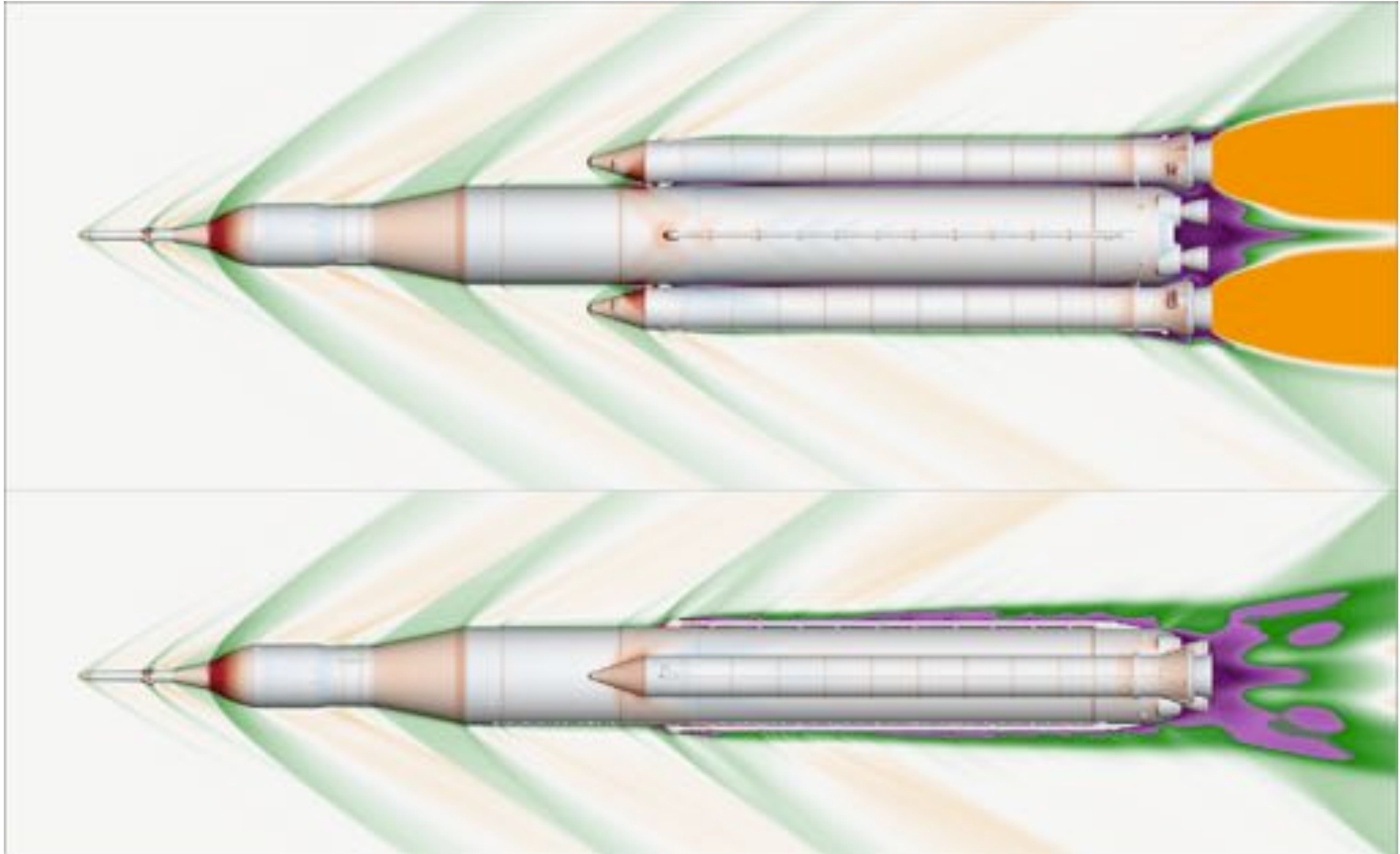
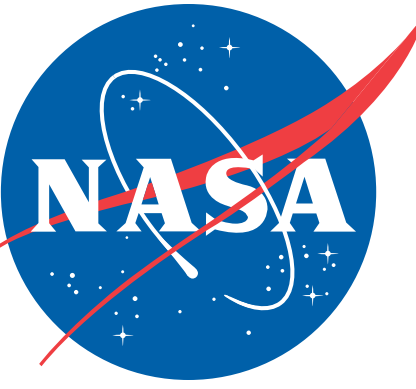
Angle of Attack

Roll Angle

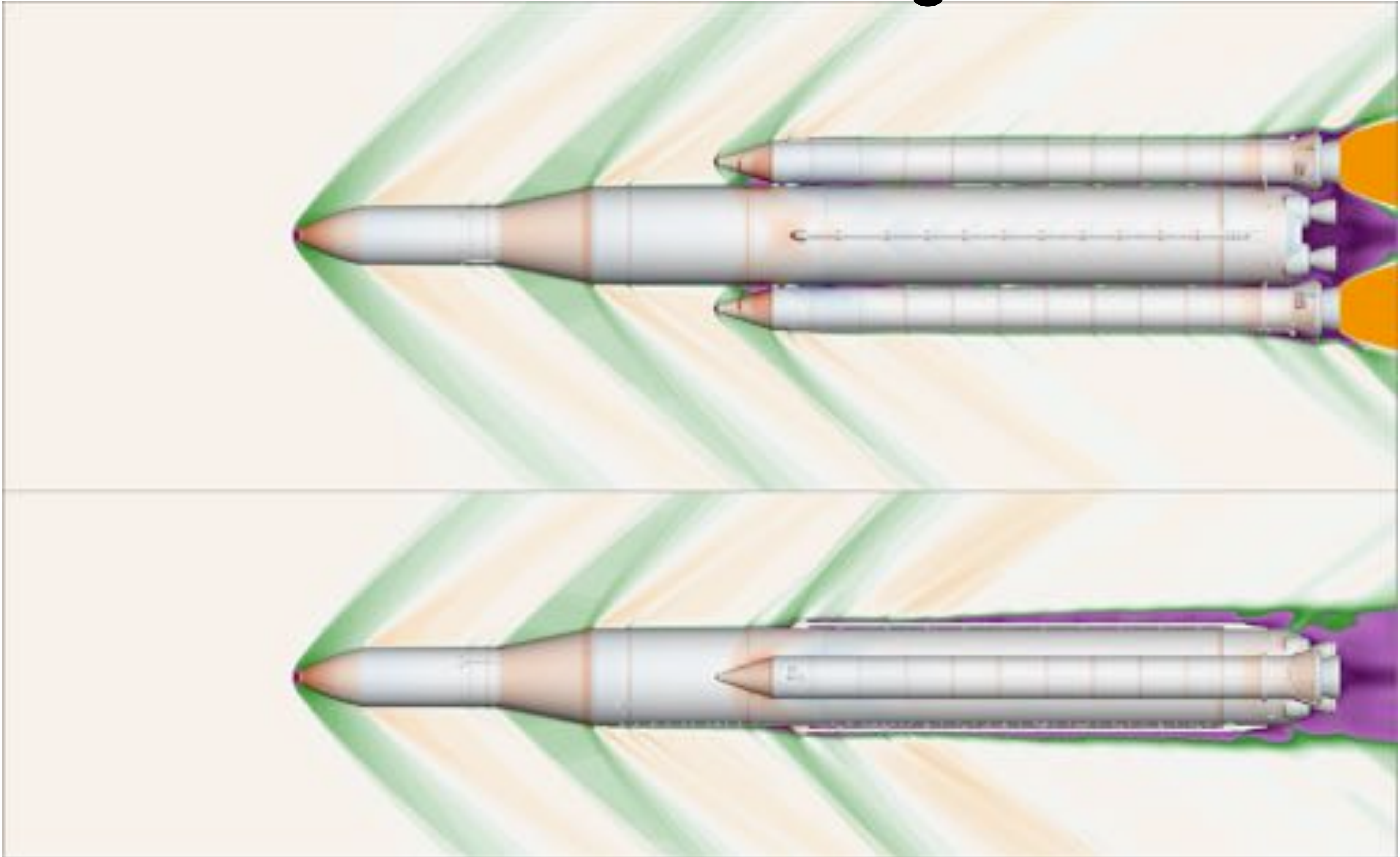
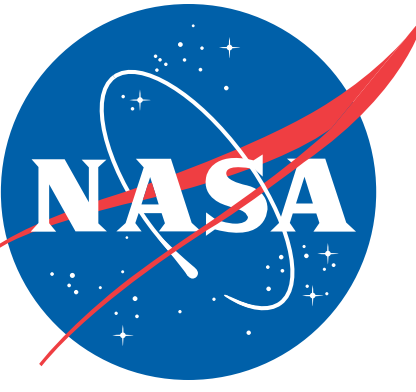




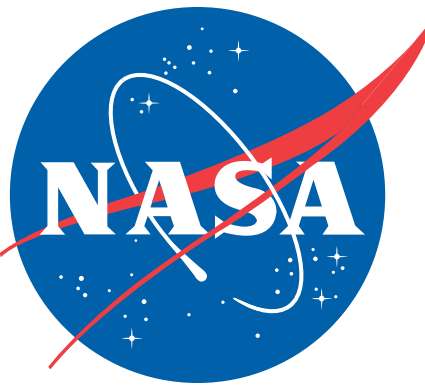
# SLS Ascent Database: Block 1 Crew



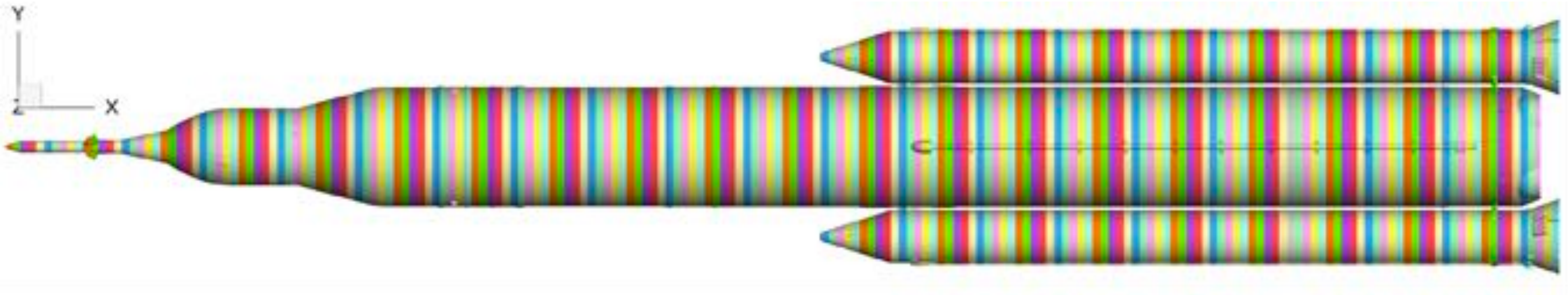
# SLS Ascent Database: Block 1 Cargo



# SLS Ascent Sectional Loads/Line Loads



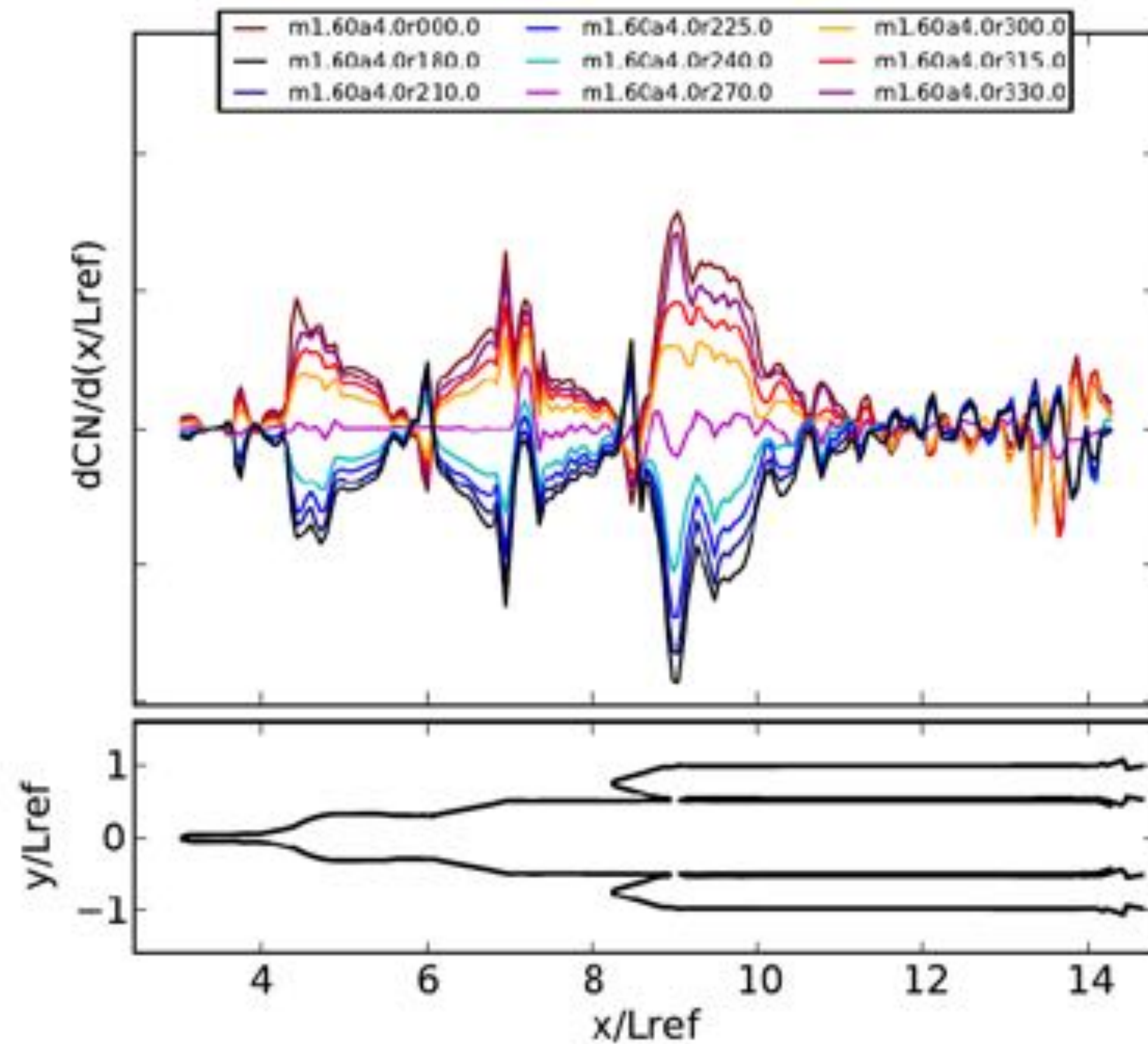
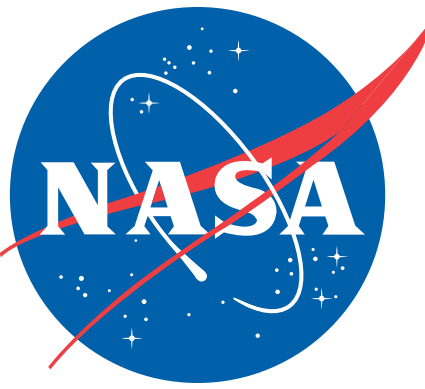
- Divide vehicle into slices



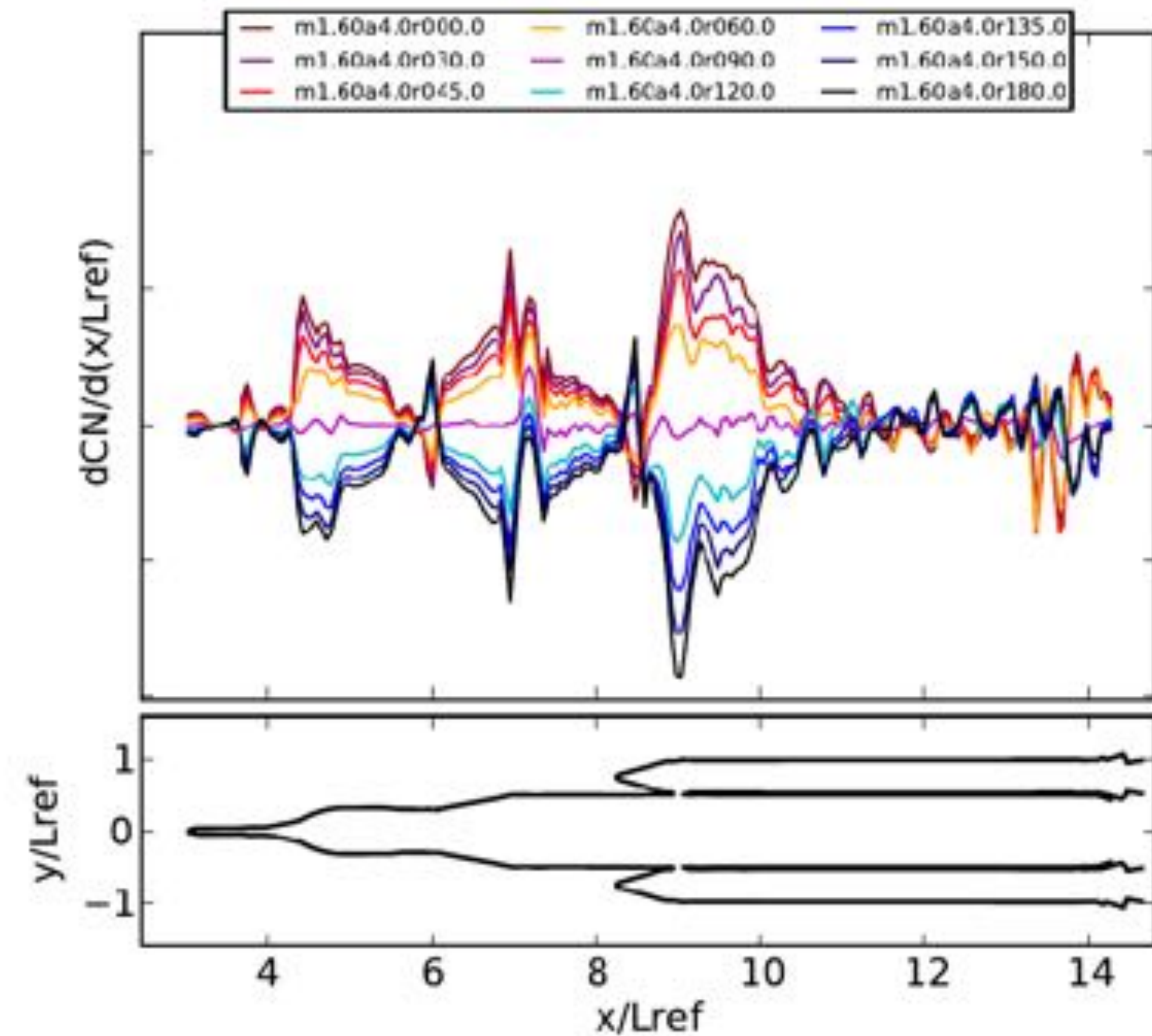
Block 1B Crew Configuration divided into 200 slices

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

# SLS Ascent Sectional Loads/Line Loads



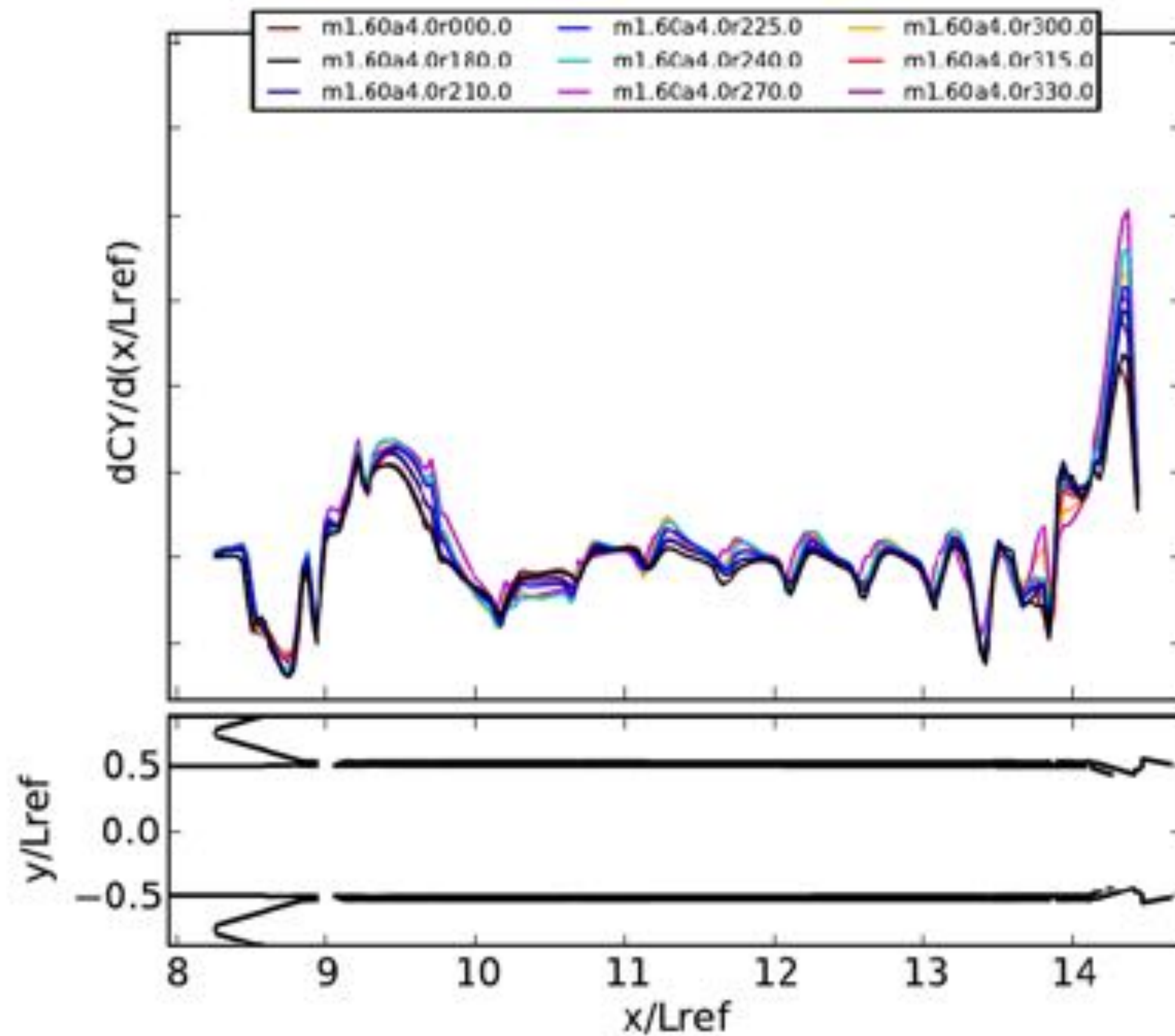
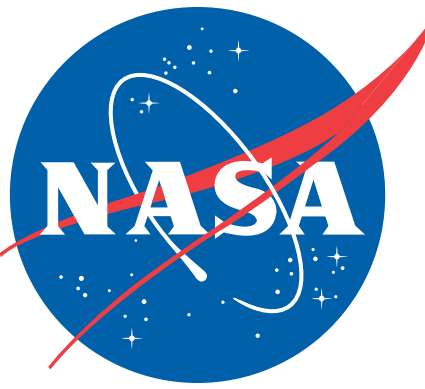
CORE/CN, - Sideslip



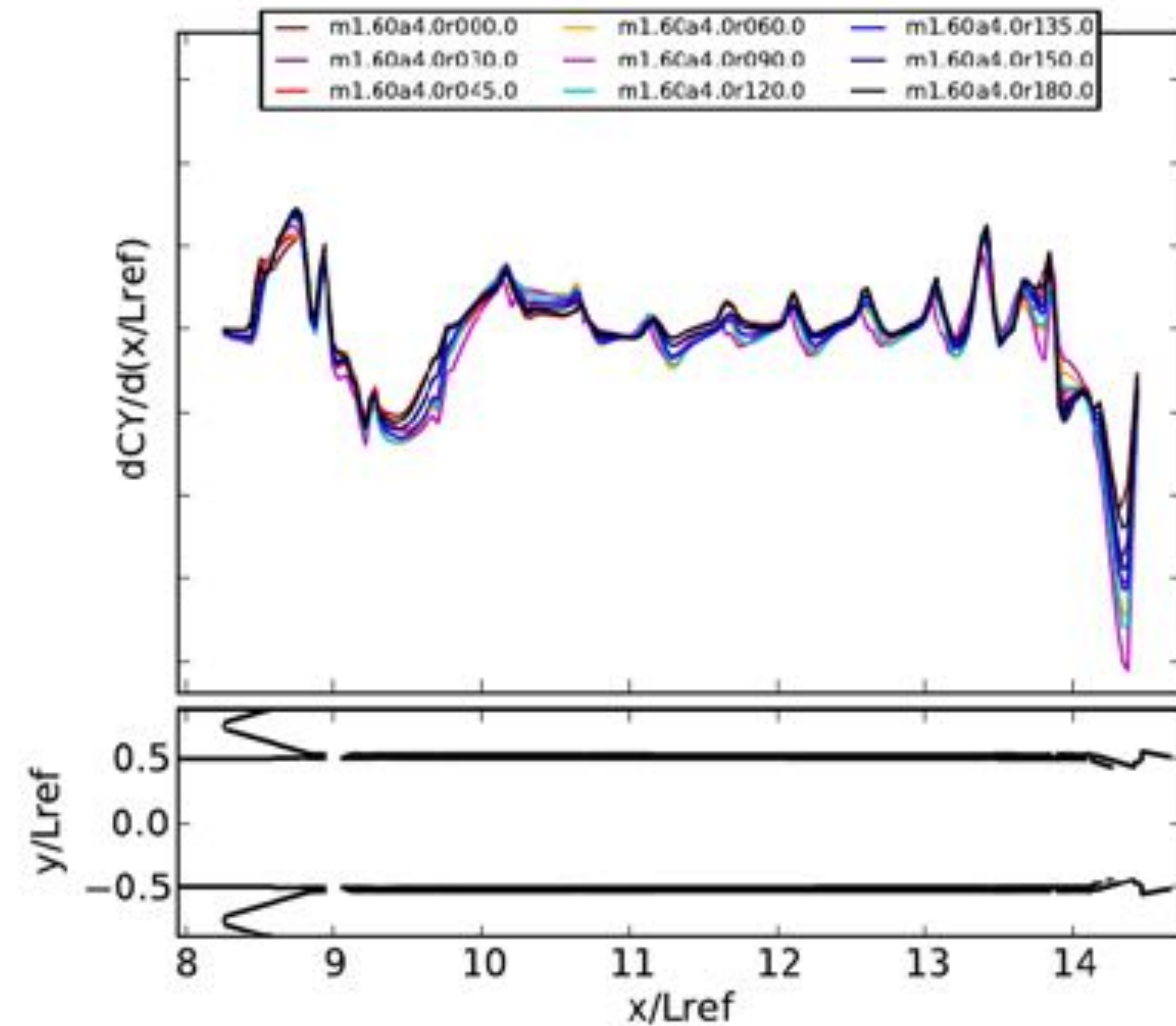
CORE/CN, + Sideslip

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

# SLS Ascent Sectional Loads/Line Loads



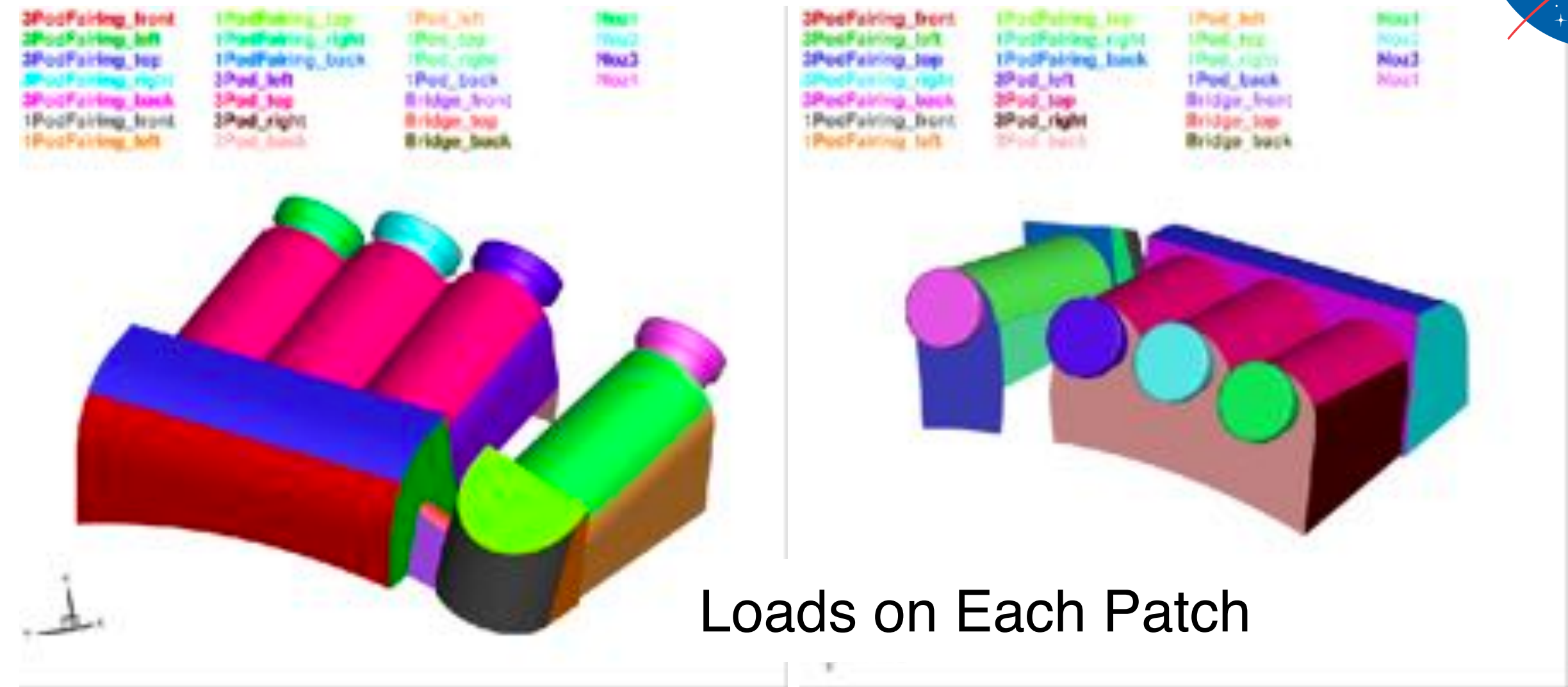
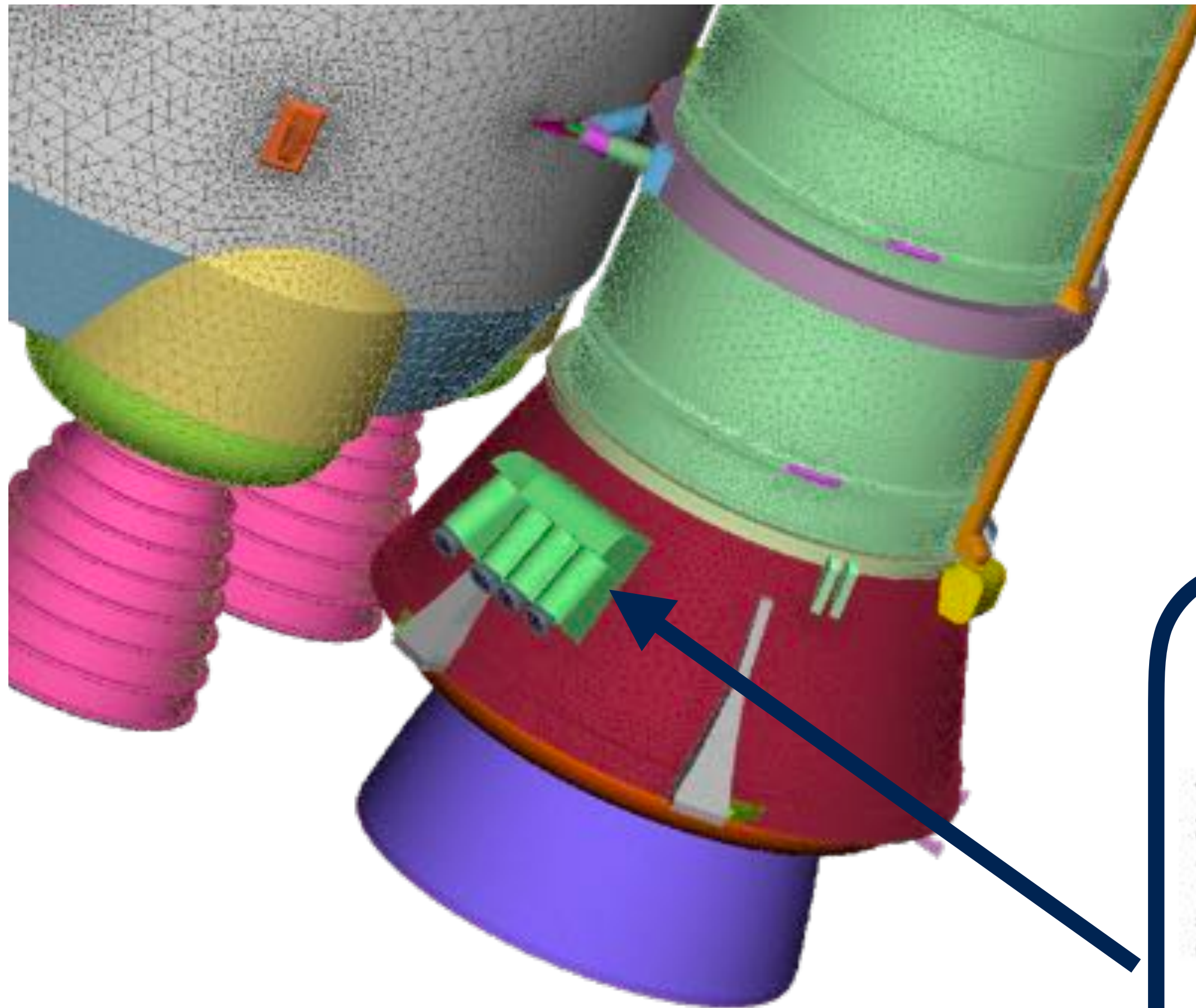
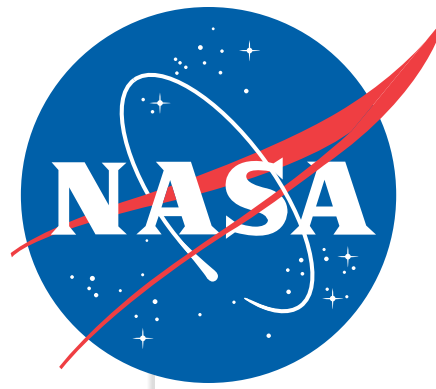
LSRB/CY, - Sideslip



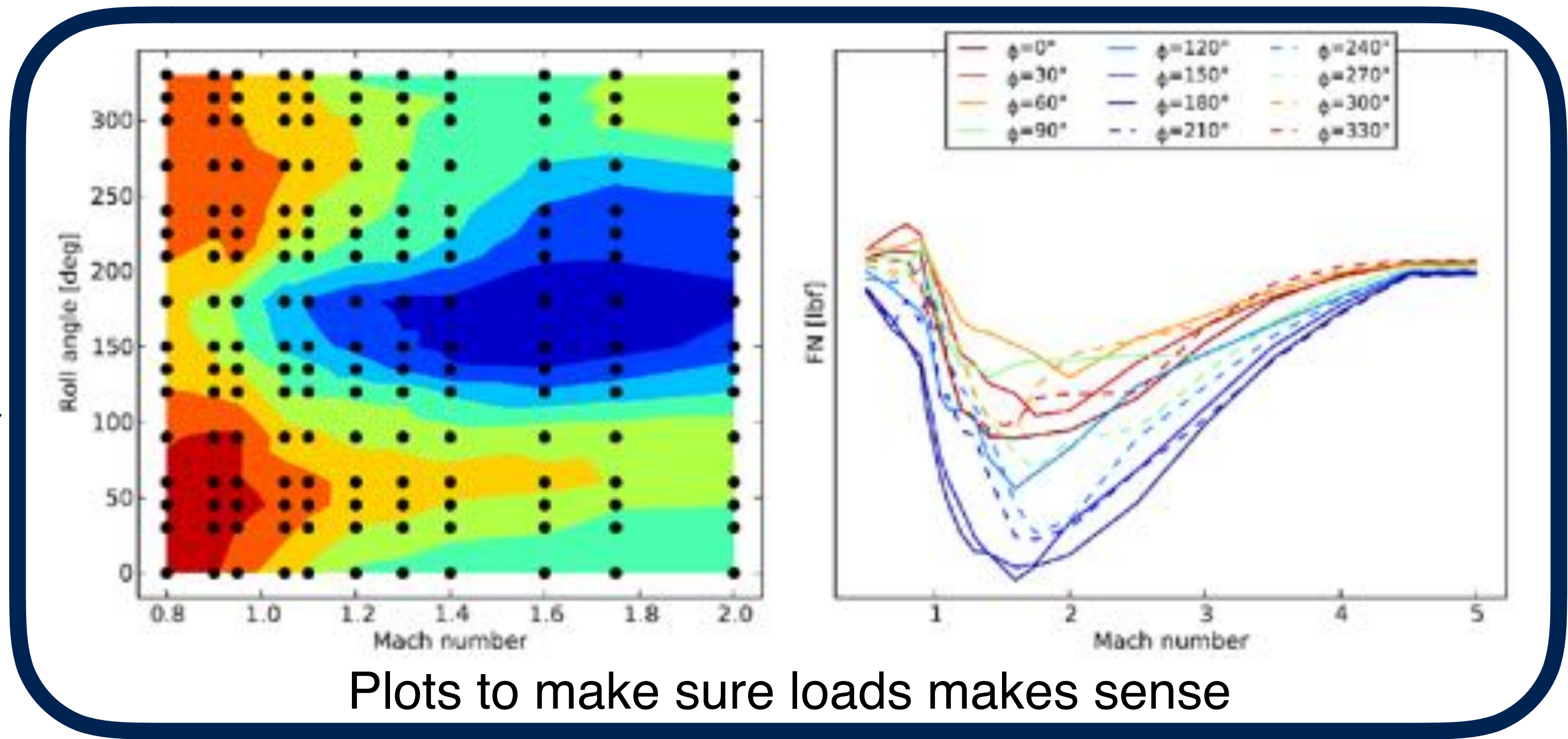
RSRB/CY, + Sideslip

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

# SLS Ascent Protuberance Air Loads

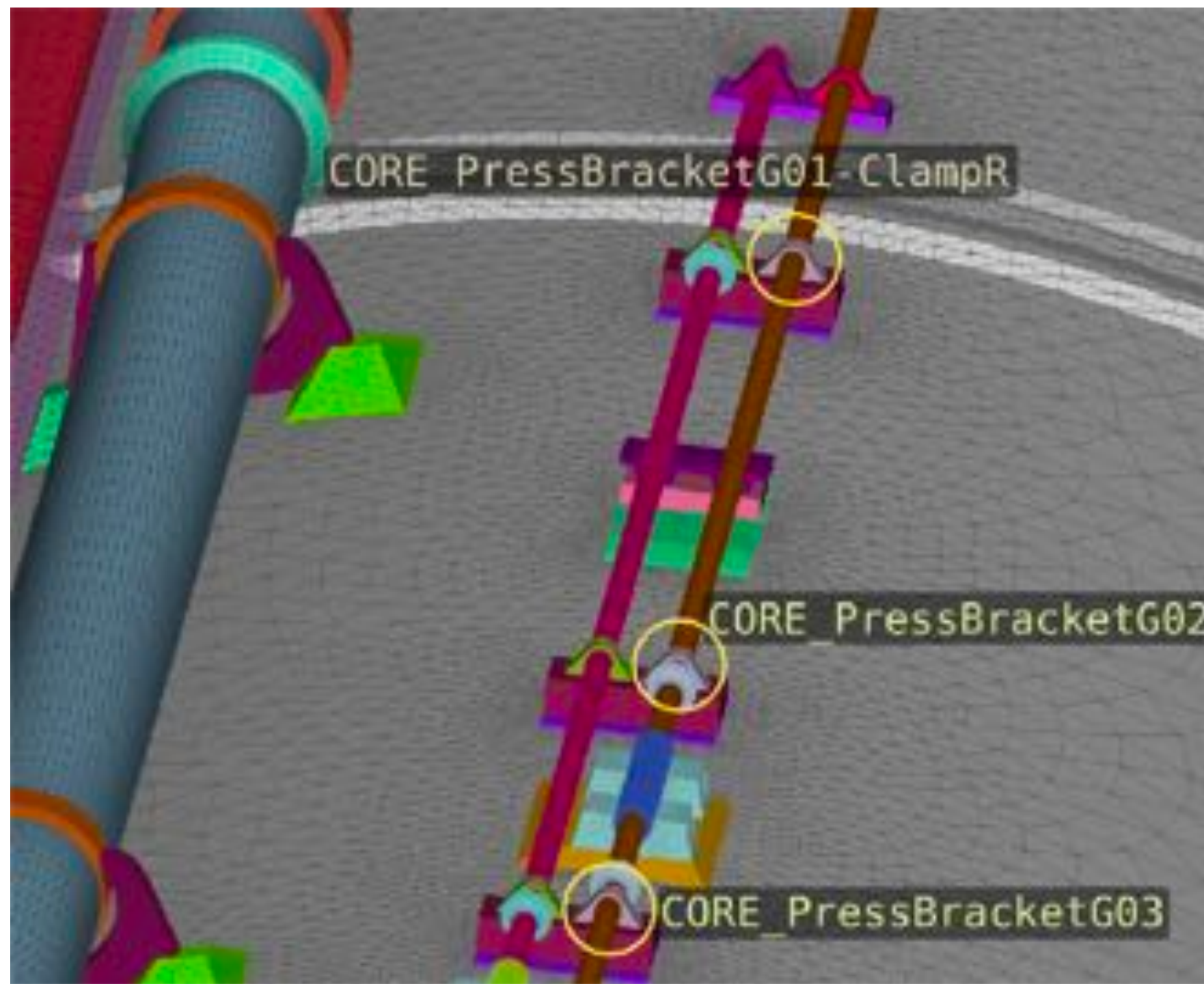
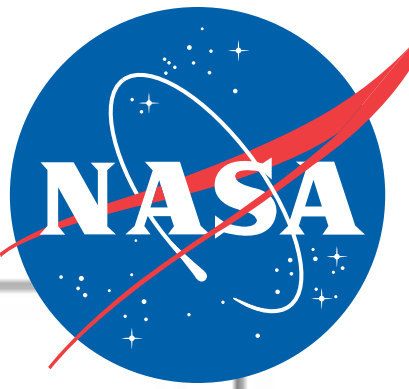


Loads on Each Patch

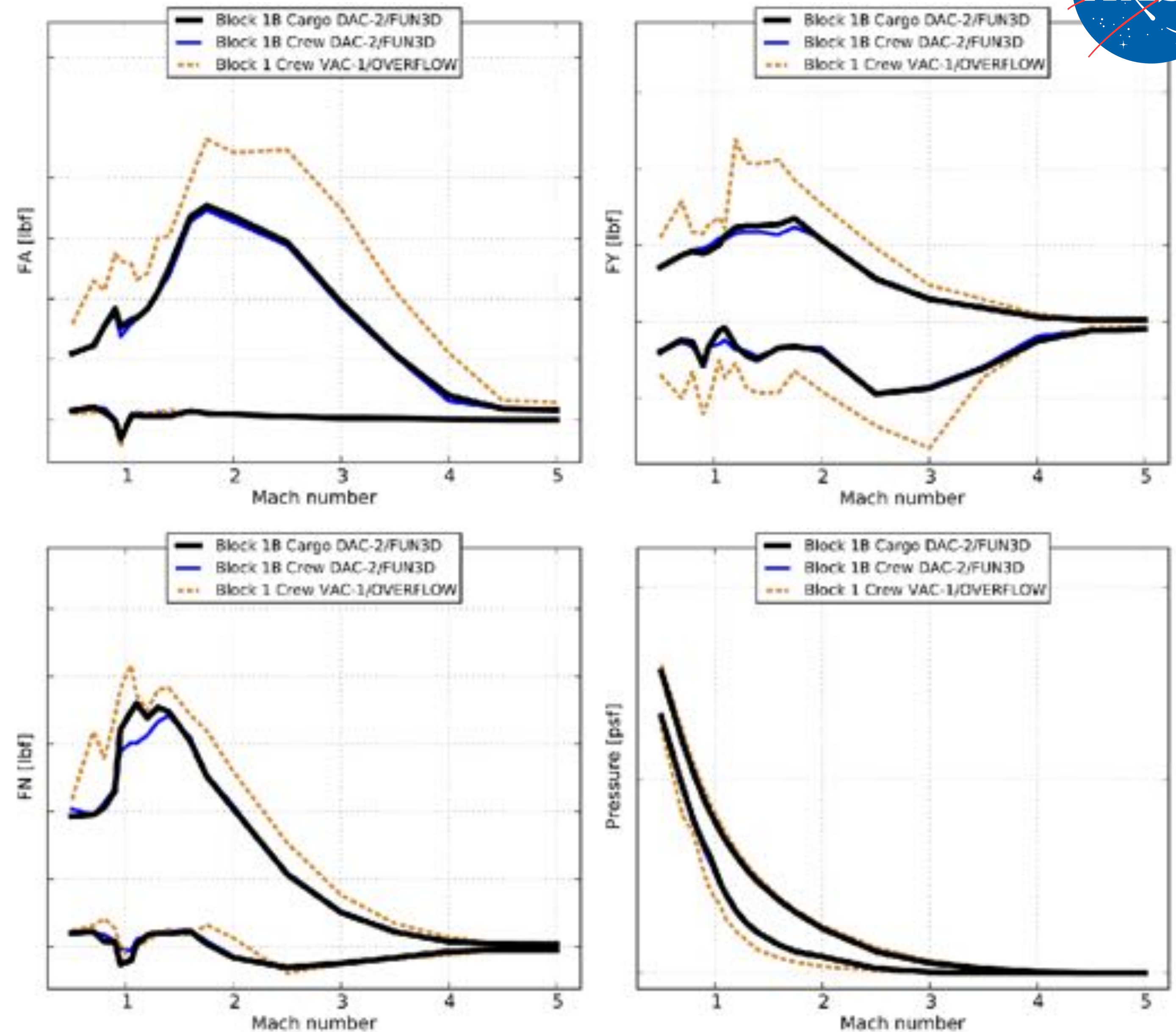


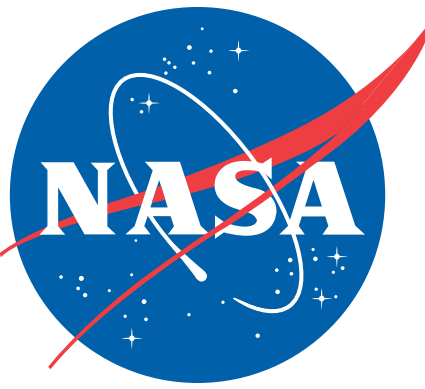
Plots to make sure loads makes sense

# SLS Ascent Pressurization Line Bracket Plots



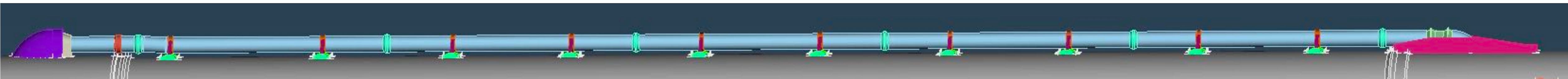
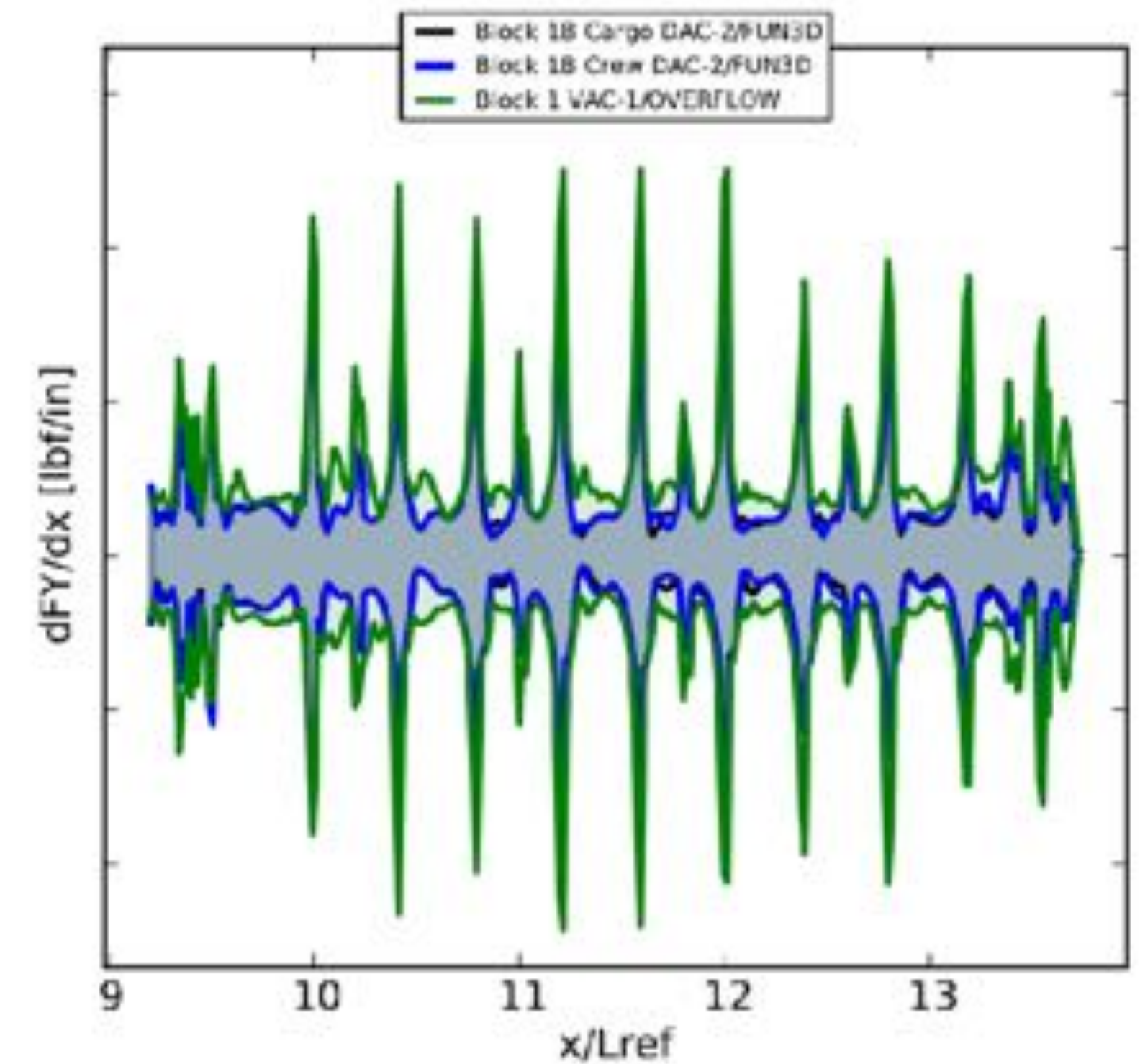
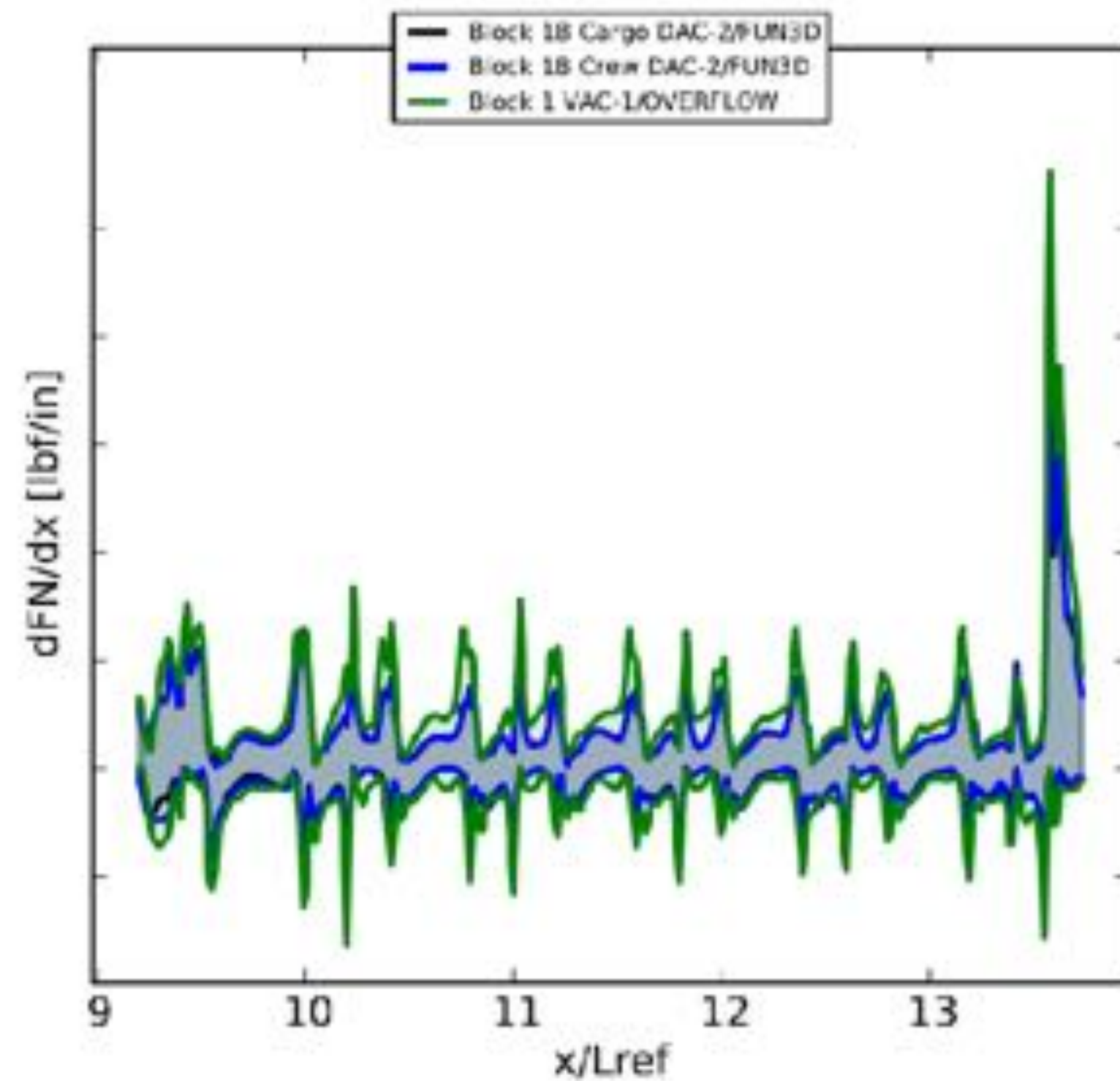
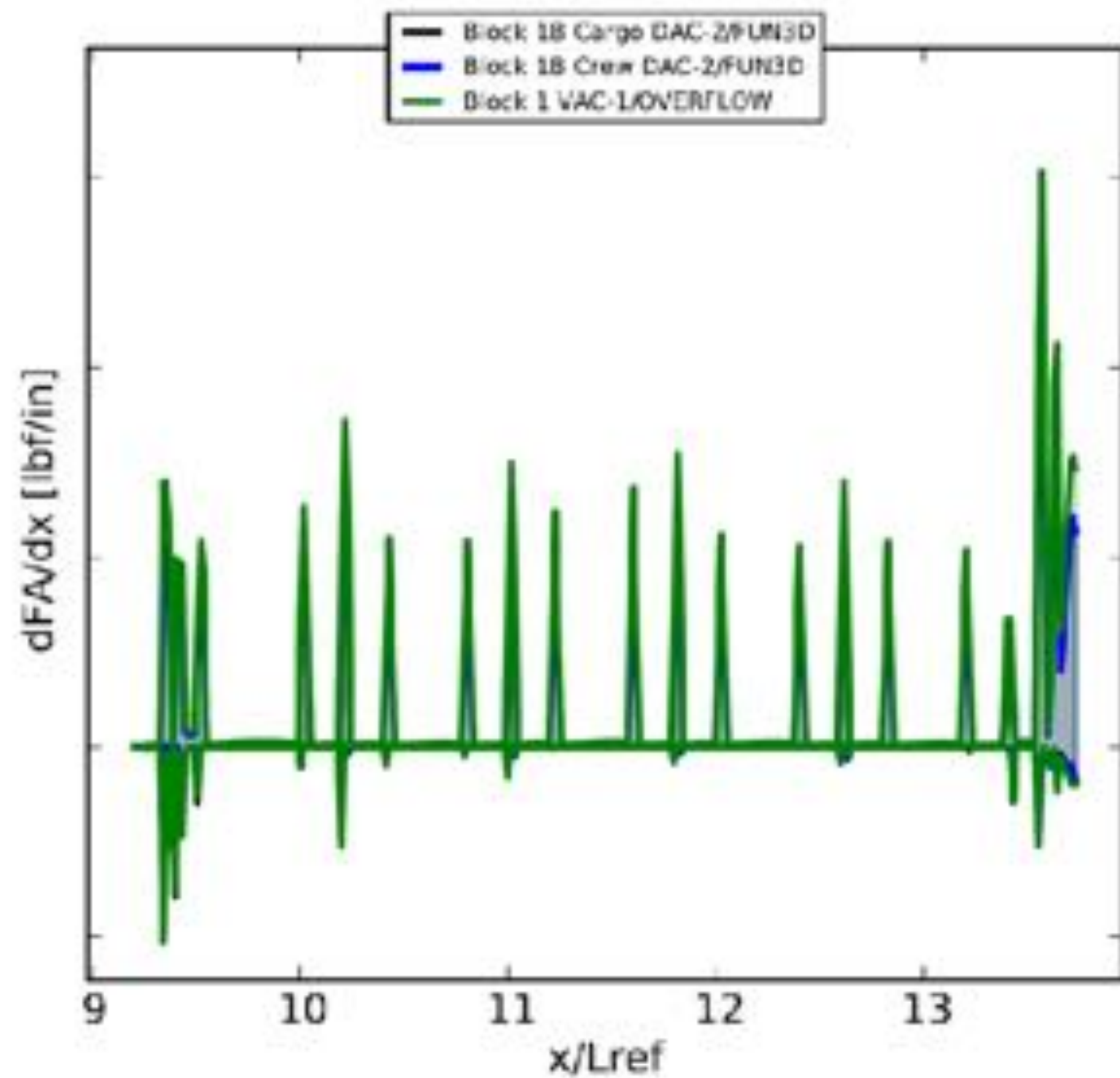
- Quantify differences in loads between each vehicle
- Check for anomalies





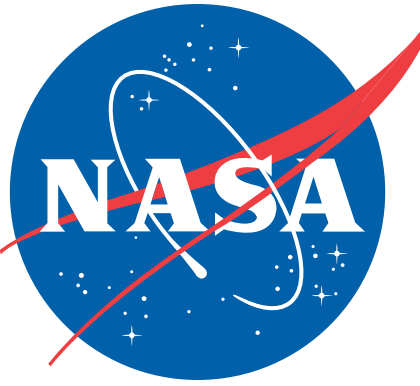
# SLS Ascent Protuberance Line Loads

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

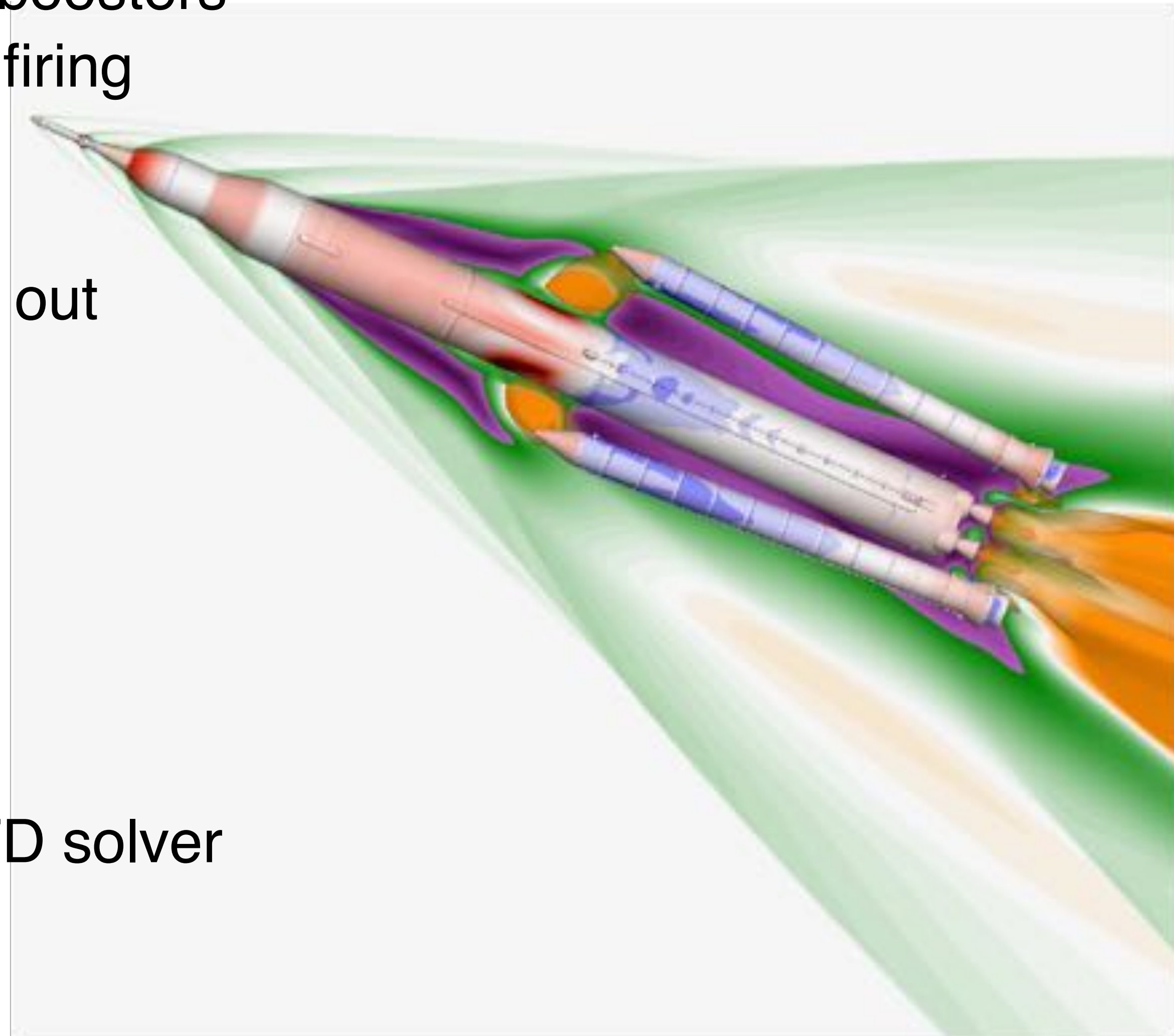




# SLS CFD Booster Separation Database

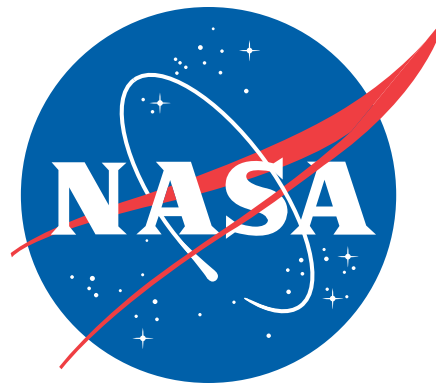


- Provide forces and moments on core and both boosters
- Complicated fluid dynamics: 14 engine plumes firing
- Large data
  - Many independent parameters
  - Off-nominal conditions: core engine out, BSM out
  - Flight geometry & Wind-tunnel geometry
  - Static and Dynamic cases
- Computational Fluid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



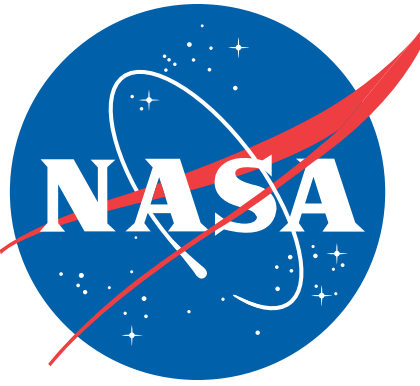
Forward  
BSMs



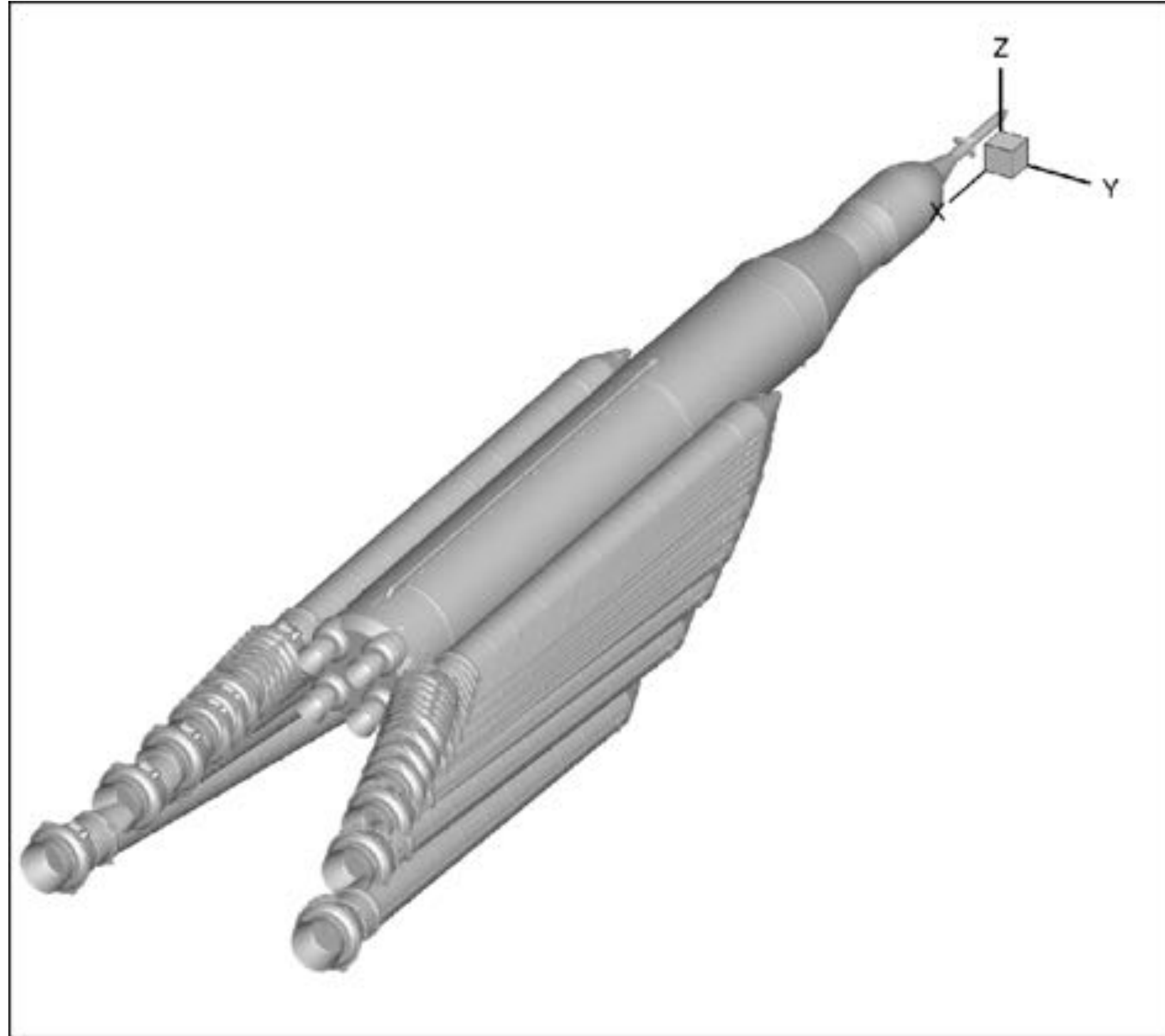
Aft  
BSMs



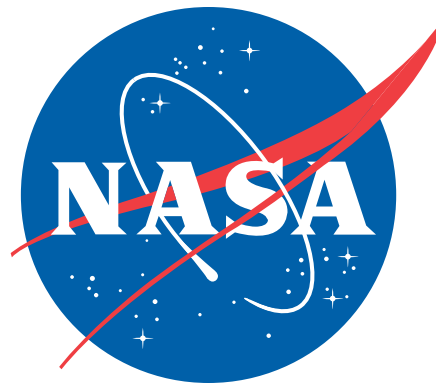
# SLS Booster Separation Aerodynamics Database



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



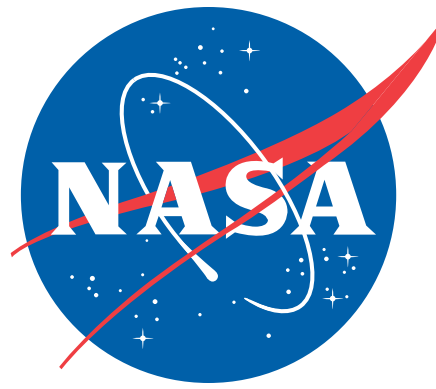
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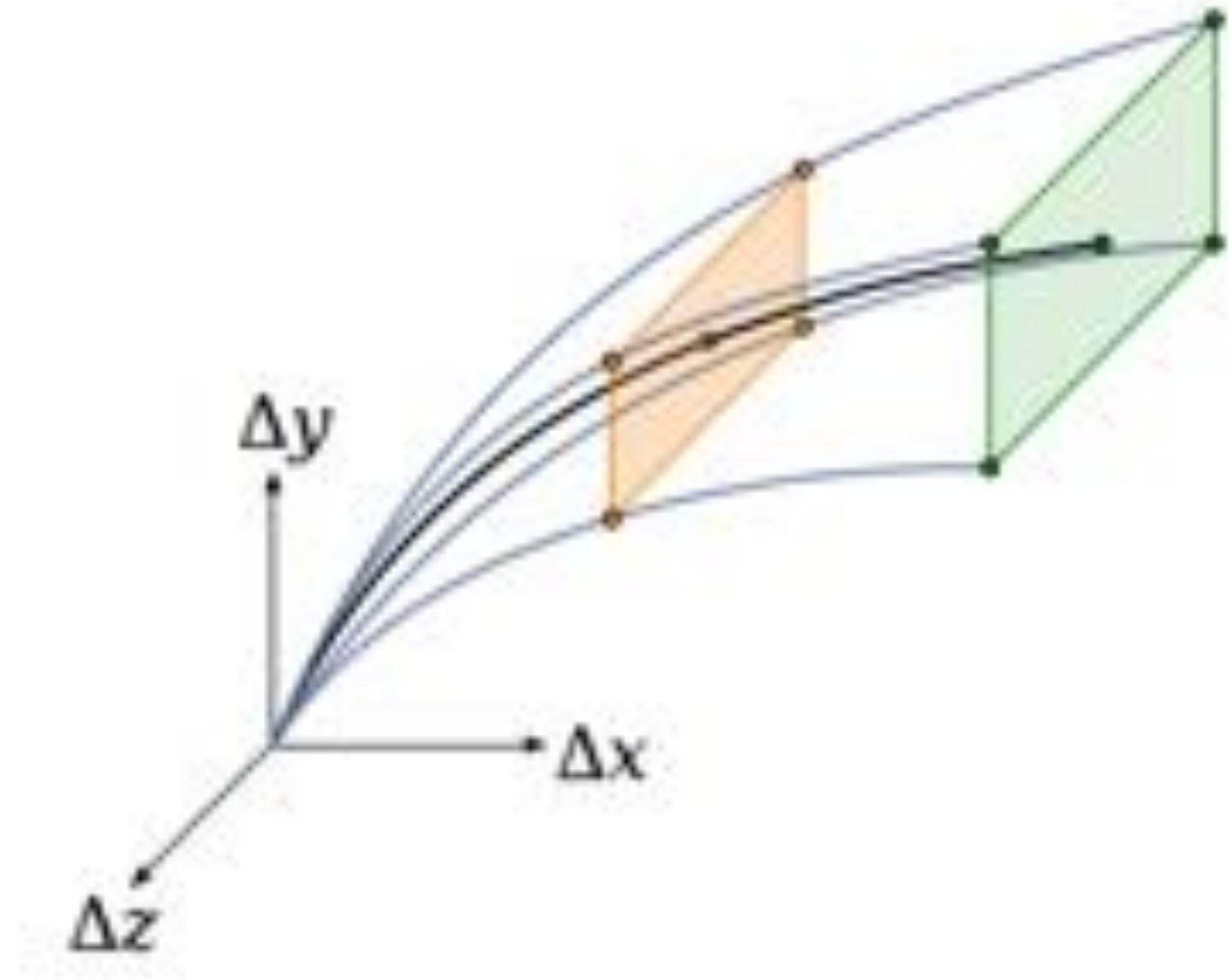
- Eight-Dimensional run matrix
  - Translational variables - 3
  - Rotational variables - 2
  - Thrust of booster separation motors - 1
  - Freestream conditions - 2
- 7-dimensional rectangular run matrix for each dx value



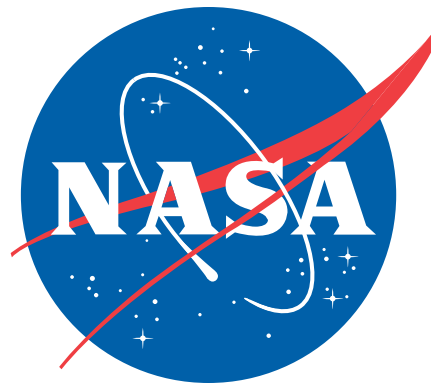
# SLS Booster Separation Aerodynamics Database



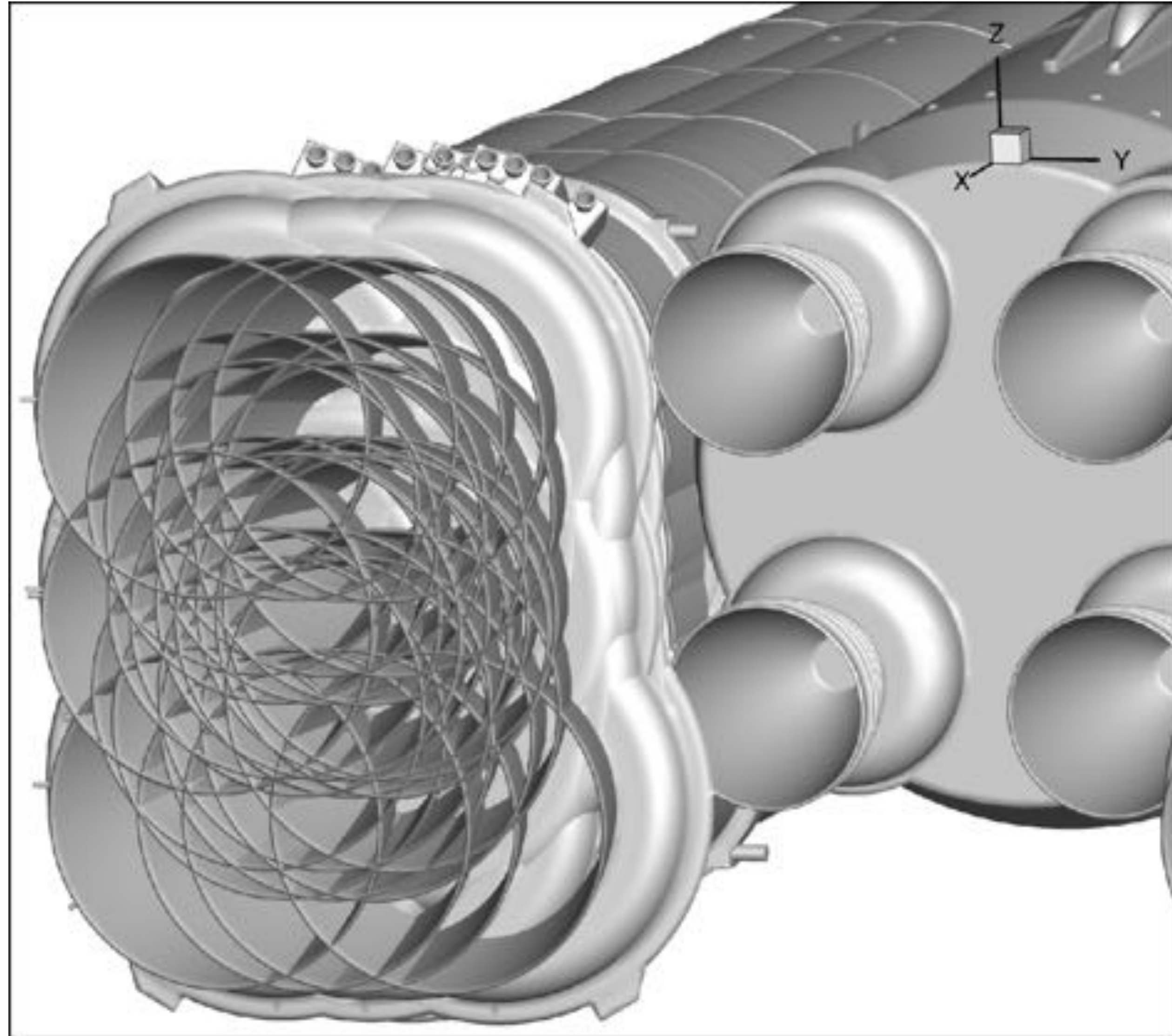
- Eight-Dimensional run matrix
  - Translational variables - 3
  - Rotational variables - 2
  - Thrust of booster separation motors - 1
  - Freestream conditions - 2
- 7-dimensional rectangular run matrix for each dx value
- Pyramid-shaped run matrix



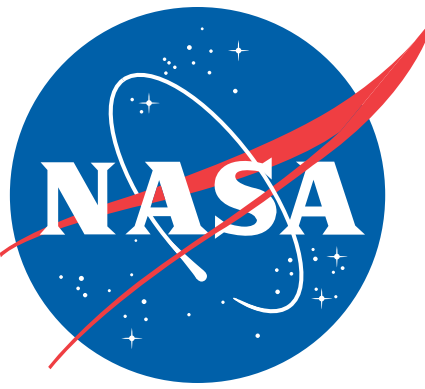
# SLS Booster Separation Aerodynamics Database



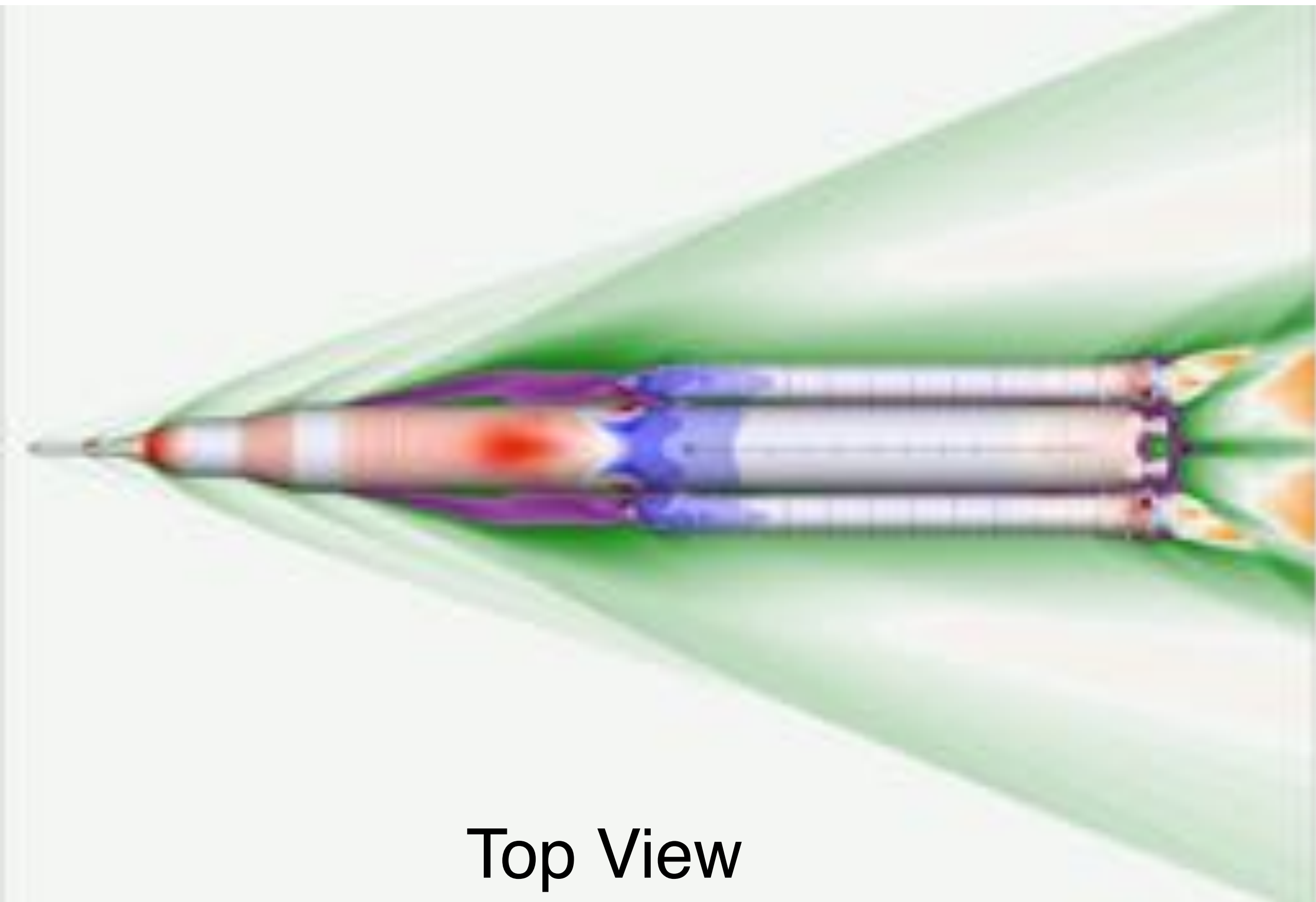
- Eight-Dimensional run matrix
  - Translational variables - 3
  - Rotational variables - 2
  - Thrust of booster separation motors - 1
  - Freestream conditions - 2
- 7-dimensional rectangular run matrix for each dx value
- Pyramid-shaped run matrix
- 22,000+ runs required



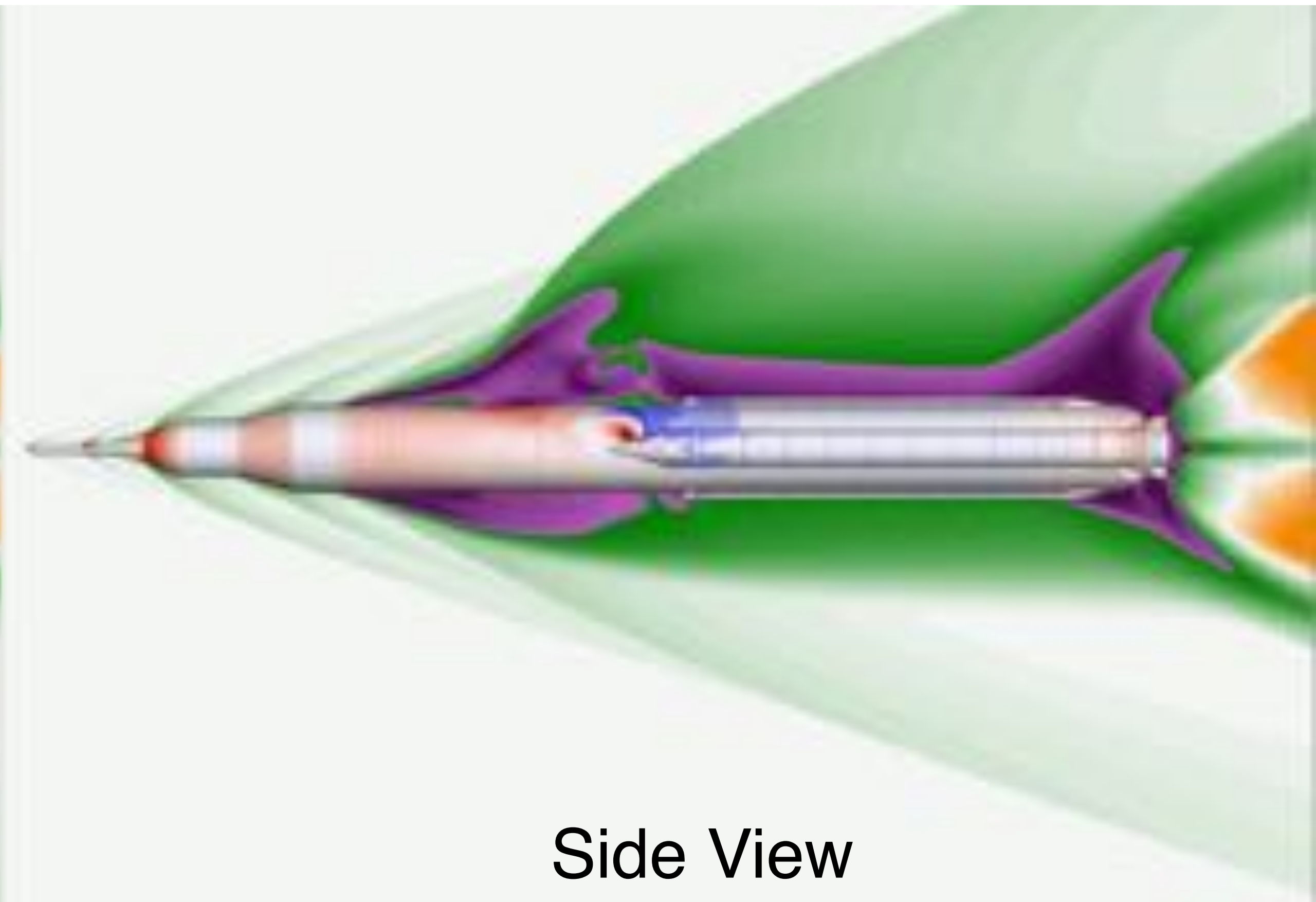
# SLS Block 1B Crew Booster Separation



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



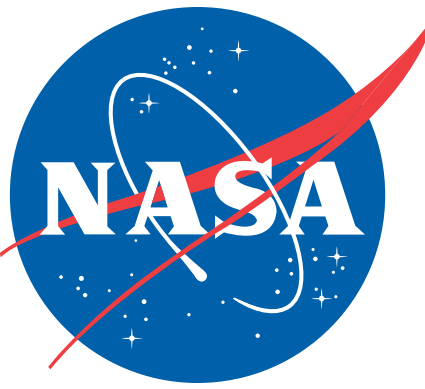
Top View



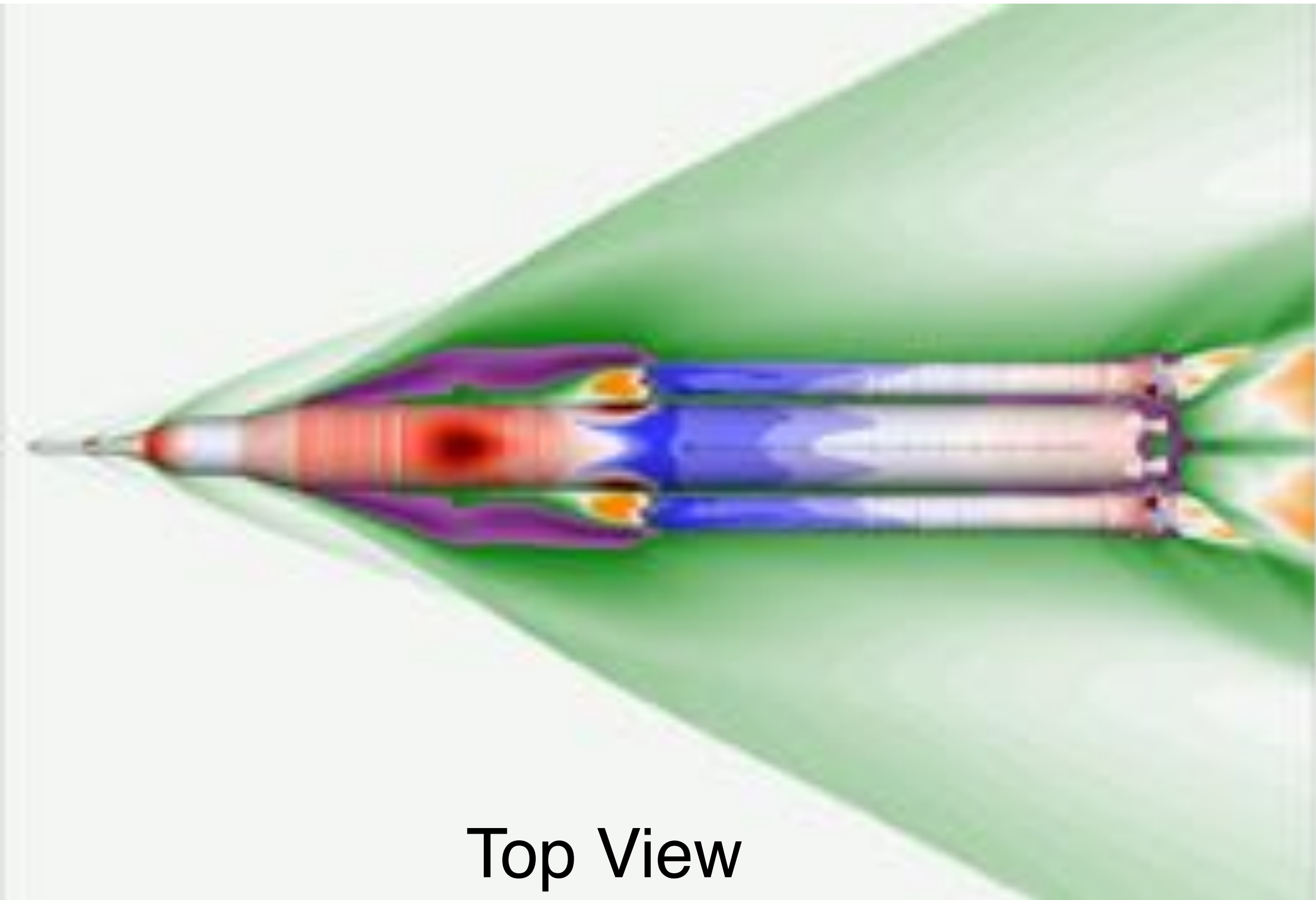
Side View

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

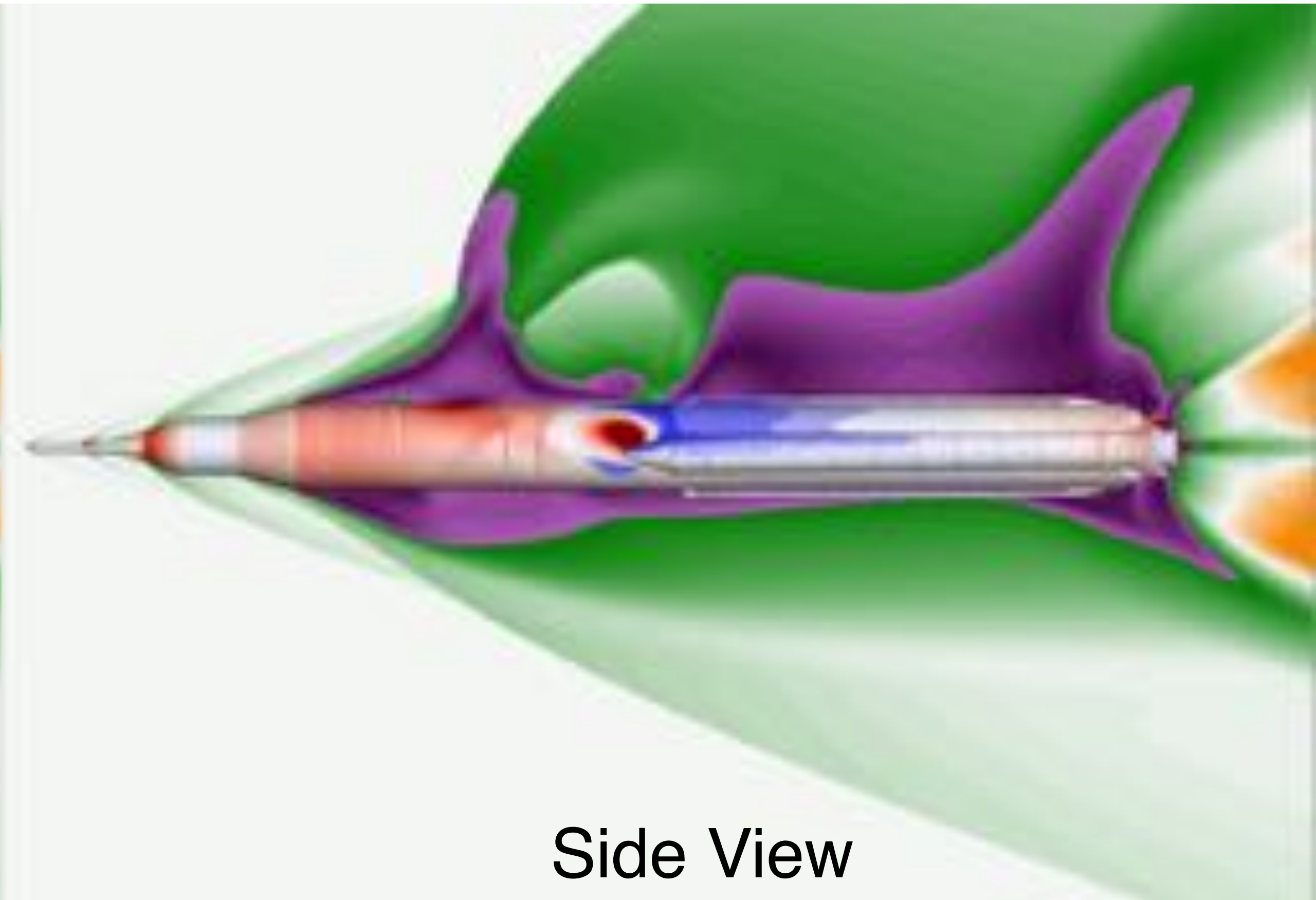
# SLS Block 1B Crew Booster Separation



Booster Proximity: Attached . . . . . Separated



Top View

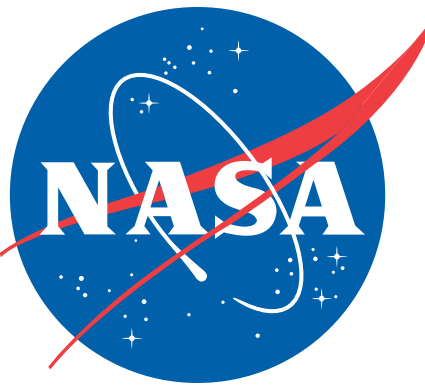


Side View

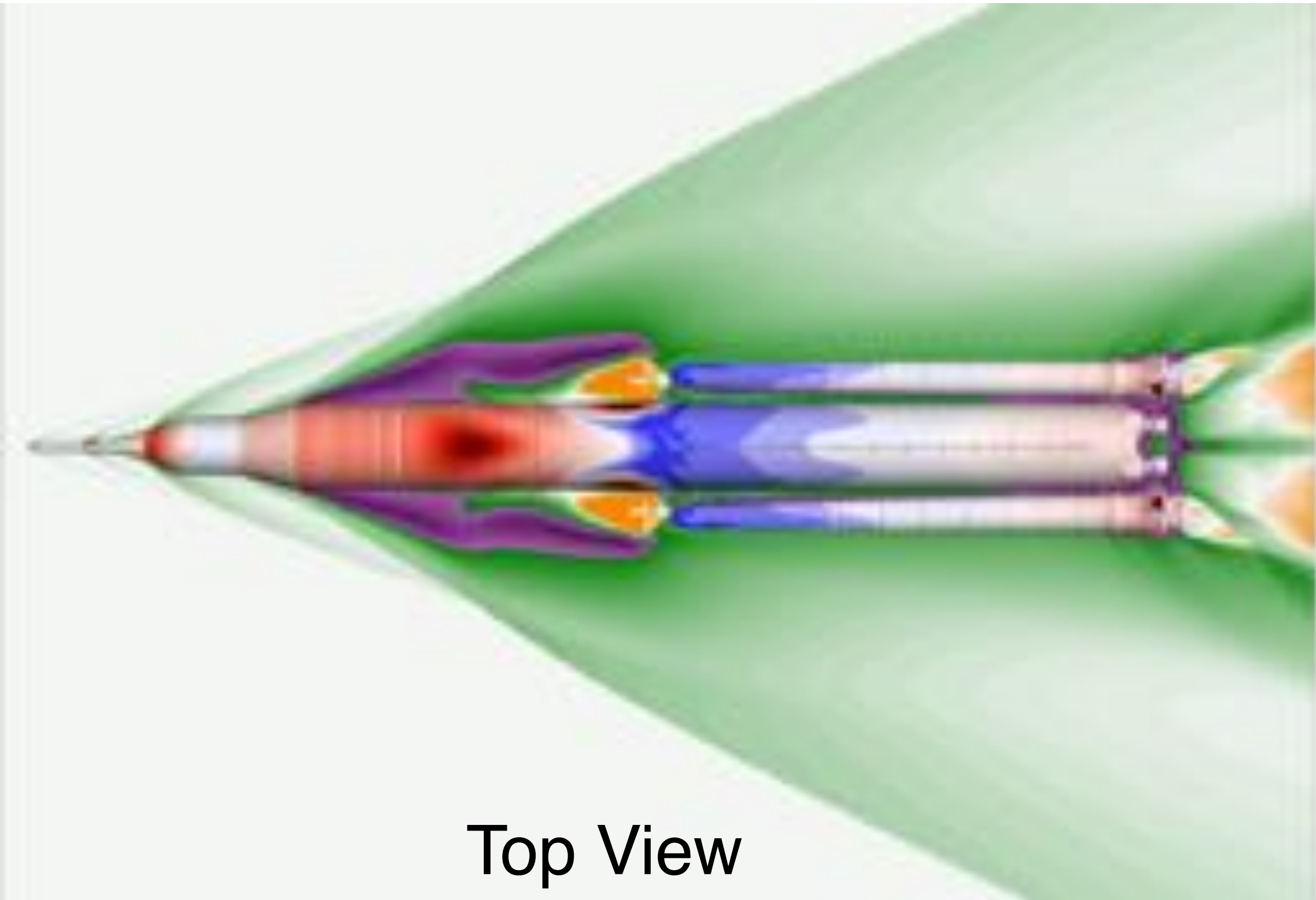
Background slice purple-green-white-orange color contours represent low to high velocities  
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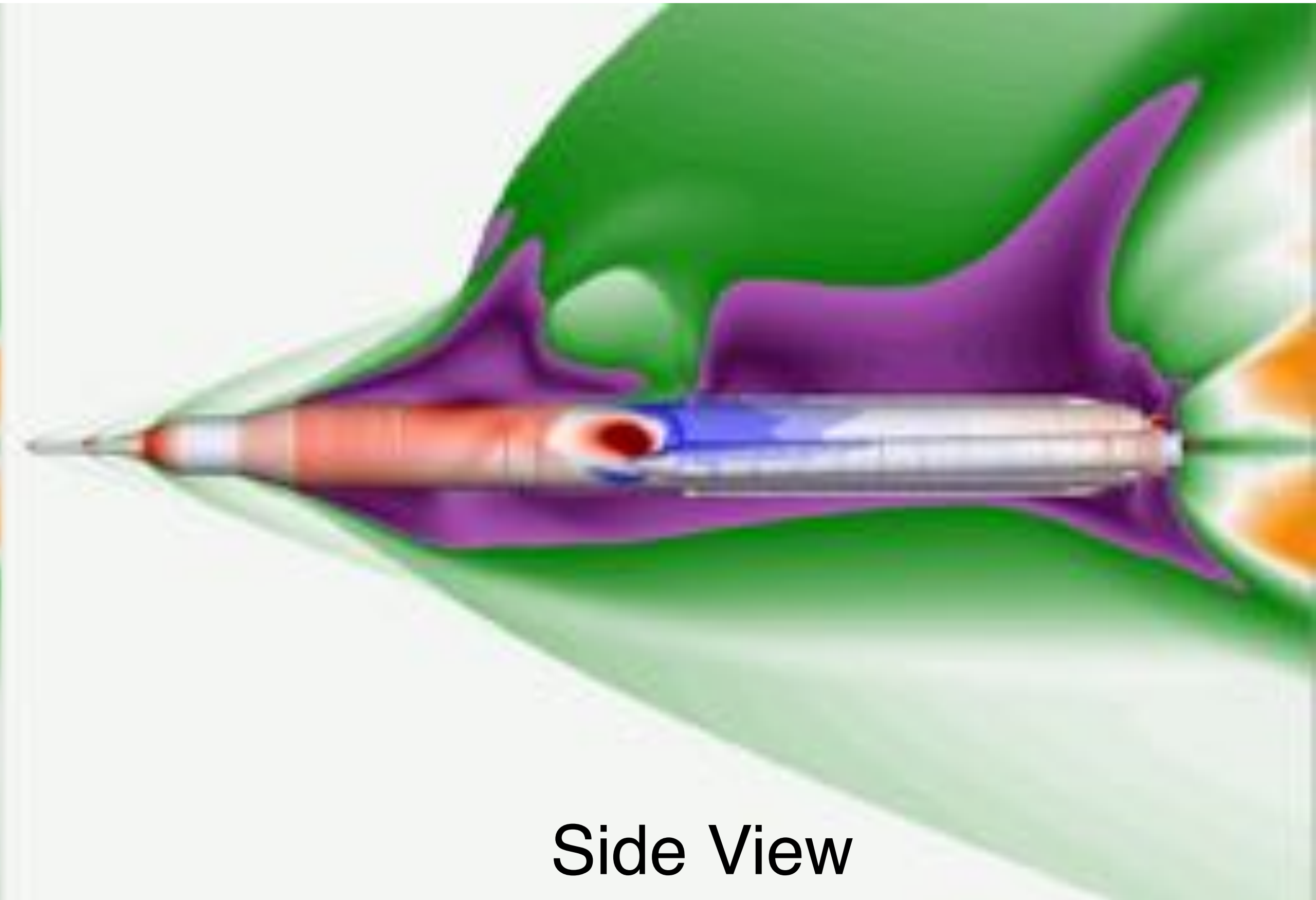
# SLS Block 1B Crew Booster Separation



Booster Proximity: Attached . . . . . Separated



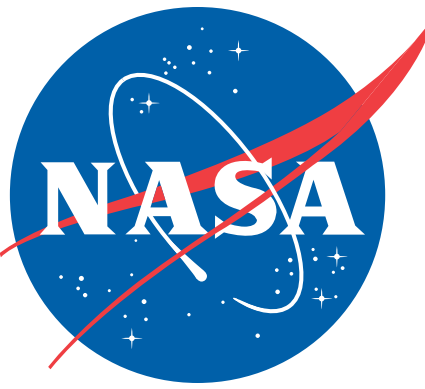
Top View



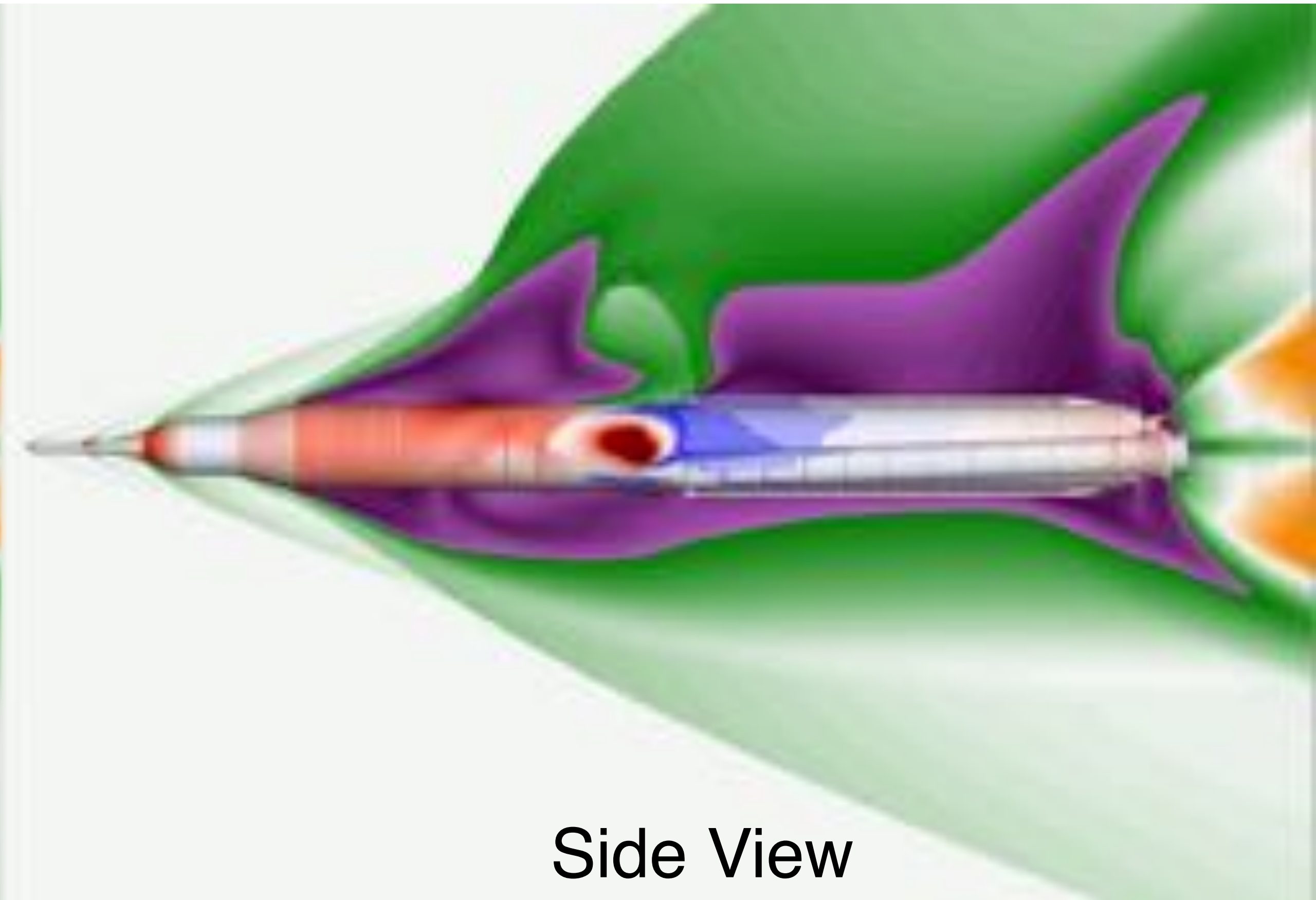
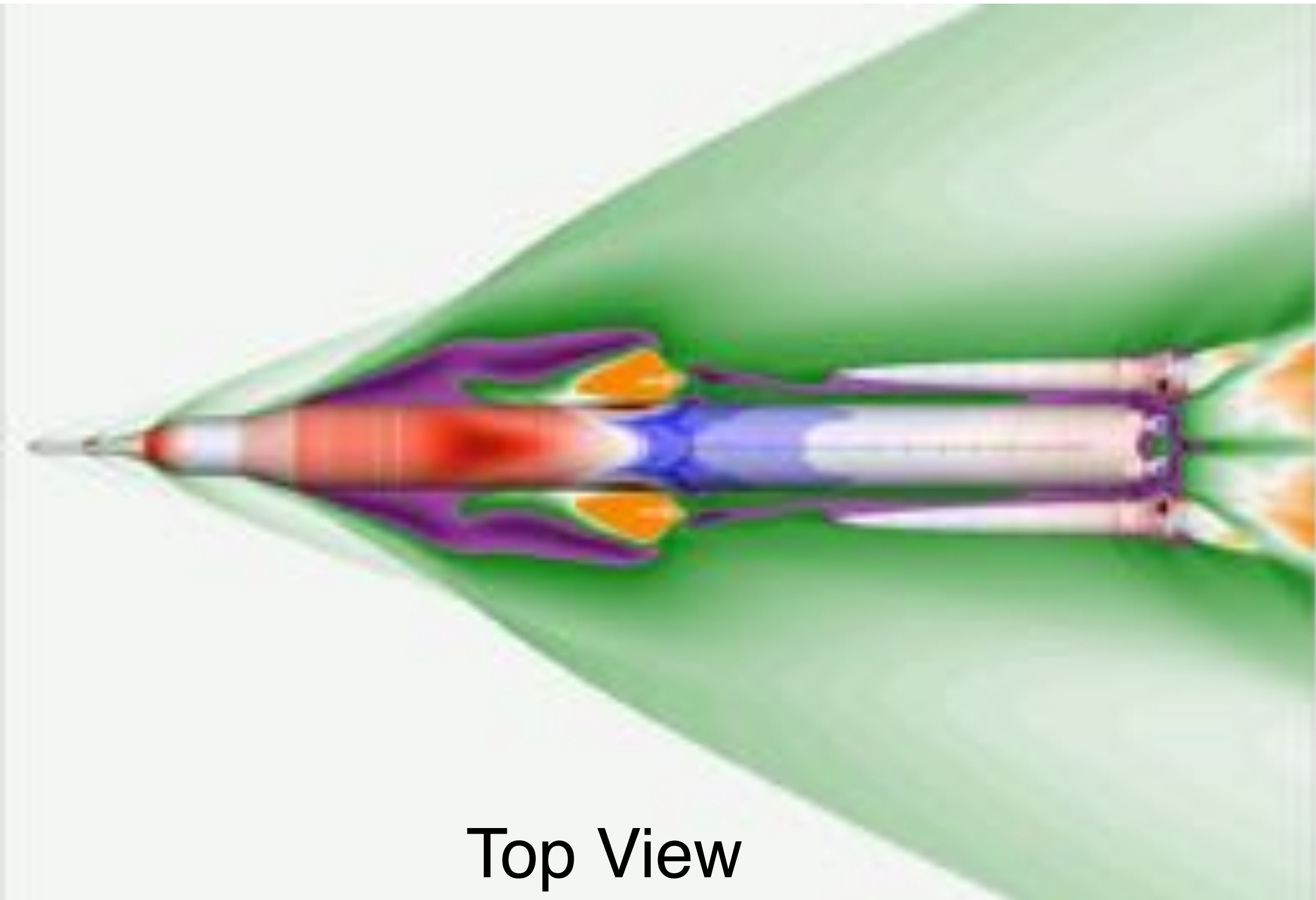
Side View

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# SLS Block 1B Crew Booster Separation

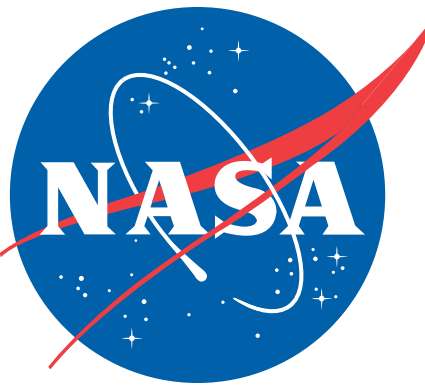


Booster Proximity: Attached . . . . . Separated

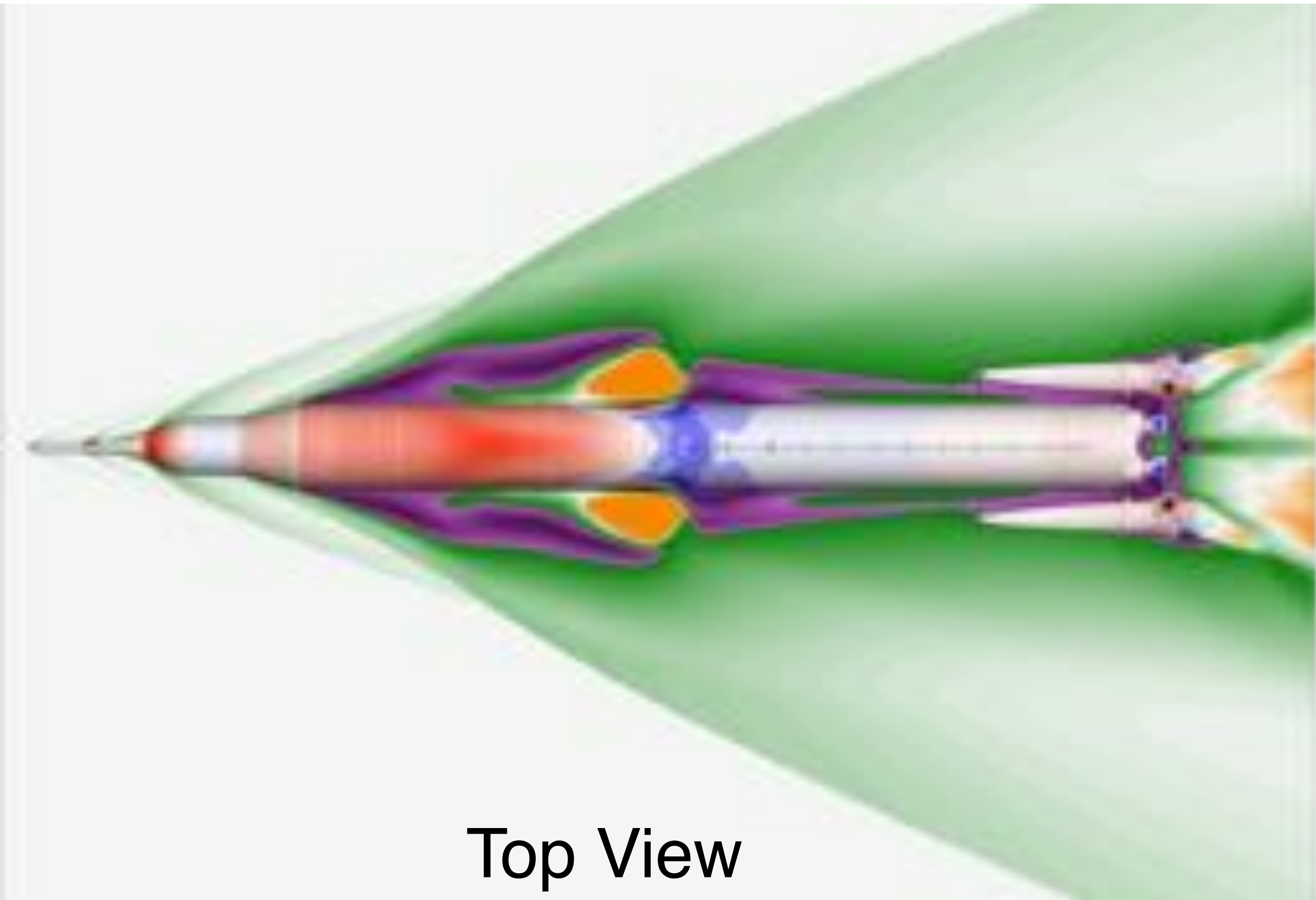


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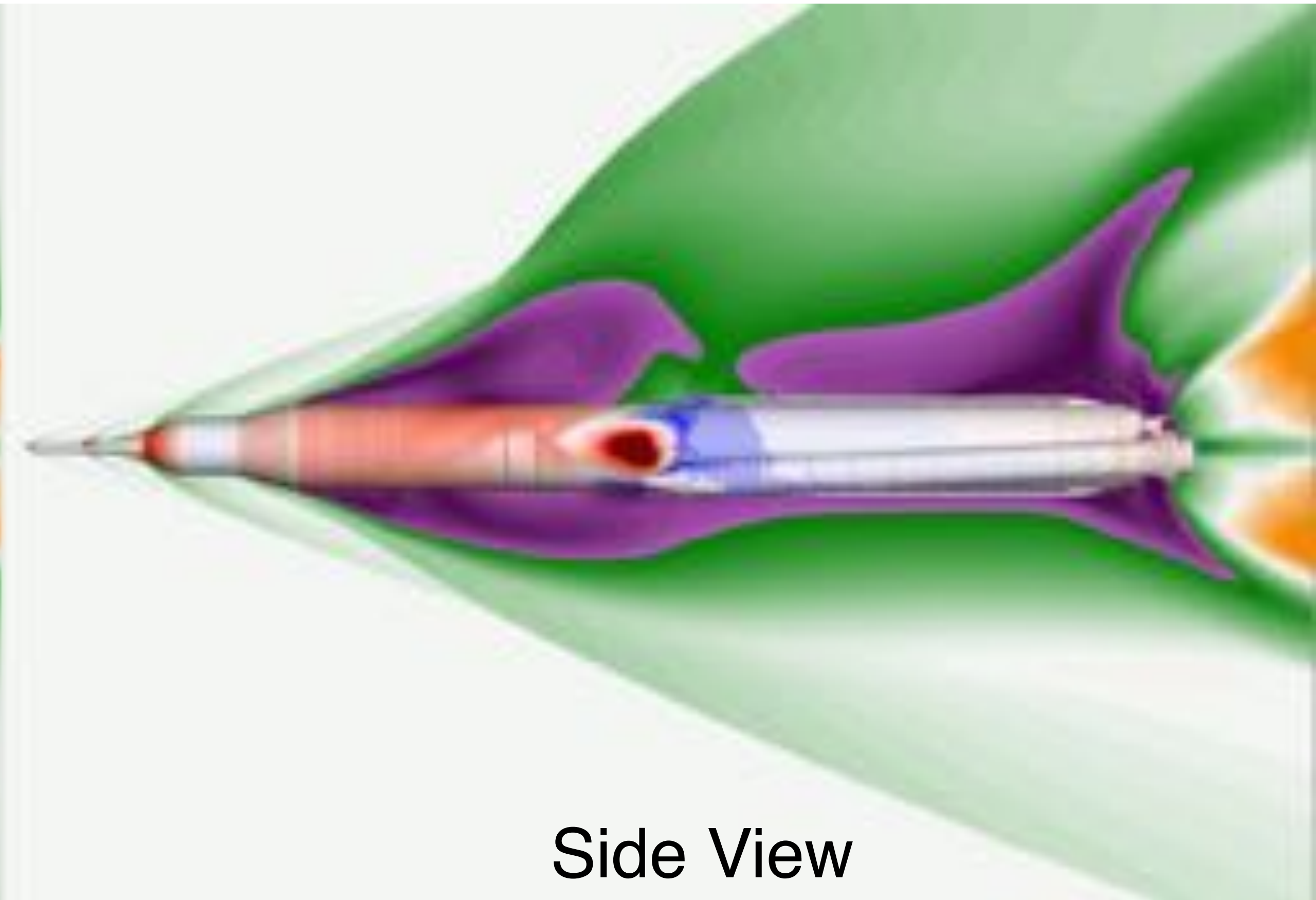
# SLS Block 1B Crew Booster Separation



Booster Proximity: Attached . . . . . Separated



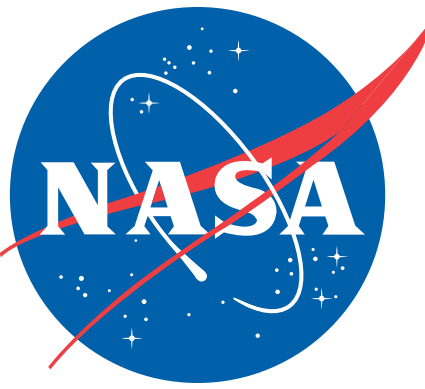
Top View



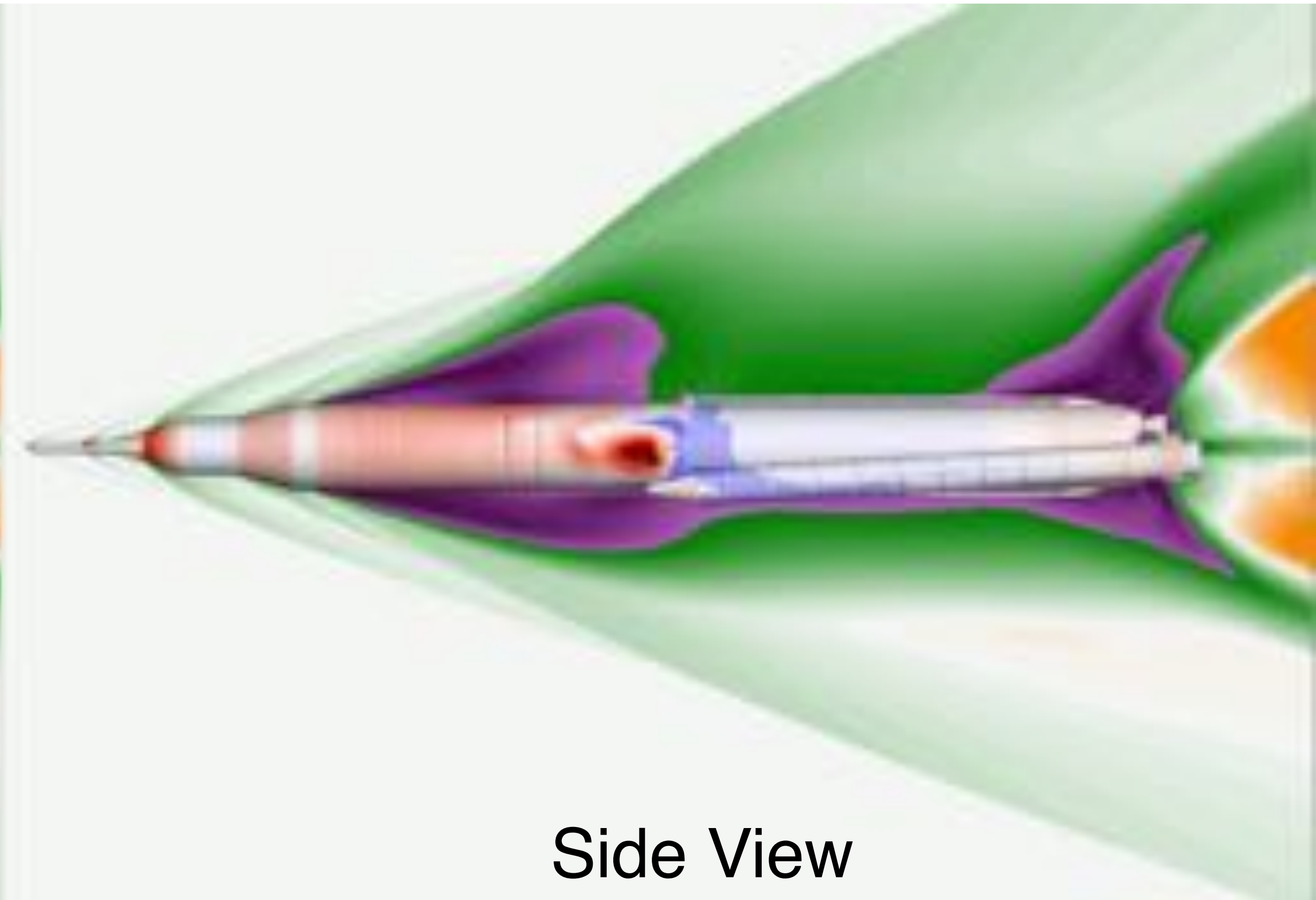
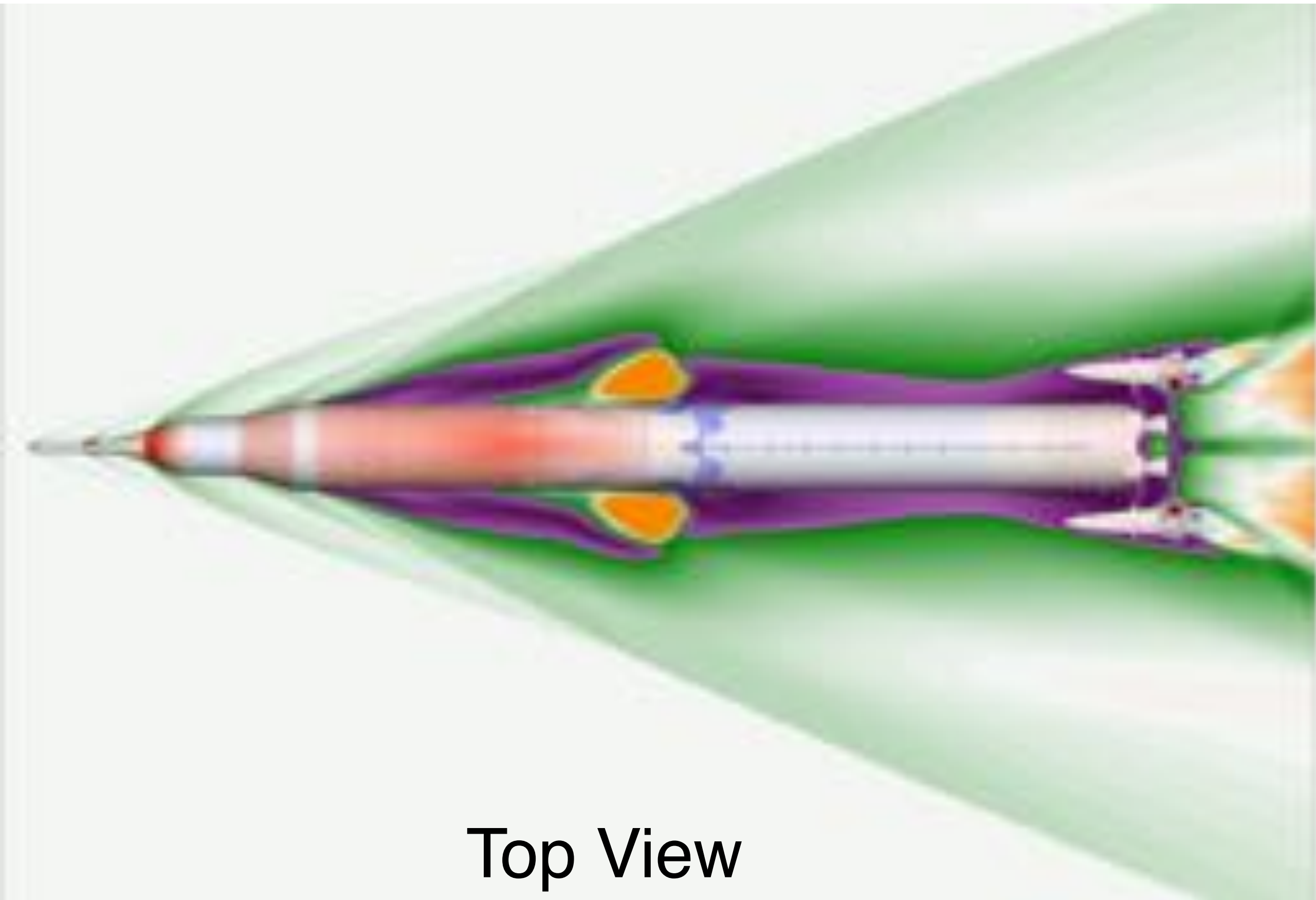
Side View

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# SLS Block 1B Crew Booster Separation

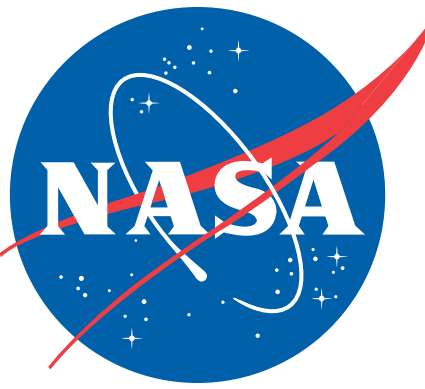


Booster Proximity: Attached . . . . . Separated

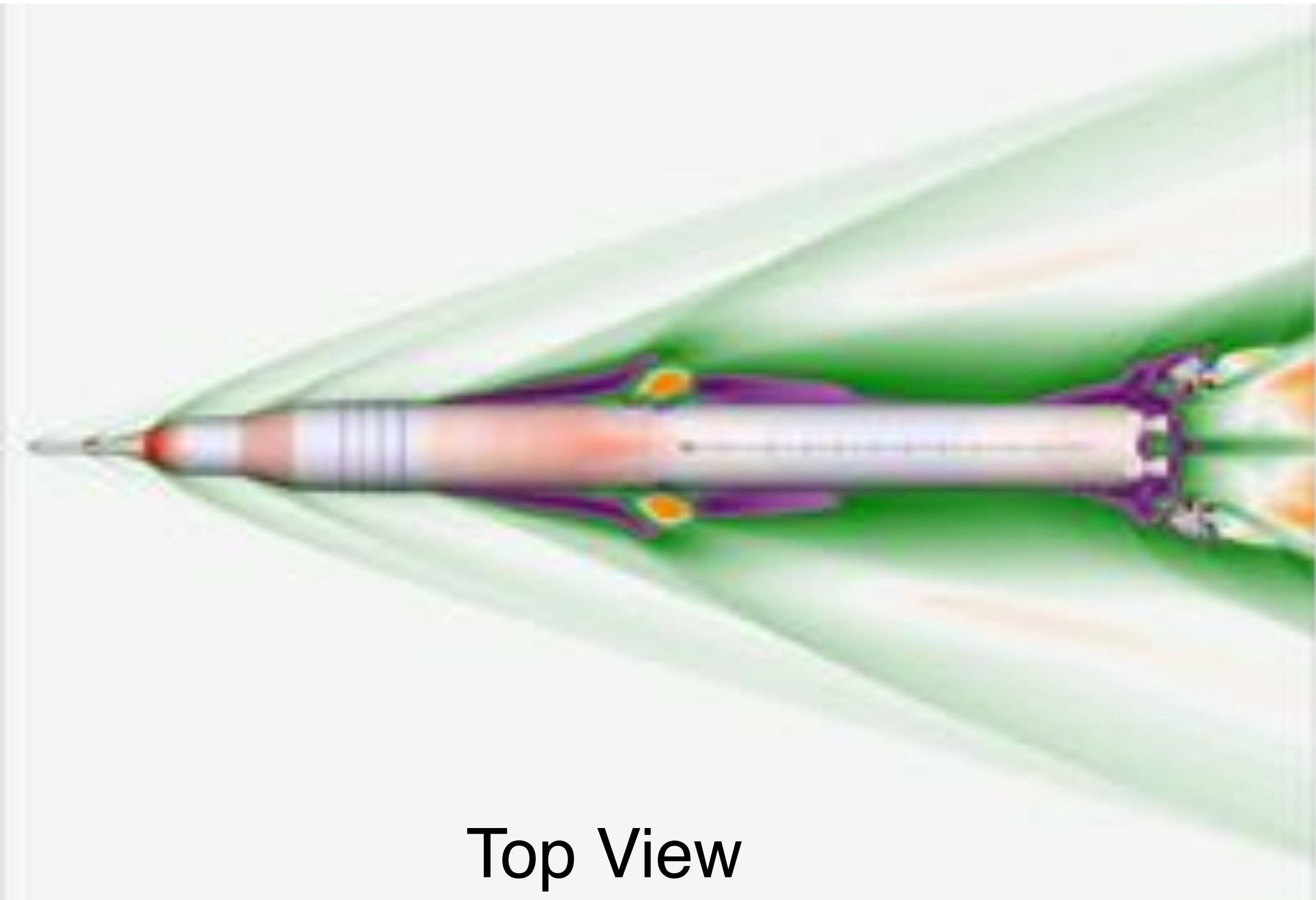


Background slice purple-green-white-orange color contours represent low to high velocities  
Vehicle surface blue-white-red color contours represent low to high pressures

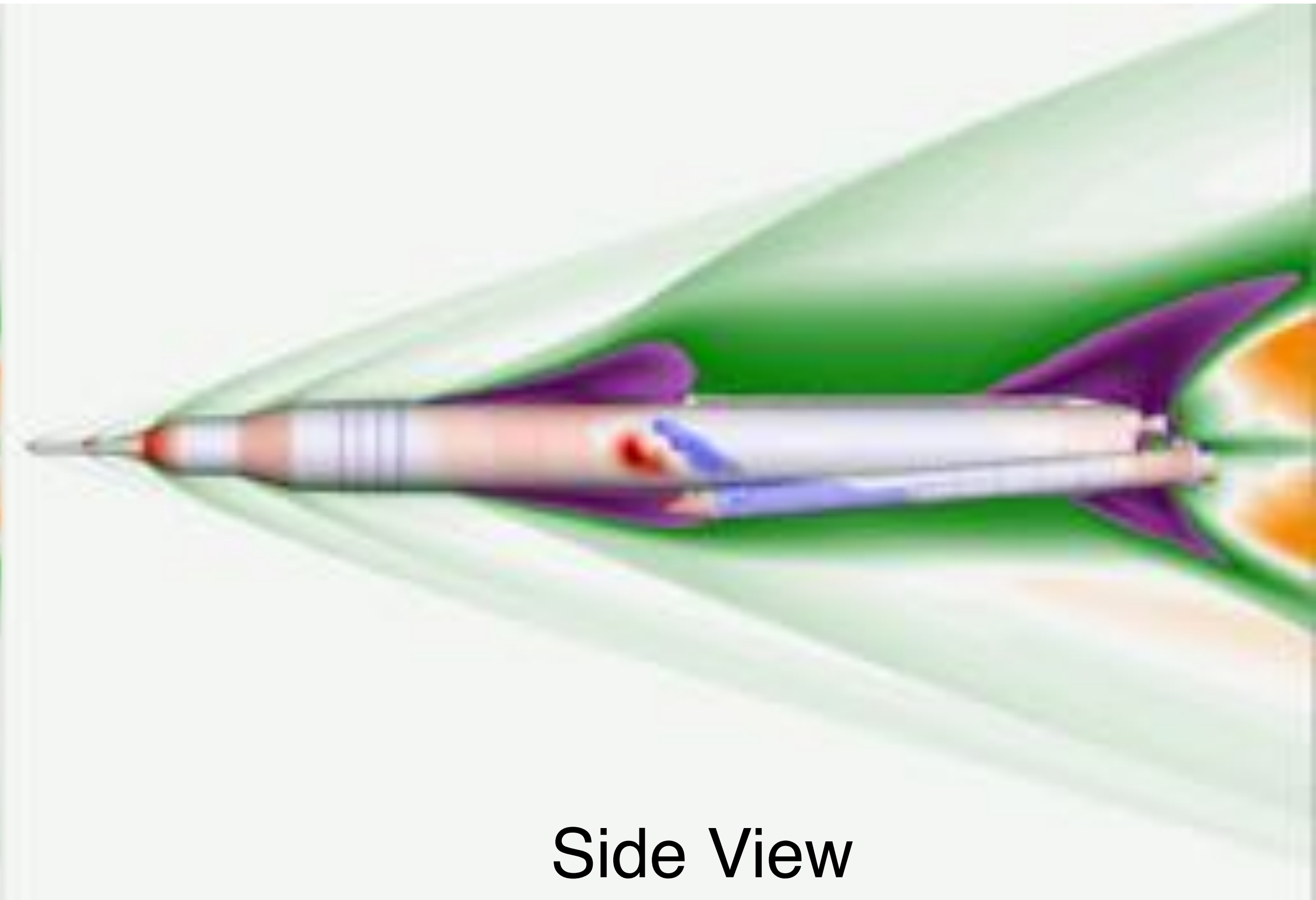
# SLS Block 1B Crew Booster Separation



Booster Proximity: Attached . . . . . Separated



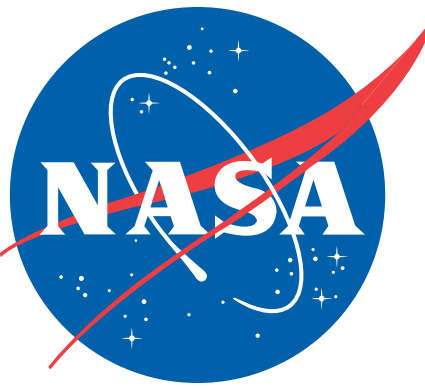
Top View



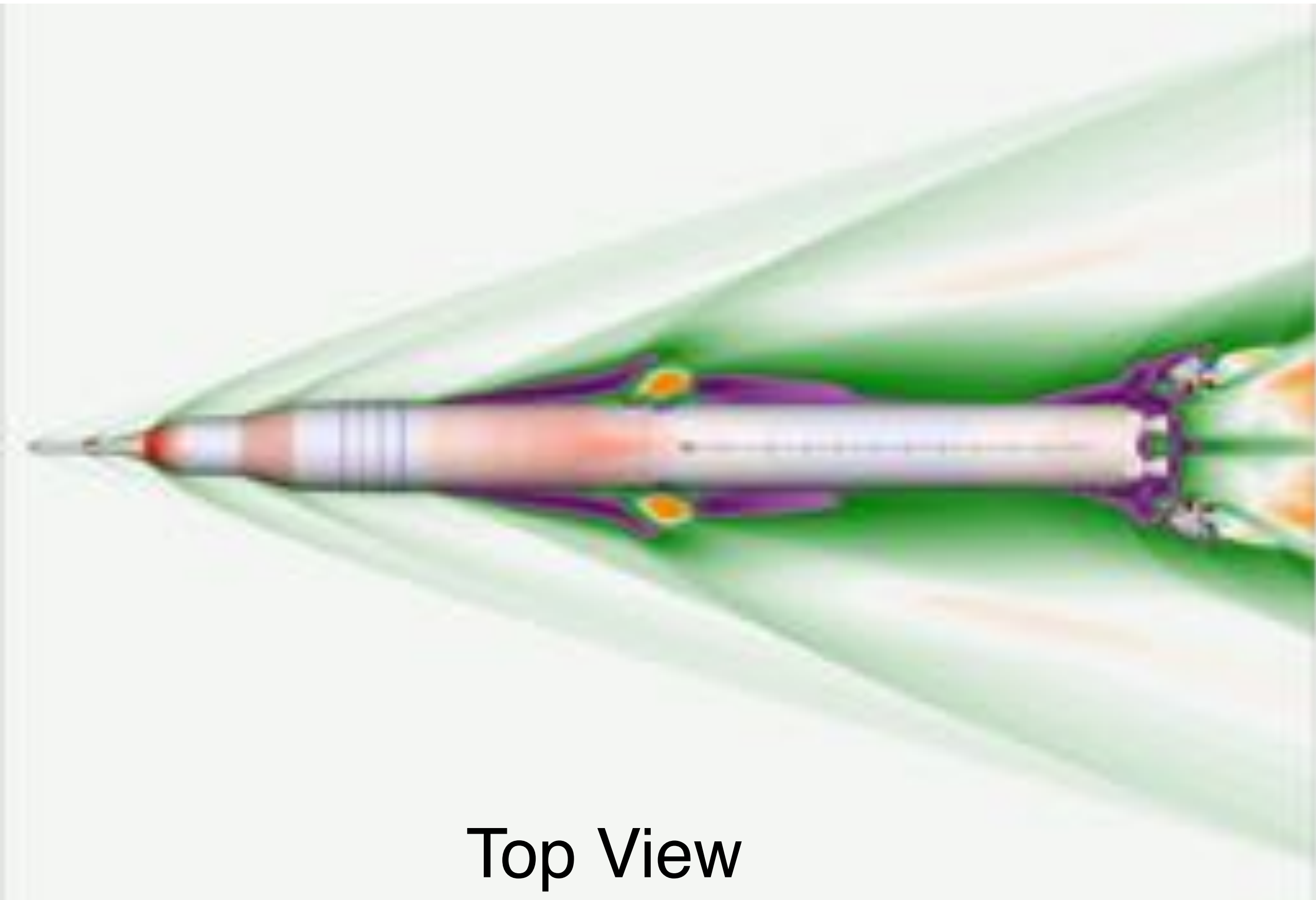
Side View

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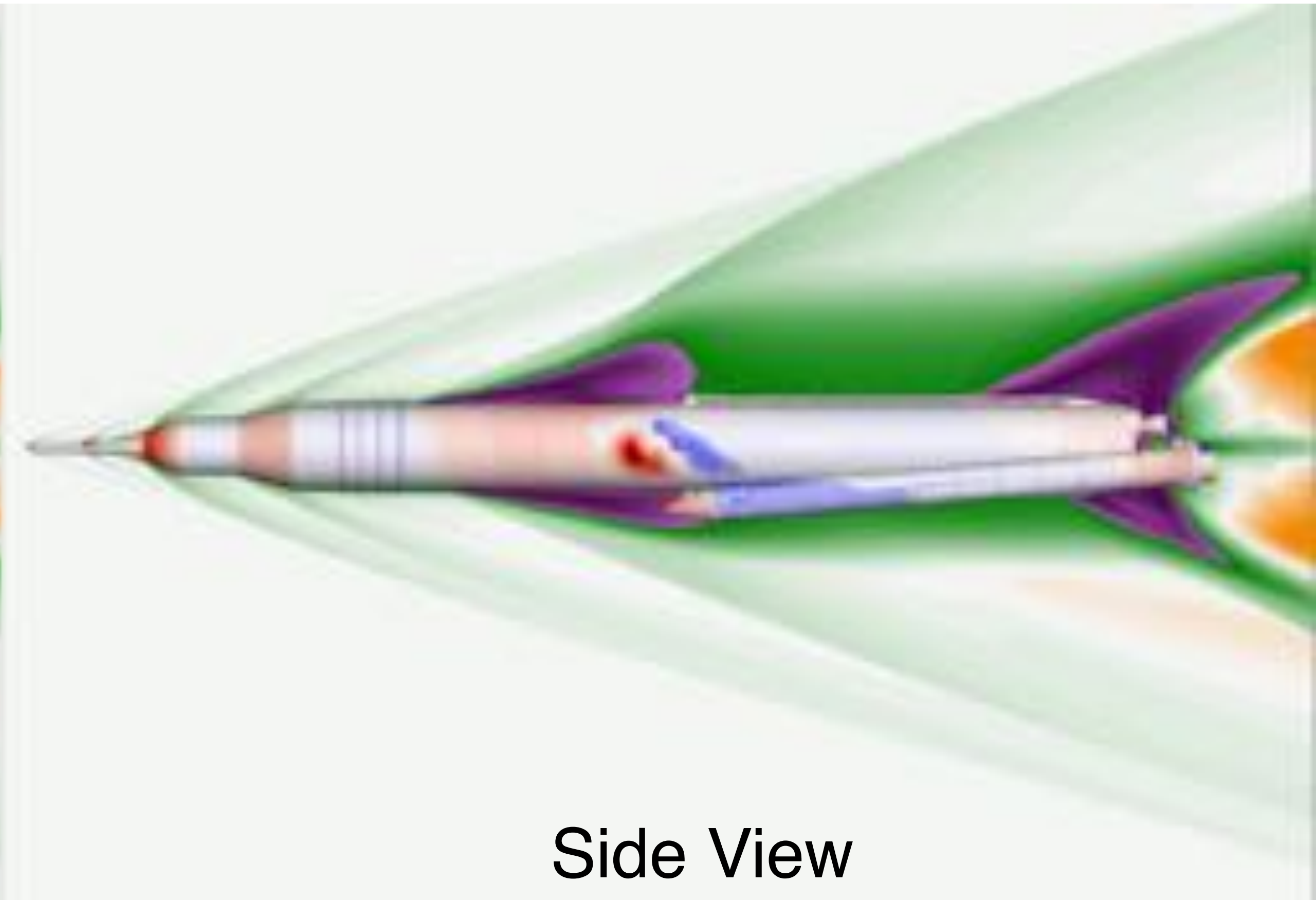
# SLS Block 1B Crew Booster Separation



Booster Proximity: Attached . . . . . Separated



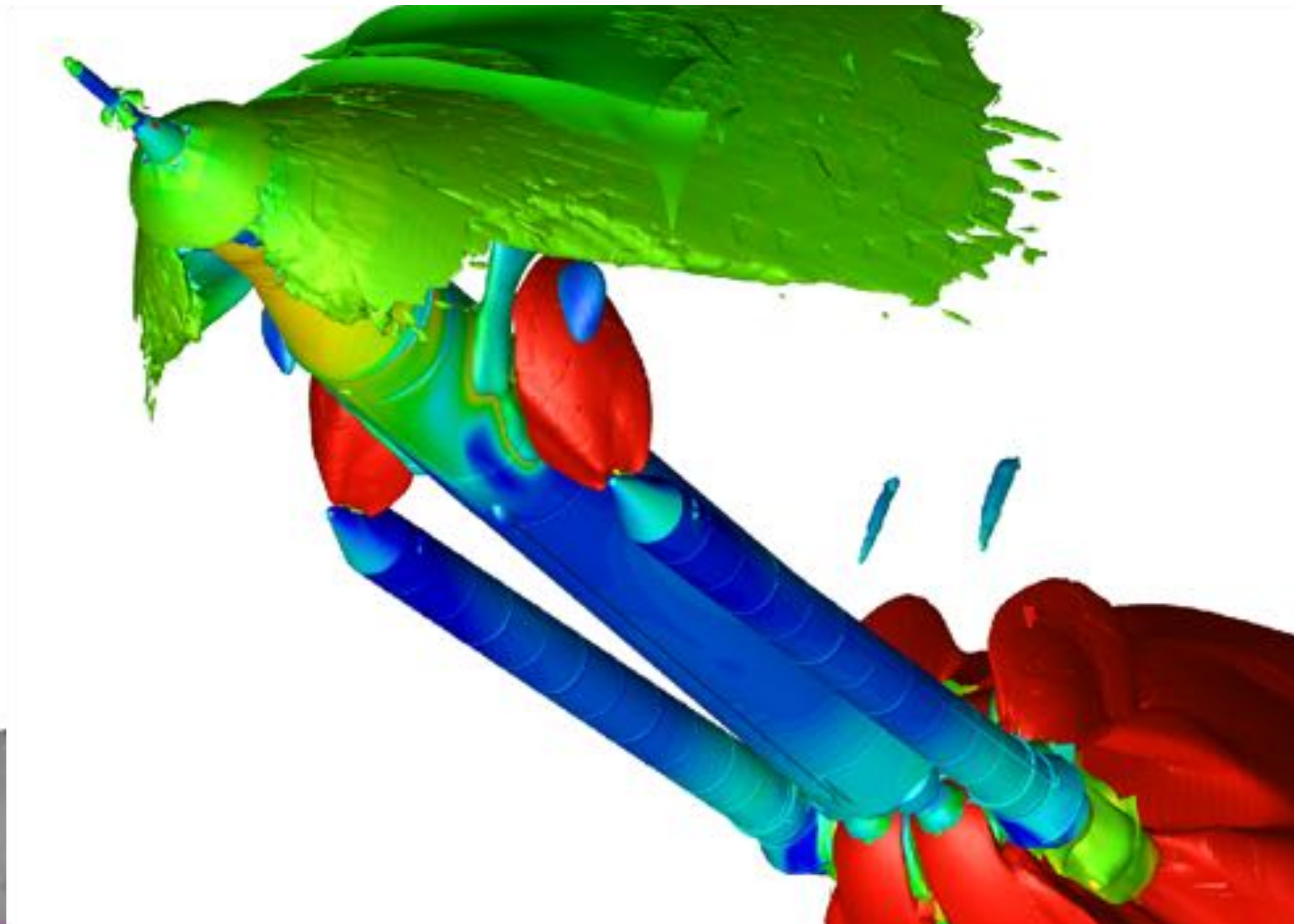
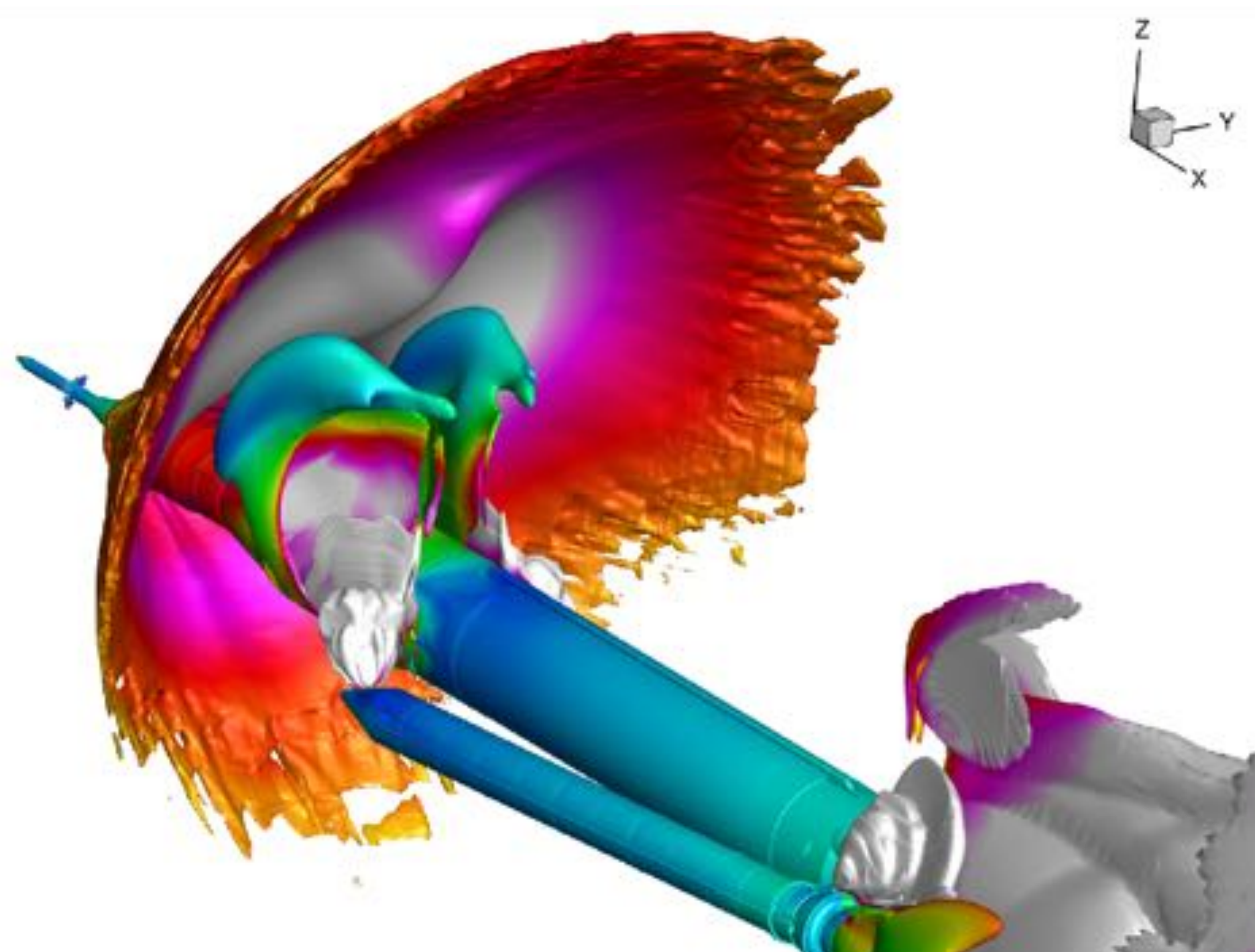
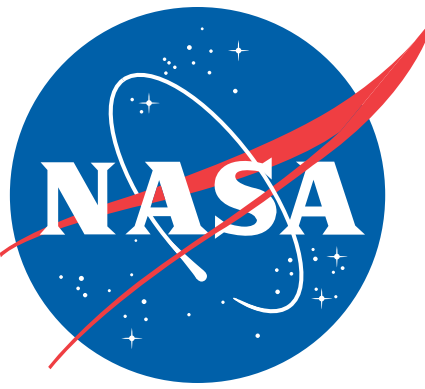
Top View



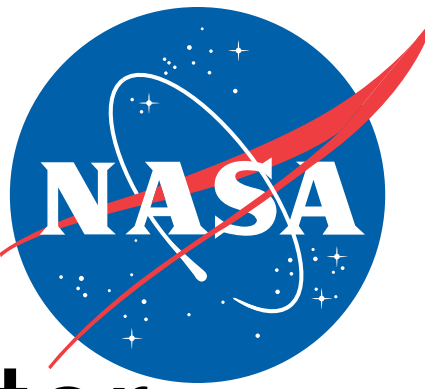
Side View

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# SLS Booster Separation (visualizations)

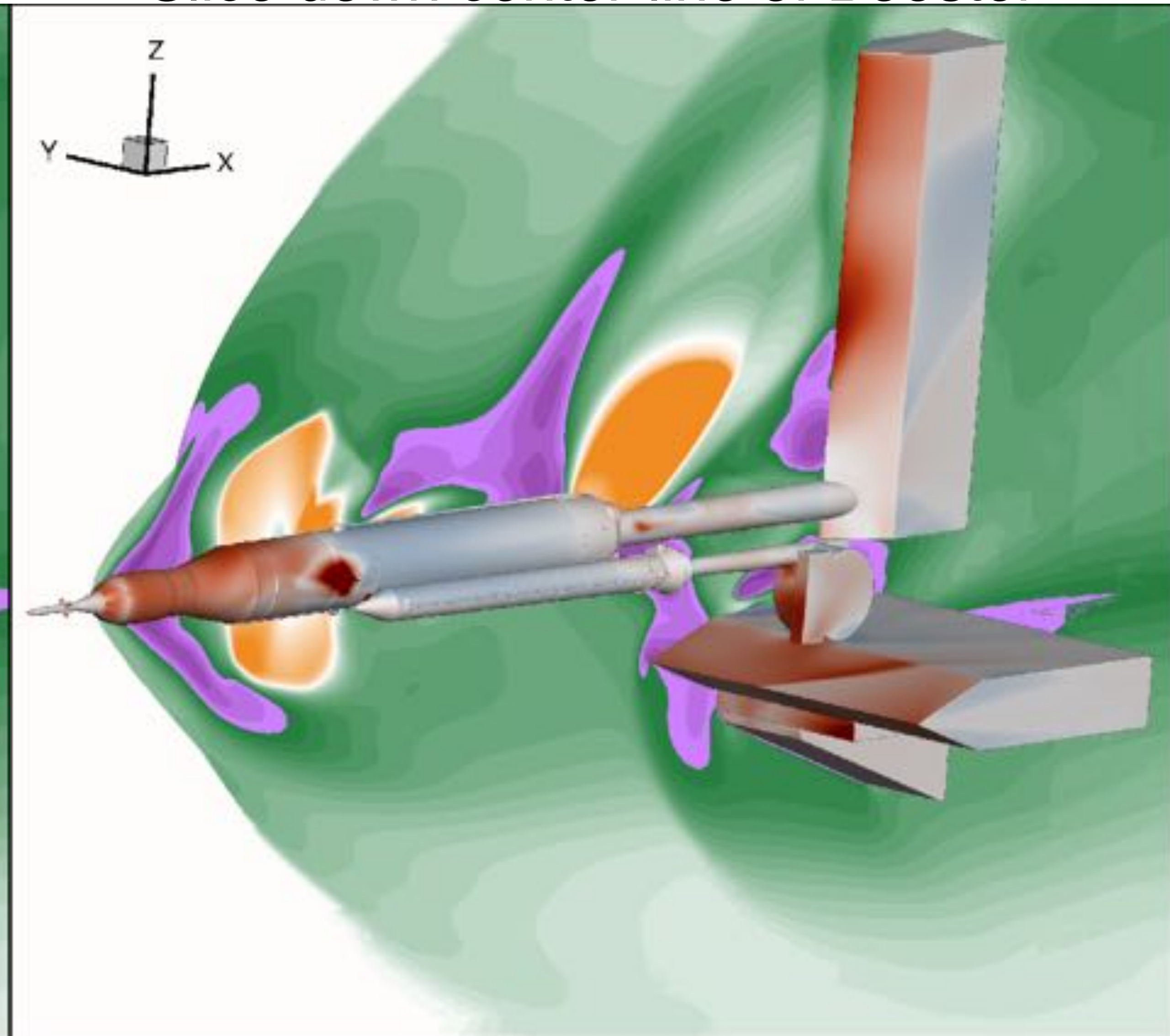
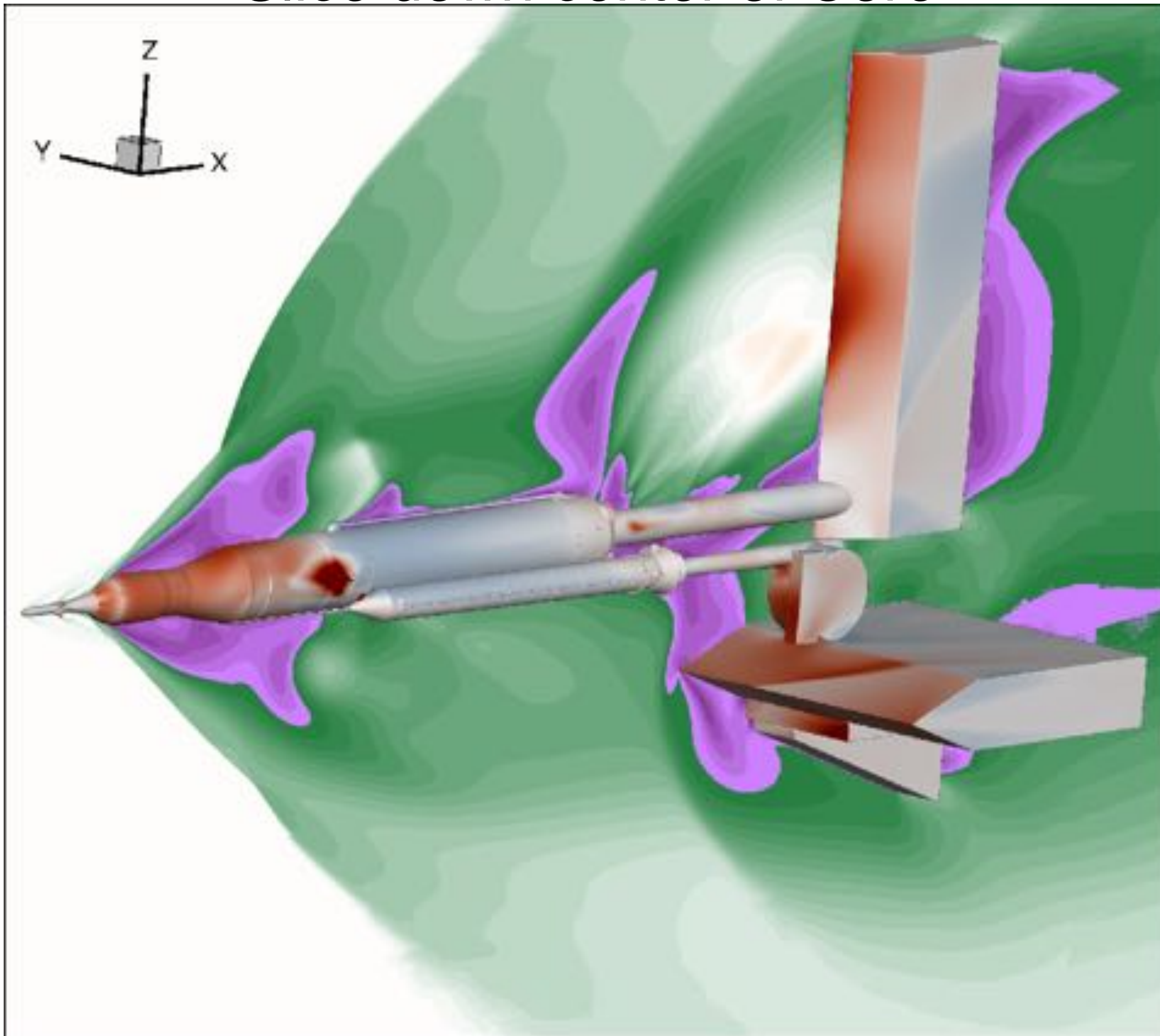


# SLS Wind Tunnel Flow Visualization (Overflow)



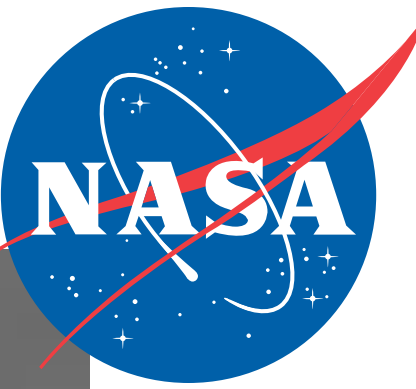
Slice down center of Core

Slice down center-line of Booster





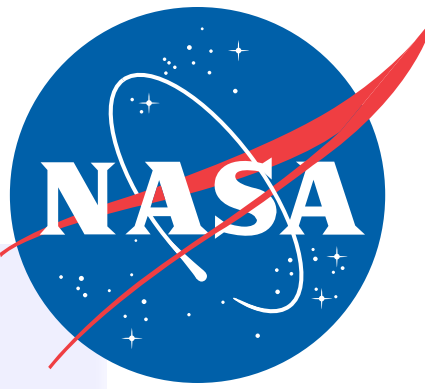
# SLS Block 1 Booster Separation



Computational Schlieren (by Pat Moran)

# SLS Block 1 Booster Separation

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



Top View



0' 0"

Iso View



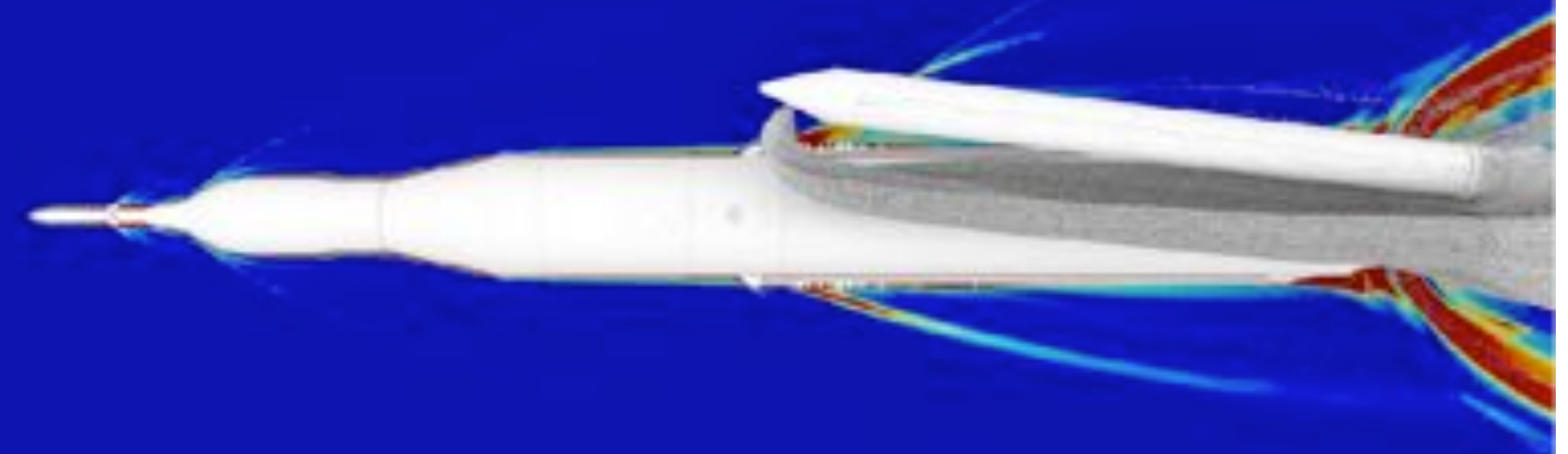
0' 0"

Side View



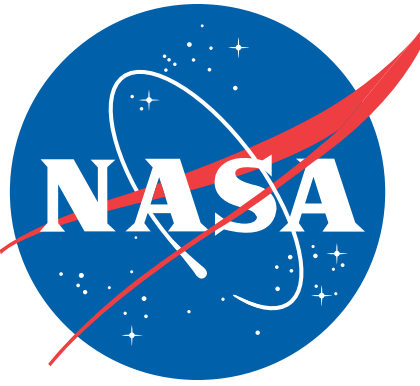
0' 0"

Side Slice (vorticity)



23' 11"

# 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!

