Building Aerodynamic Databases for the SLS Design Process

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SLS: 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
SLS: NASA Space Launch System Family

- **SLS Block 1**: 322 ft
  - Orion Multi-purpose Crew Vehicle
  - Interim Cryogenic Propulsion Stage
  - Launch Vehicle Stage Adapter
  - Core Stage
  - Solid Rocket Boosters

- **SLS Block 1B Crew**: 364 ft
  - Universal Stage Adapter
  - Cargo Fairing
  - Exploration Upper Stage
  - Interstage
  - SLS Block 1B Crew

- **SLS Block 1B Cargo**: 327 ft
  - Cargo Fairing
  - Exploration Upper Stage
  - Interstage
  - SLS Block 1B Cargo

- **SLS Block 2 Cargo**: 365 ft
  - Cargo Fairing
  - Exploration Upper Stage
  - Interstage
  - Advanced Boosters
  - RS-25 Engines
  - SLS Block 2 Cargo
SLS: NASA Space Launch System Block 1
SLS: NASA Space Launch System Block 1B Crew
SLS: NASA Space Launch System Block 2 Cargo
SLS: Future of Exploration
SLS Liftoff, Ascent, and Booster Separation
Building Aerodynamic Database: Ascent

- 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
Ascent Aerodynamics Database

- Three-Dimensional run matrix
  - Mach number (altitude)
  - Angle of attack
  - Roll Angle
- Rectangular 2-D run matrix based on Mach number
- 1300+ cases total
Building Aerodynamic Database: Booster Separation

- 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)
  - Cart3D inviscid CFD solver
  - FUN3D viscous CFD solver
  - Overflow viscous CFD solver
  - Overflow-D viscous dynamic moving body CFD solver
Booster Separation Aerodynamics Database

- Eight-Dimensional run matrix
  - Translational variables - 3
  - Rotational variables - 2
  - Thrust of booster separation motors - 1
  - Freestream conditions - 2
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
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
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
NAS Pleiades & Electra Supercomputer

- SGI Ice cluster with Intel Xeon processors
- InfiniBand in a dual-plane hypercube technology
- Pleiades
  - 7.24 Pflop/s peak cluster
  - 11,440 nodes; 246,048 cores
  - 935 TB Memory
  - Broadwell, Haswell, Ivy Bridge, & Sandy Bridge Nodes
- Electra
  - 4.79 Pflops/ peak cluster
  - 2,304 nodes; 78,336 cores
  - 368 TB Memory
  - Skylake and Broadwell Nodes
Computational Resources Consumed 2017

- Over 71 million core hours
- Over 500 terabytes of storage used

- Block 1 Crew Ascent
  - 3000+ cases
  - 36 million core hours
- Block 1B Crew Ascent & Booster Separation
  - ~1,300 + ~3000 cases
  - 25 million core hours
- Block 1B Cargo Ascent Database
  - ~1,300 cases
  - 5 million core hours
SLS Block 1 Crew Ascent

Altitude: Low • • • • • • • • • • • High

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 1 Crew Ascent

Altitude: Low • • • • • • • • • • • • High

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SLS Block 1 Booster Separation

Computational Schlieren (by Pat Moran)
SLS Block 1 Booster Separation

Top View

Iso View

Side View

Side Slice (vorticity)
SLS Block 1B Crew Ascent

Altitude: Low • • • • • • • • • • • • • • • • • • High

Top View

Side View

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SLS Block 1B Crew Booster Separation

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

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

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SLS Block 1B Crew Booster Separation

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

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

Top View

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SLS Block 1B Crew Booster Separation

Boosters 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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Conclusions

- NAS Pleiades Supercomputer enabled the creation of a CFD-based database for SLS booster separation
  - Created 4 aerodynamic databases for 3 vehicles
  - Over 71 Million core-hours over the last year
  - Over 8000 FUN3D cases
  - Over 1100 Overflow cases
  - 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