Building Aerodynamic Databases for the SLS Design Process

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Supercomputing 2017, November 12-16, 2017
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

322 ft

Launch Abort System
Orion Multi-purpose Crew Vehicle
Interim Cryogenic Propulsion Stage
Launch Vehicle Stage Adapter

364 ft

Universal Stage Adapter
Core Stage
Solid Rocket Boosters

327 ft

Cargo Fairing
Exploration Upper Stage
Interstage
Core Stage
Solid Rocket Boosters

365 ft

Cargo Fairing
Exploration Upper Stage
Interstage
Core Stage
Advanced Boosters
RS-25 Engines

SLS Block 1
SLS Block 1B Crew
SLS Block 1B Cargo
SLS Block 2 Cargo
SLS: NASA Space Launch System Block 1
SLS: NASA Space Launch System Block 1B Crew
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

Particles Colored by BSM Nozzle
(Pat Moran, Tim Sandstrom)
SLS Block 1B Crew Ascent

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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