Launch, Ascent, and Vehicle Aerodynamics
Scale-resolving Simulations for NASA Applications

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High-Fidelity Industrial LES/DNS Symposium (HiFiLeD)
Nov 14-16, 2018, Brussels, Belgium
Motivation

LAVA Framework

Launch: Kennedy Space Center Infrastructure Redesign
  - Ignition over-pressure waves – Cartesian
  - Thermal loads – Unstructured

Ascent: Orion Multi-Purpose Crew Vehicle Launch Abort System
  - Transient pressure loads – Cartesian

Vehicle Aerodynamics: Low-Boom Flight Demonstrator
  - Jet noise – Curvilinear
✓ Increase predictive use of computational aerosciences capabilities for next generation aviation and space vehicle concepts.

- The next frontier is to use wall-modeled and/or wall-resolved large-eddy simulation (LES) to predict:
  - Unsteady loads and fatigue
  - Buffet and shock BL interaction
  - Fan, jet, and airframe noise
  - Active flow control
  - Buffet and shock BL interaction
Challenges

✓ Mesh generation: flexibility, automation, adaption

| Structured Cartesian AMR | Unstructured Arbitrary Polyhedral | Structured Curvilinear |

✓ Modeling turbulent boundary layers and sub-filter scales

✓ Increasing computational efficiency
Launch, Ascent, and Vehicle Aerodynamics
LAVA Framework

Structured Cartesian AMR
- Navier-Stokes
- Lattice Boltzmann

Unstructured Arbitrary Polyhedral Navier-Stokes

Structured Curvilinear Navier-Stokes

Post-Processing Tools

Far Field Acoustic Solver

Conjugate Heat Transfer

Actuator Disk Models

Aero-Structural

6 DOF Body Motion

Other Solvers & Frameworks

Prismatic Layers

Multi-Physics:
- Multi-Phase
- Combustion
- Chemistry
- Electro-Magnetics

Other Development Efforts
- Higher order methods
- Curvilinear grid generation
- Wall modeling
- LES/DES/ILES Turbulence
- HEC (optimizations, accelerators, etc)

LAVA
Object Oriented Framework
C++ / Fortran with MPI Parallelism

Kiris at al. AST-2016 and AIAA-2014-0070
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Kennedy Space Center Infrastructure Redesign

Computational fluid dynamics (CFD) support is essential in the analysis and design of the launch pad.
Predicting Ignition Over-Pressure Waves

Provided unsteady pressure loads on launch infrastructure for a variety of different flame trench positions, designs, and launchers.
Provided unsteady thermal loads on main flame deflector for different positions, designs, and launchers

- Arbitrary poly unstructured mesh (21 M cells)
- Polygonal prism boundary layer mesh ($y^+ < 1$)
- SA-DES Turbulence model
- $Dt = 3.5e^{-5}$ secs with 20 subiterations

Unsteady SRB plenum data was used from STS-1. *Likely inconsistencies with STS-135*

Water sound suppression system is not modeled. *May affect wave propagation speed*
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ORION
Launch Abort System (LAS)

Ensuring Astronaut Safety
NASA is developing technologies that will enable humans to explore new destinations in the solar system. America will use the Orion spacecraft, launched atop the Space Launch System rocket, to send a new generation of astronauts beyond low-Earth orbit to places like an asteroid and eventually Mars. In order to keep astronauts safe in such difficult, yet exciting missions, NASA and Lockheed Martin collaborated to design and build the Launch Abort System.
Predict Loads for Launch Abort Motor Test

Rendering of the Orion Launch Abort System (LAS) qualification ground test (QM1) simulated using LAVA Cartesian with adaptive mesh refinement (AMR). Video showcases the turbulent structures resolved in the plumes colored by Mach number. Pressure is shown on the vertical cut-plane where blue is low and red is high. We provided loads on heat shield fixture and crane to help ground test designers ensure safety of the test and reduce risk in data collection.

Picture of ST1 test at Orbital ATK facility in Utah
Post Abort Motor Test Validation

Ignition Overpressure (IOP) versus Time

- QM1 Measurements
- LAVA Simulation

Pressure (Pa) vs. Time (s)
Wind Tunnel Validation

-- Wind Tunnel Measurements
-- LAVA Predictions
Rendering of the Orion Launch Abort Vehicle (LAV) during an ascent abort simulation where the vehicle is traveling at transonic speeds when abort is triggered. Video showcases the turbulent structures resolved in the plumes colored by gauge pressure. Each pixel turning from blue to white to red indicates a source of acoustic waves that can impinge on the apparatus and cause vibrations. The delta difference in unsteady loads between the QM-1 and LAV at different flight conditions is used to determine vehicle detailed design requirements.
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High Fidelity Jet Noise Simulation Methodology for Airport Noise Prediction of Emerging Commercial Supersonic Technologies

- Radical Installation Concepts
- Validation of Jet Prediction Capabilities
- Shielding Concept Capabilities

Grand Challenge

Predict full Aircraft Noise with Installation and Propulsion

Path Towards the Grand Challenge

Commercial Supersonic Technologies (CST)
Advanced Air Vehicle Program (AAVP)
Round Jet Acoustics Experimental Validation

- Experiment performed by Bridges and Wernet using the Small Hot Jet Acoustic Rig (SHJAR) at NASA Glenn
- Baseline axisymmetric convergent Small Metal Chevron (SMC000) nozzle at Set Point 7 (SP7) & Set Point 3 (SP3)
- Similar conditions were analyzed in Bres et. al. AIAA-2015-2535, but the boundary layer thickness is 5.5 times smaller in this study

<table>
<thead>
<tr>
<th>Bridges et. al. (NASA-TM-2011-216807)</th>
<th>SP3</th>
<th>SP7</th>
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<tbody>
<tr>
<td>Acoustic Mach number ( U_{\text{jet}}/c_\infty )</td>
<td>0.5</td>
<td>0.9</td>
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<tr>
<td>Jet temperature ratio ( T_e/T_\infty )</td>
<td>0.950</td>
<td>0.835</td>
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<tr>
<td>Nozzle pressure ratio ( p_t/p_\infty )</td>
<td>1.197</td>
<td>1.861</td>
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<tr>
<td>Nozzle Diameter ( D )</td>
<td>2.0” ~ 0.0508 m</td>
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<table>
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<tr>
<th>Solver</th>
<th>( x/D_j ) [-]</th>
<th>Error [%]</th>
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<tr>
<td>Bridges &amp; Wernet</td>
<td>7.8</td>
<td>-</td>
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<tr>
<td>Wind, RANS-SA-2D</td>
<td>6.84</td>
<td>-12.3</td>
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<tr>
<td>LAVA, RANS-NLES-SEM-3D</td>
<td>7.90</td>
<td>1.2</td>
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1 Wind Data, Objectives and Metrics from NASA Turbulence Modeling Resource (TMR) website: https://turbmodels.larc.nasa.gov

RMS center-line velocity

RMS lip-line velocity

Capturing Shielding Effects

- Choice of FWH surface mesh size & placement not trivial
- Need to establish best practices as a community

Hybrid RANS/LES Simulation of Jet Surface Interaction Noise.
Next Step Towards Radical Installation Concepts

Objective:

✓ Significantly increase complexity (last step before “grand challenge”).
✓ Multi-stream nozzle with shielding and installation effects.
✓ Comparison with comprehensive experimental database.

Picture taken from:
NASA Test Report: Top-Mounted Propulsion Test 2017 (TMP17)
Lessons Learned

- Invest in robustness and reducing turnaround time
- Develop continuous verification & validation
- Build in flexibility to use the best tool for the deliverable

Pressure on the vertical plane (white is high, black is low) during ascent abort at Mach 0.7, $\alpha = 20^\circ$, $\beta = 0^\circ$
Acknowledgements

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