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

Francois Cadieux, Michael Barad, Emre Sozer, James Jensen, Gerrit-Daniel Stich, Jeffrey Housman, Joseph Kocheemoolayil, and Cetin Kiris

Computational Aerosciences Branch

NASA Ames Research Center

High-Fidelity Industrial LES/DNS Symposium (HiFiLeD)

Nov 14-16, 2018, Brussels, Belgium

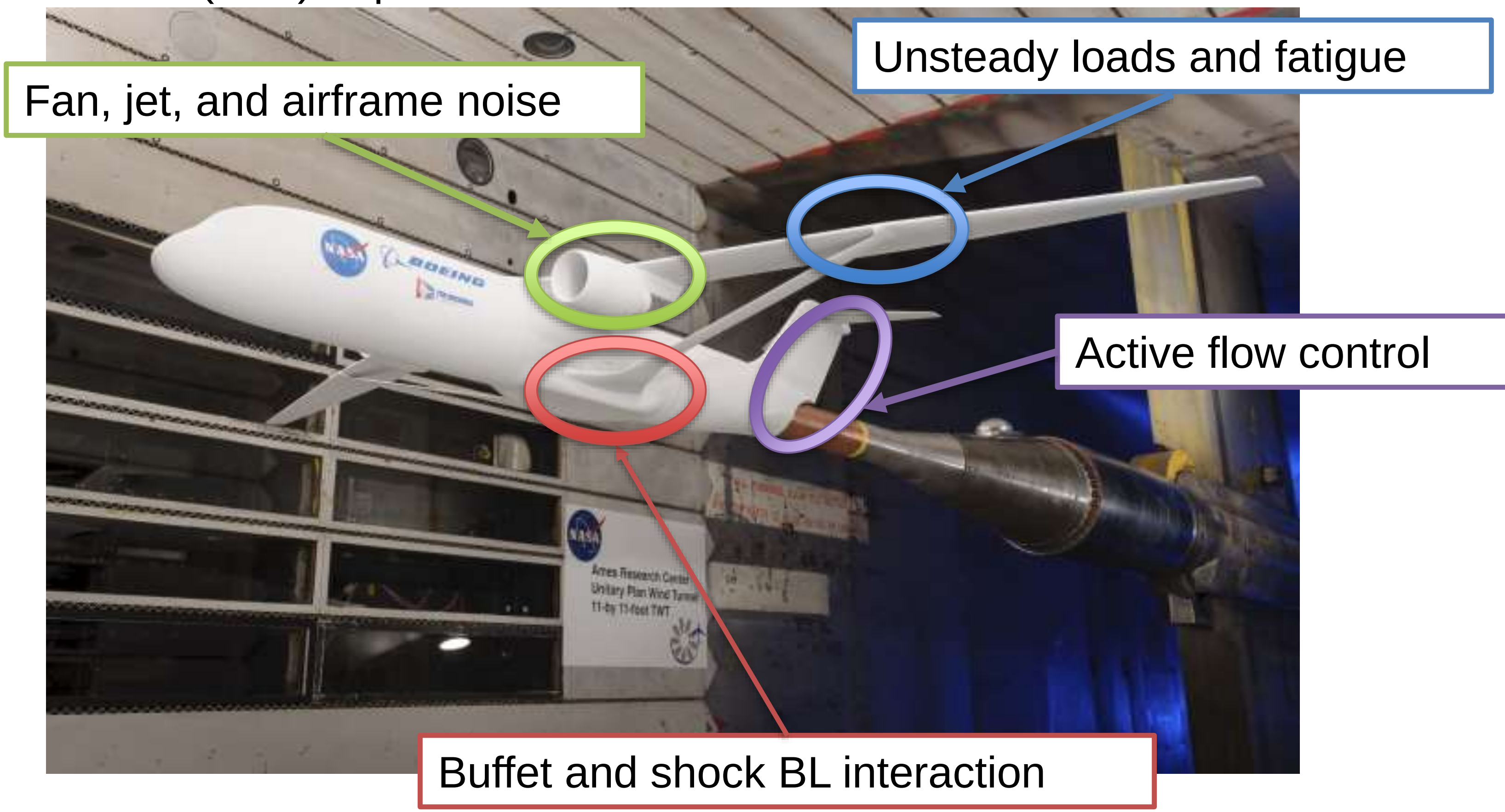
Outline

- **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

Motivation

✓ **Increase predictive use of computational aerosciences capabilities for next generation aviation and space vehicle concepts.**

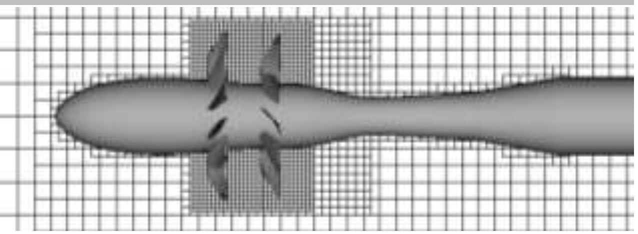
- The next frontier is to use wall-modeled and/or wall-resolved large-eddy simulation (LES) to predict:



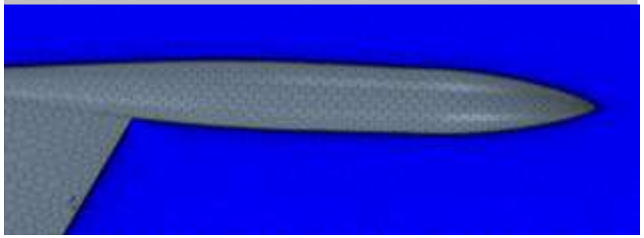
Challenges

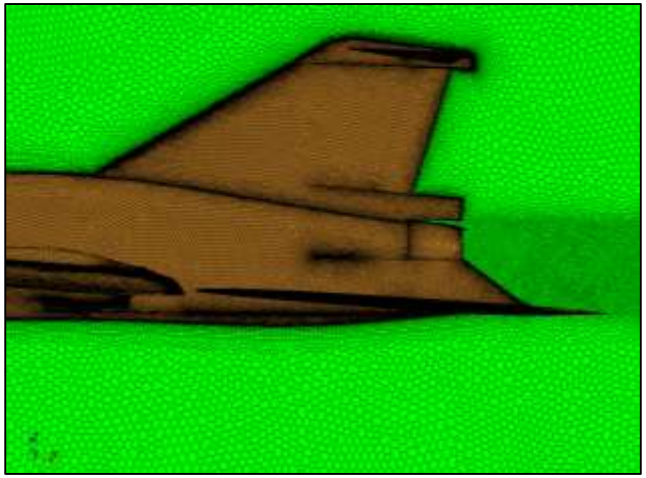
- ✓ **Mesh generation: flexibility, automation, adaption**

Structured Cartesian AMR

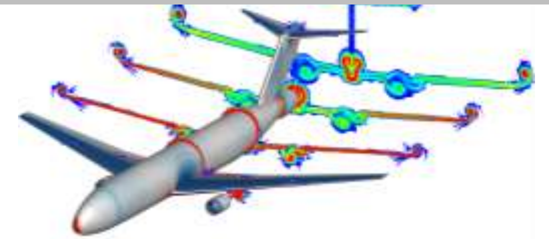


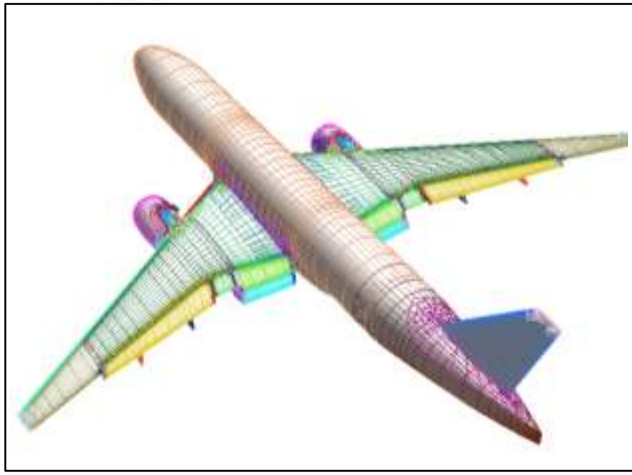
Unstructured Arbitrary Polyhedral





Structured Curvilinear

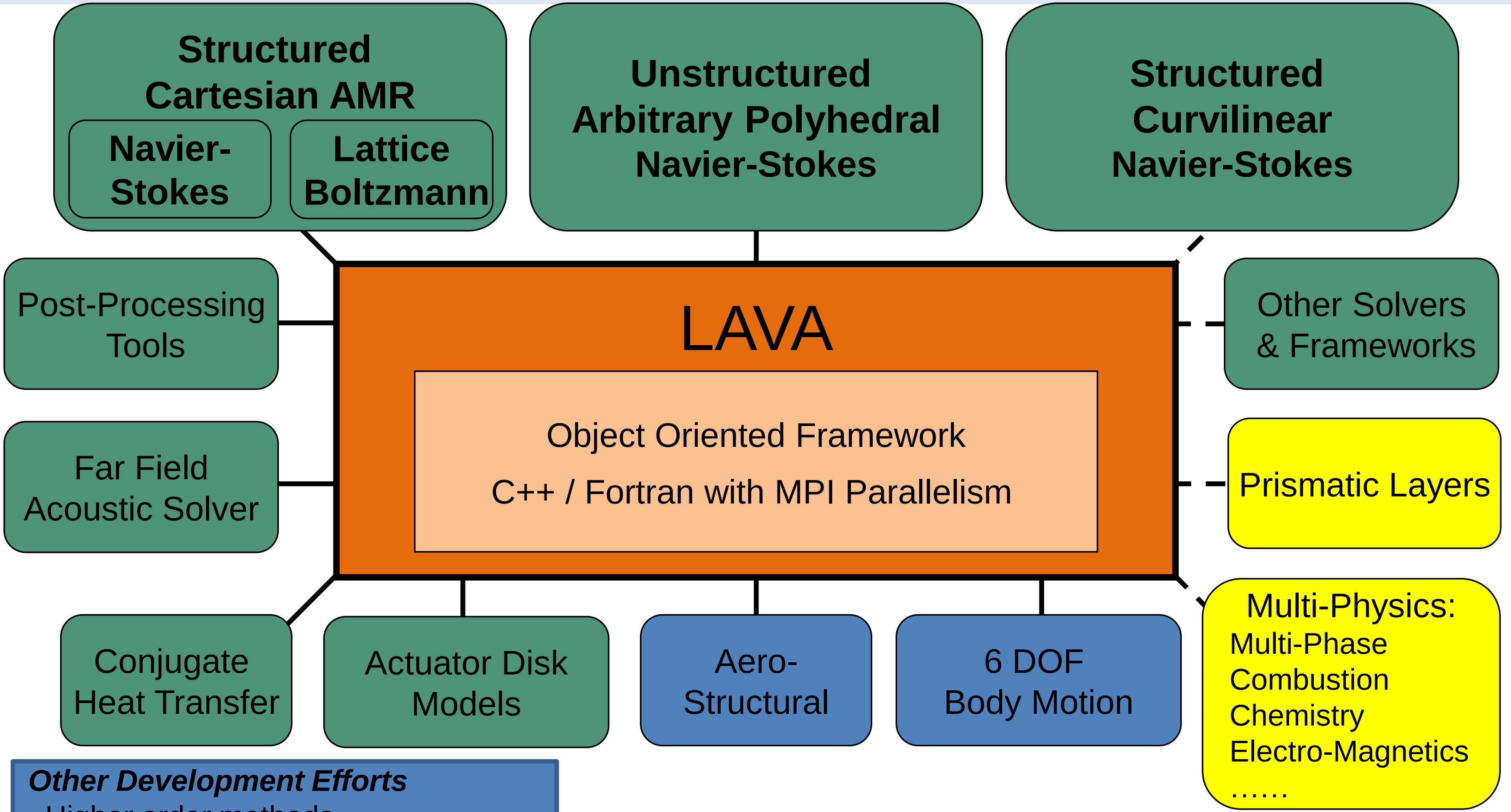




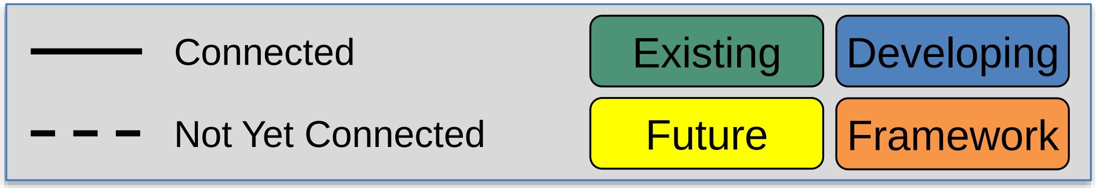
- ✓ **Modeling turbulent boundary layers and sub-filter scales**

- ✓ **Increasing computational efficiency**

Launch, Ascent, and Vehicle Aerodynamics
LAVA Framework



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



Kiris at al. AST-2016 and AIAA-2014-0070

Outline

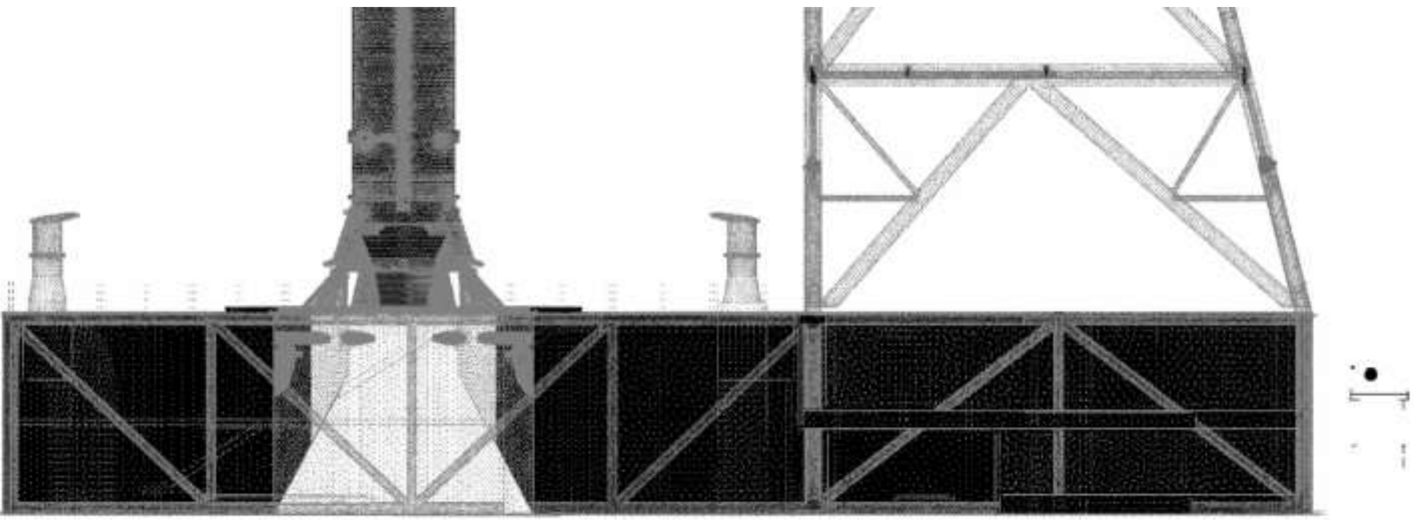
- **Motivation**
- **LAVA Framework**
- **Launch: Kennedy Space Center Infrastructure Redesign**
  - Ignition over-pressure waves – Cartesian
  - Thermal loads – Unstructured
- **Ascent: Orion Multi-Purpose Crew Vehicle Launch Abort System**
  - Transient pressure loads – Cartesian
- **Vehicle Aerodynamics: Low-Boom Flight Demonstrator**
  - Jet noise – Curvilinear

Kennedy Space Center Infrastructure Redesign

Computational fluid dynamics (CFD) support is essential in the analysis and design of the launch pad.

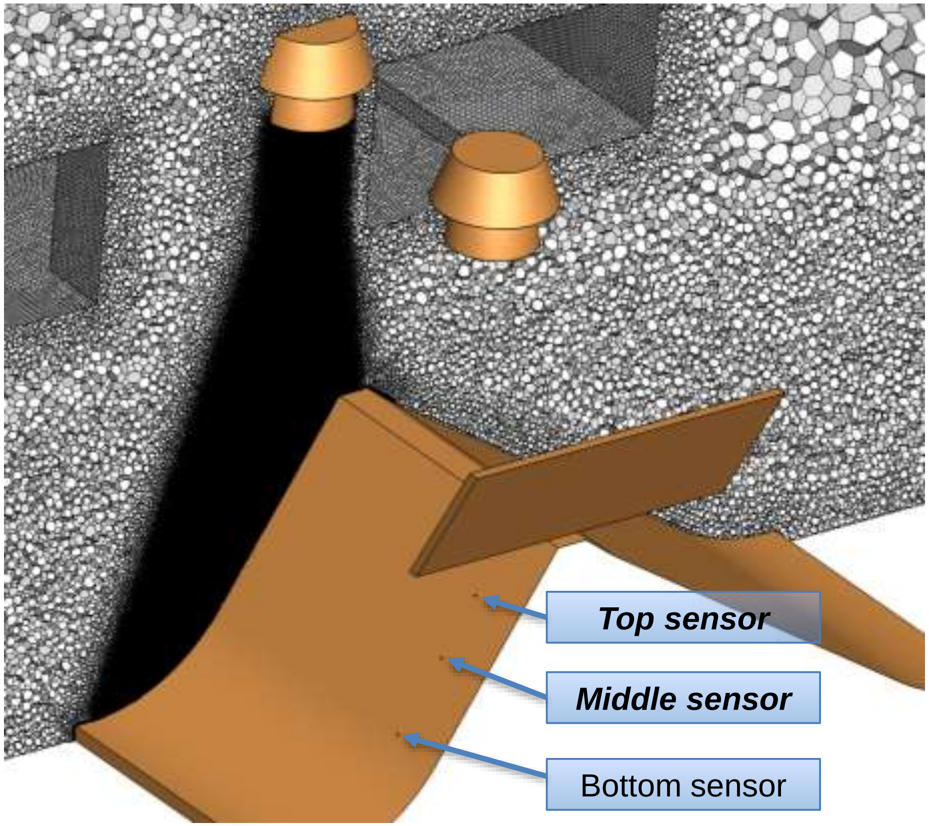
Predicting Ignition Over-Pressure Waves

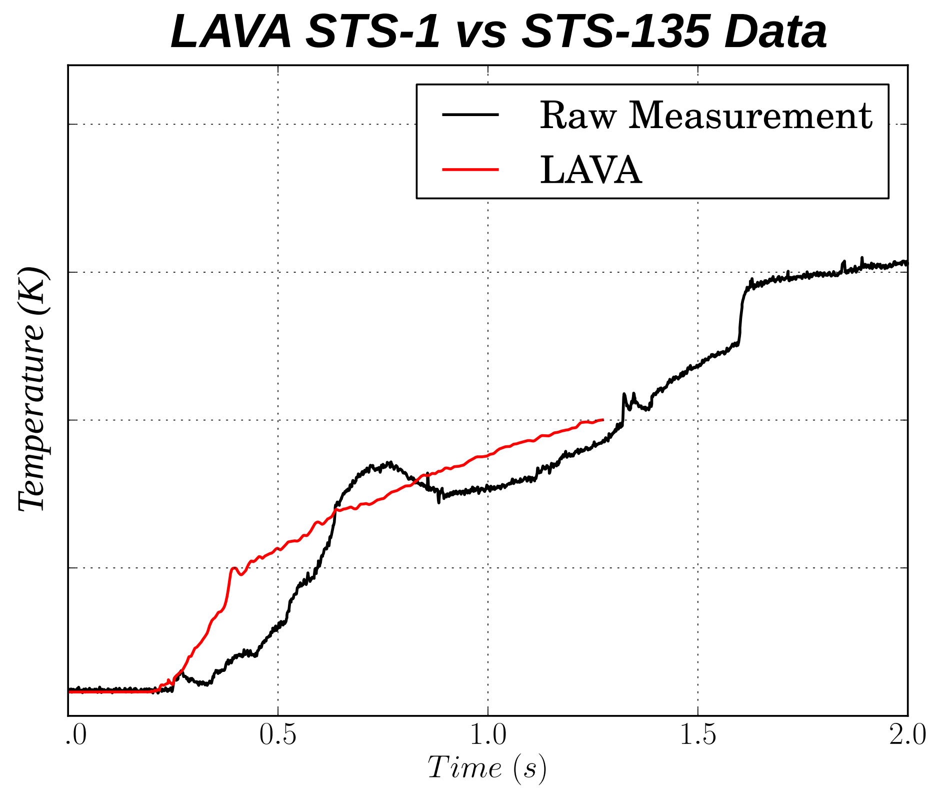
Provided unsteady pressure loads on launch infrastructure for a variety of different flame trench positions, designs, and launchers



Predicting Thermal Loads

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*

Outline

- **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

National Aeronautics and Space Administration

ORION

Launch Abort System (LAS)

NASAfacts

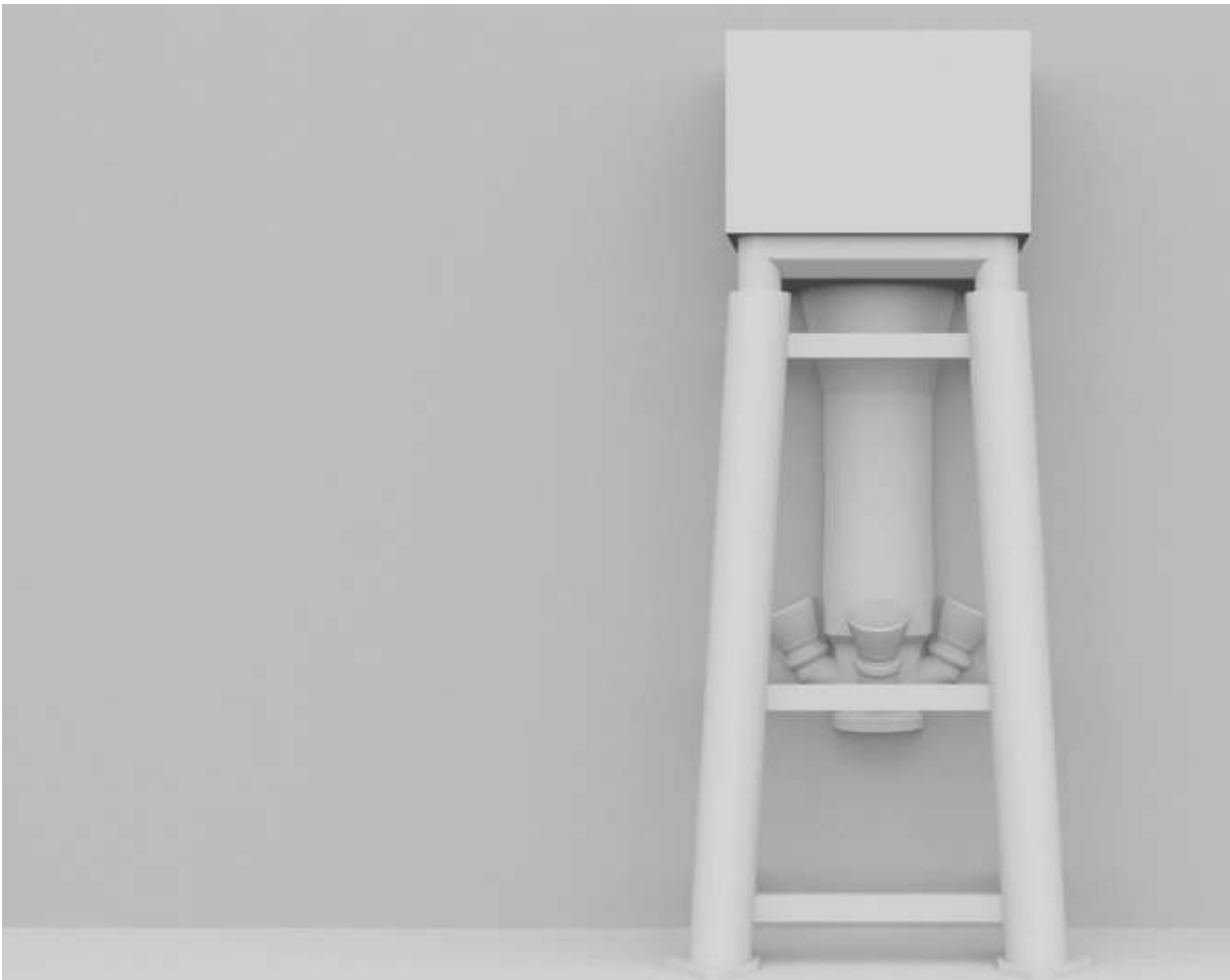
Ensuring Astronaut Safety

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

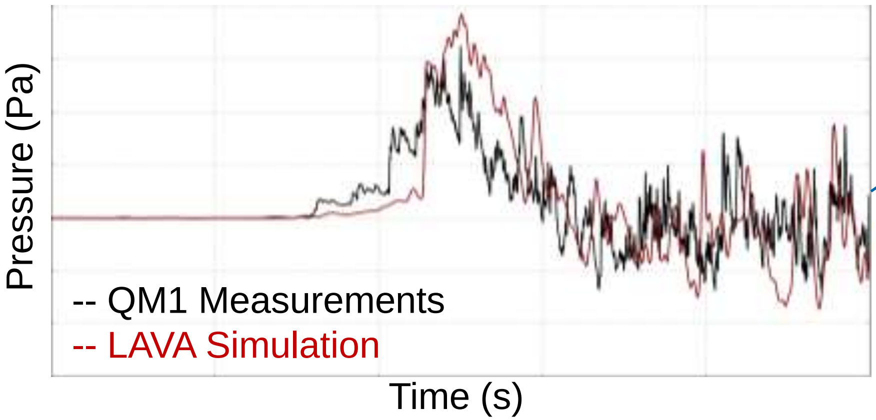
Rendering of the Orion Launch Abort System (LAS) qualification ground test (QM1) simulated using LAVA Cartesian with adaptive mesh refinement (AMR). Video showcases the turbulent structures resolved in the plumes colored by Mach number. Pressure is shown on the vertical cut-plane where blue is low and 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.

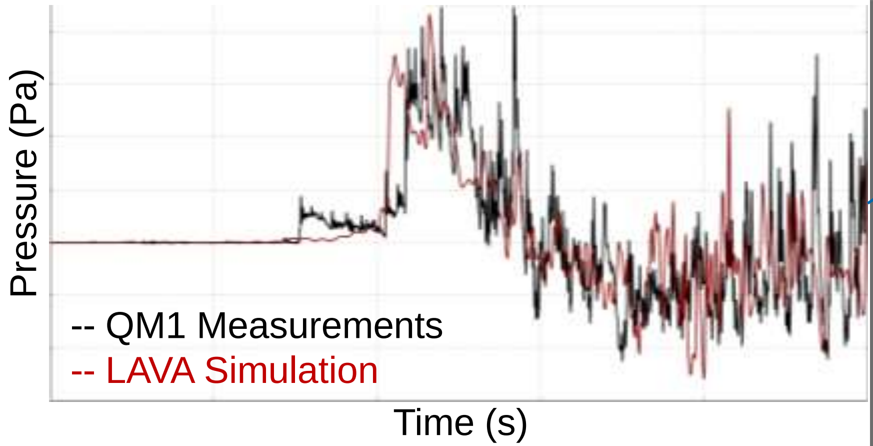
Picture of ST1 test at Orbital ATK facility in Utah

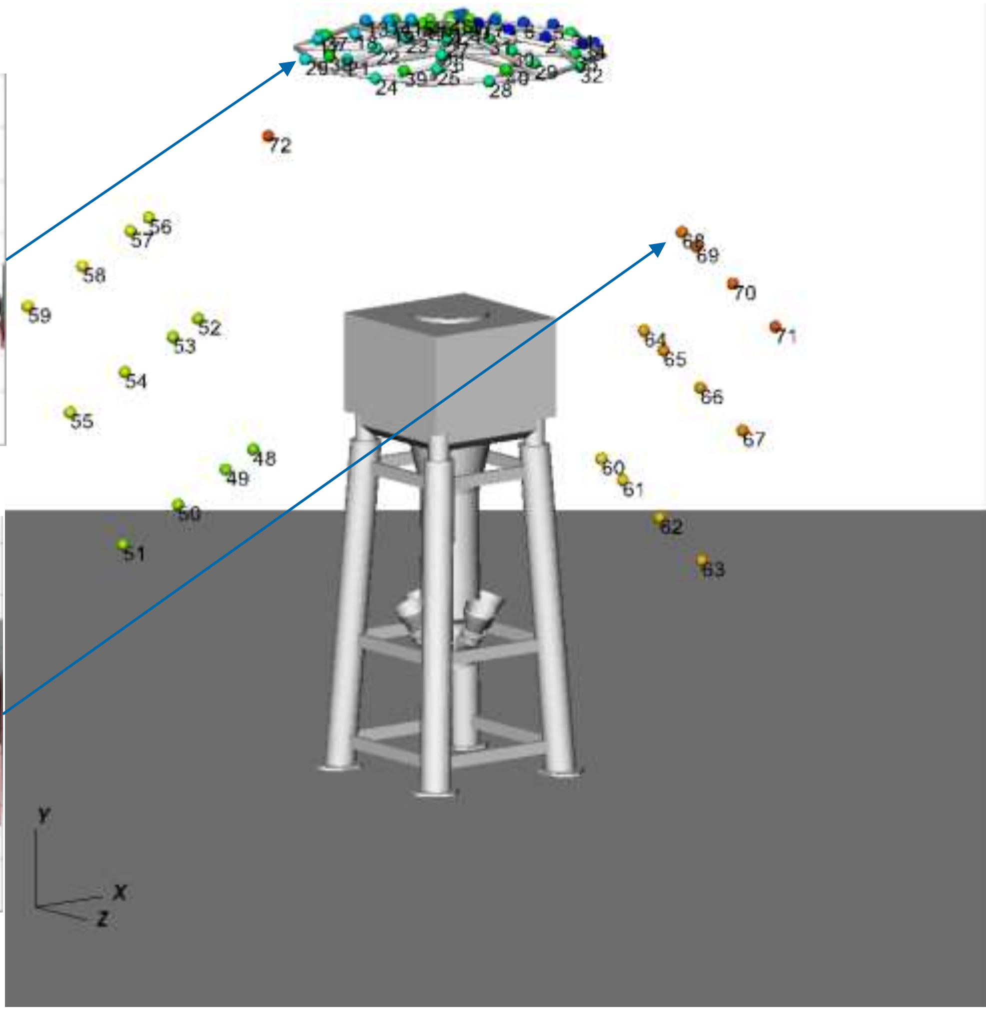


Post Abort Motor Test Validation

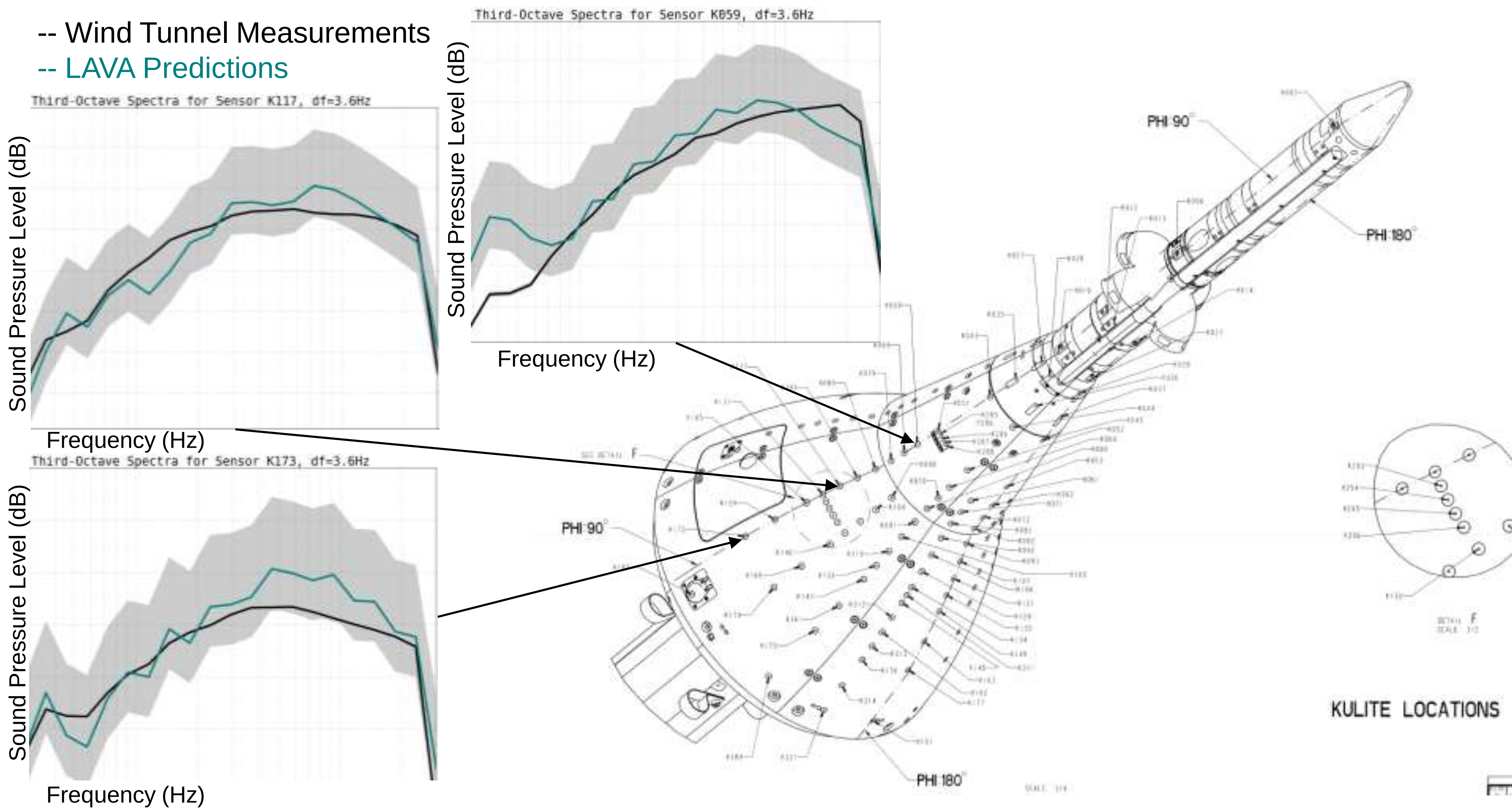
Ignition Overpressure (IOP) versus Time







Wind Tunnel Validation



From Ground/WT Test to Flight Vehicle

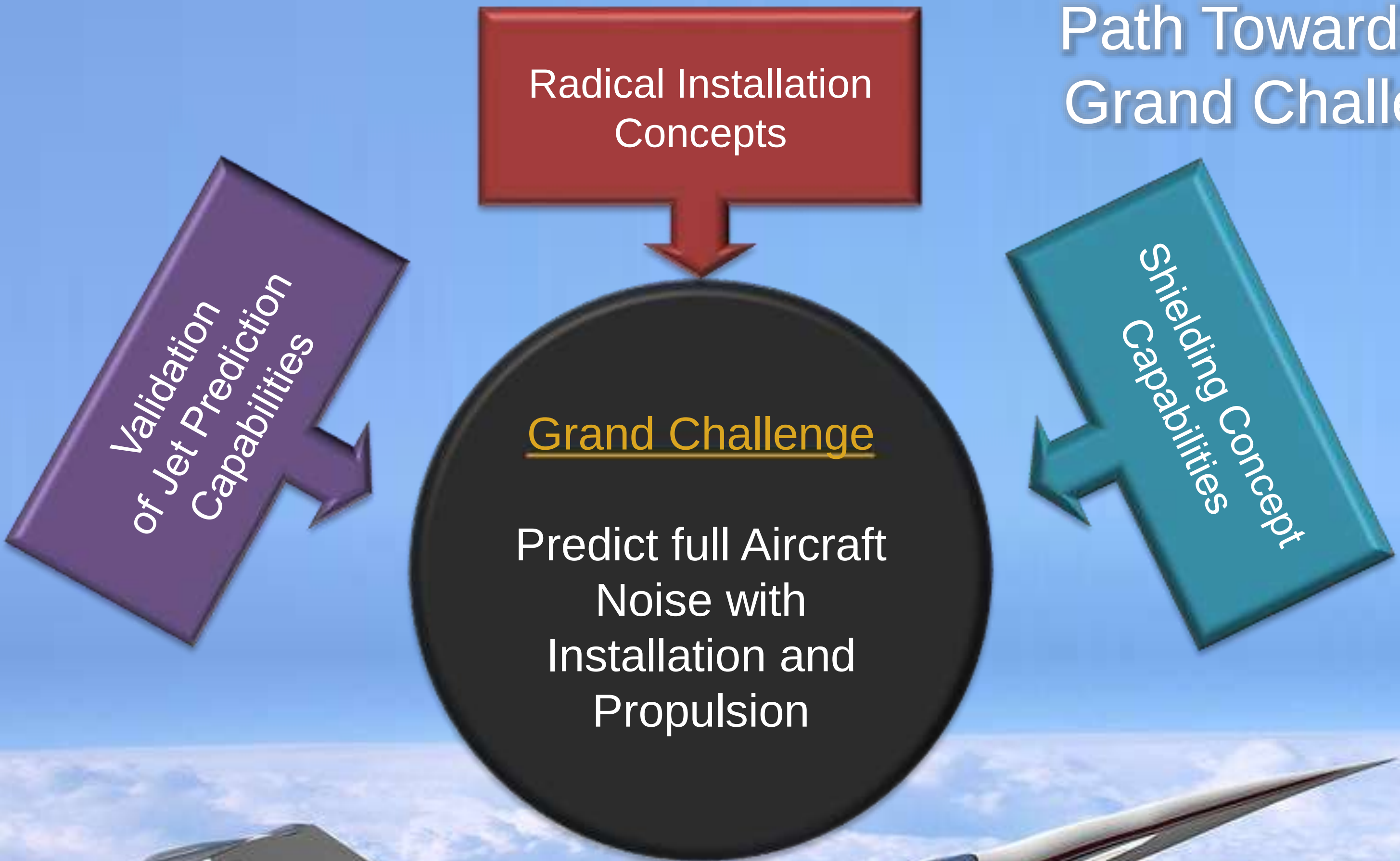
Rendering of the Orion Launch Abort Vehicle (LAV) during an ascent abort simulation where the vehicle is traveling at transonic speeds when abort is triggered. Video showcases the turbulent structures resolved in the plumes colored by gauge pressure. Each pixel turning from blue to white to red indicates 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.

Outline

- **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

High Fidelity Jet Noise Simulation Methodology for Airport Noise Prediction of Emerging Commercial Supersonic Technologies

Path Towards the Grand Challenge



Commercial Supersonic Technologies (CST)

Advanced Air Vehicle Program (AAVP)

Round Jet Acoustics Experimental Validation

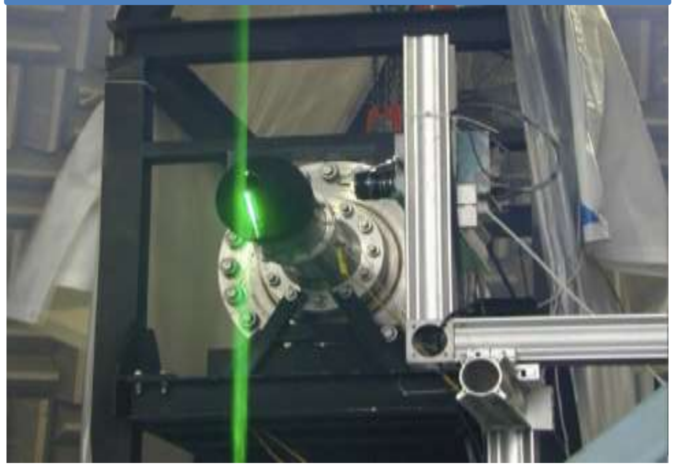
- ✓ Experiment performed by Bridges and Wernet using the Small Hot Jet Acoustic Rig (SHJAR) at NASA Glenn
- ✓ Baseline axisymmetric convergent Small Metal Chevron (SMC000) nozzle at Set Point 7 (SP7) & Set Point 3 (SP3)
- ✓ Similar conditions were analyzed in Bres et. al. AIAA-2015-2535, but the boundary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

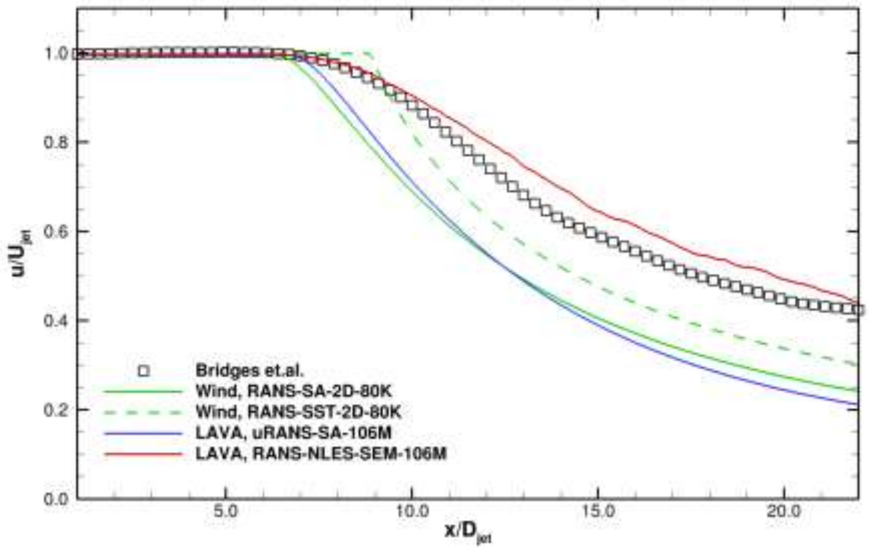
Bridges et. al. (NASA-TM-2011-216807)	SP3	SP7
Acoustic Mach number U_{jet}/c_{∞}	0.5	0.9
Jet temperature ratio T_e/T_{∞}	0.950	0.835
Nozzle pressure ratio p_t/p_{∞}	1.197	1.861
Nozzle Diameter D	2.0” ~ 0.0508 m	

Solver	x/D_j [-]	Error [%]
Bridges & Wernet	7.8	-
Wind, RANS-SA-2D	6.84	-12.3
LAVA, RANS-NLES-SEM-3D	7.90	1.2

[1] Wind Data, Objectives and Metrics from NASA Turbulence Modeling Resource (TMR) website: https://turbmodels.larc.nasa.gov

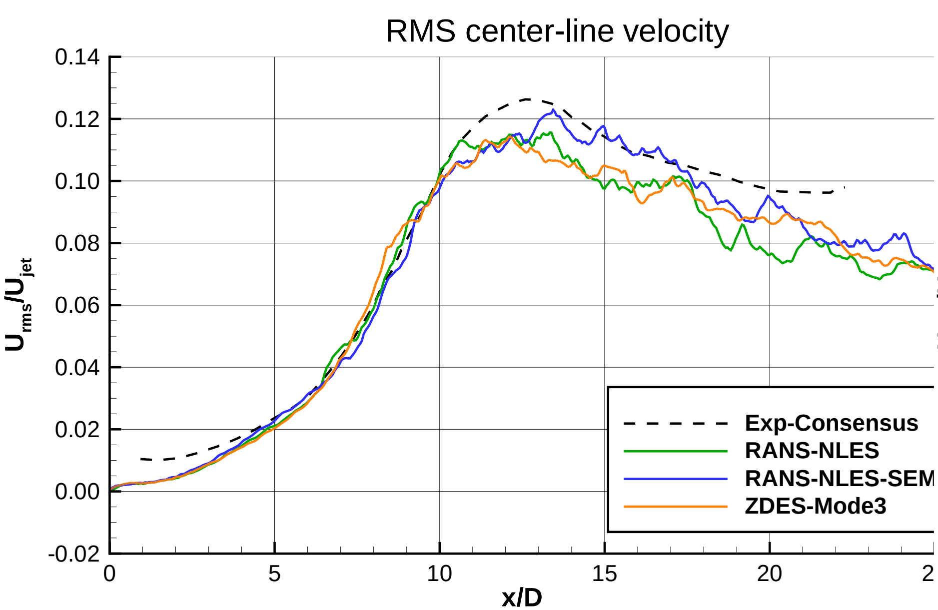
PIV measurement device

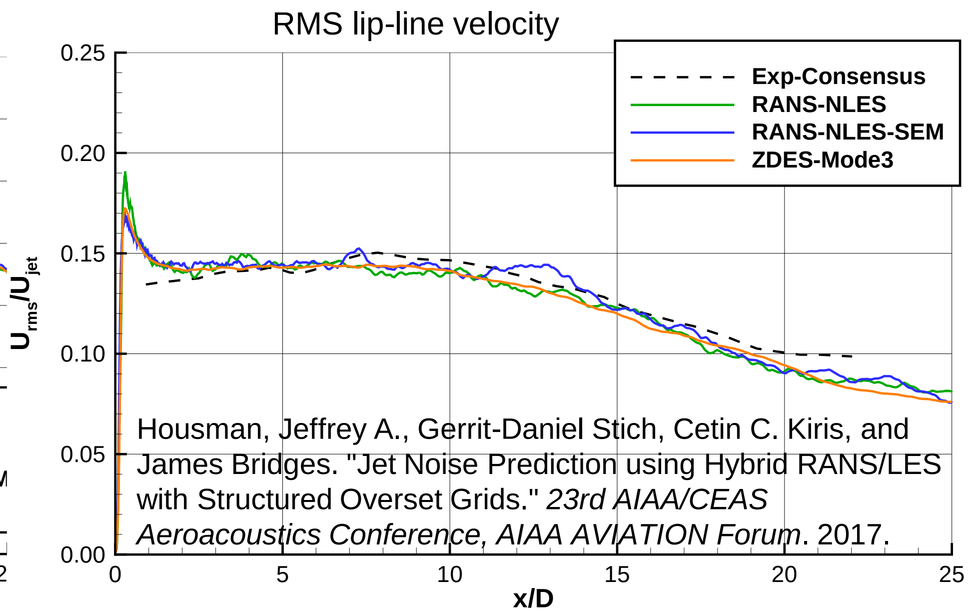




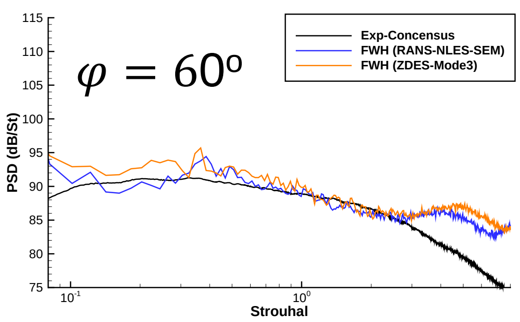
Housman, Jeffrey A., Gerrit-Daniel Stich, Cetin C. Kiris, and James Bridges. "Jet Noise Prediction using Hybrid RANS/LES with Structured Overset Grids." *23rd AIAA/CEAS Aeroacoustics Conference, AIAA AVIATION Forum*. 2017.

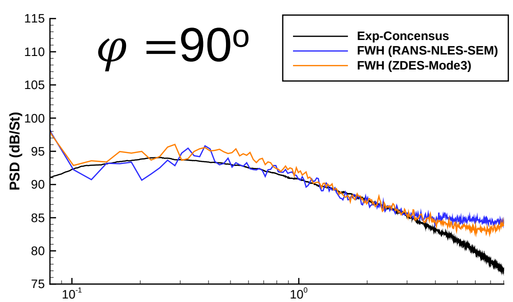
SP 7 Round Jet – Farfield Results

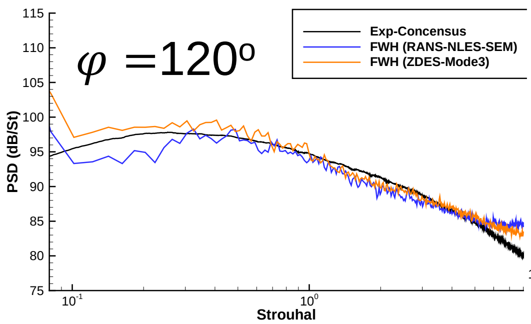


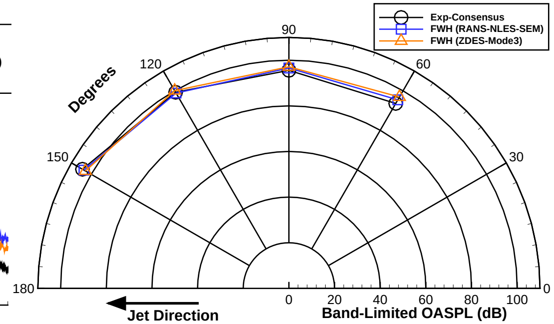


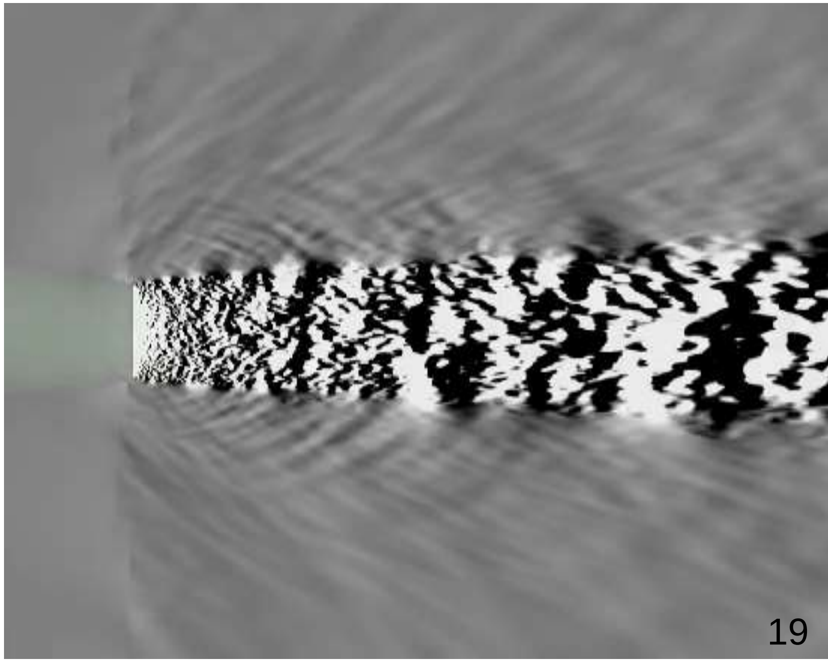
Housman, Jeffrey A., Gerrit-Daniel Stich, Cetin C. Kiris, and James Bridges. "Jet Noise Prediction using Hybrid RANS/LES with Structured Overset Grids." *23rd AIAA/CEAS Aeroacoustics Conference, AIAA AVIATION Forum*. 2017.



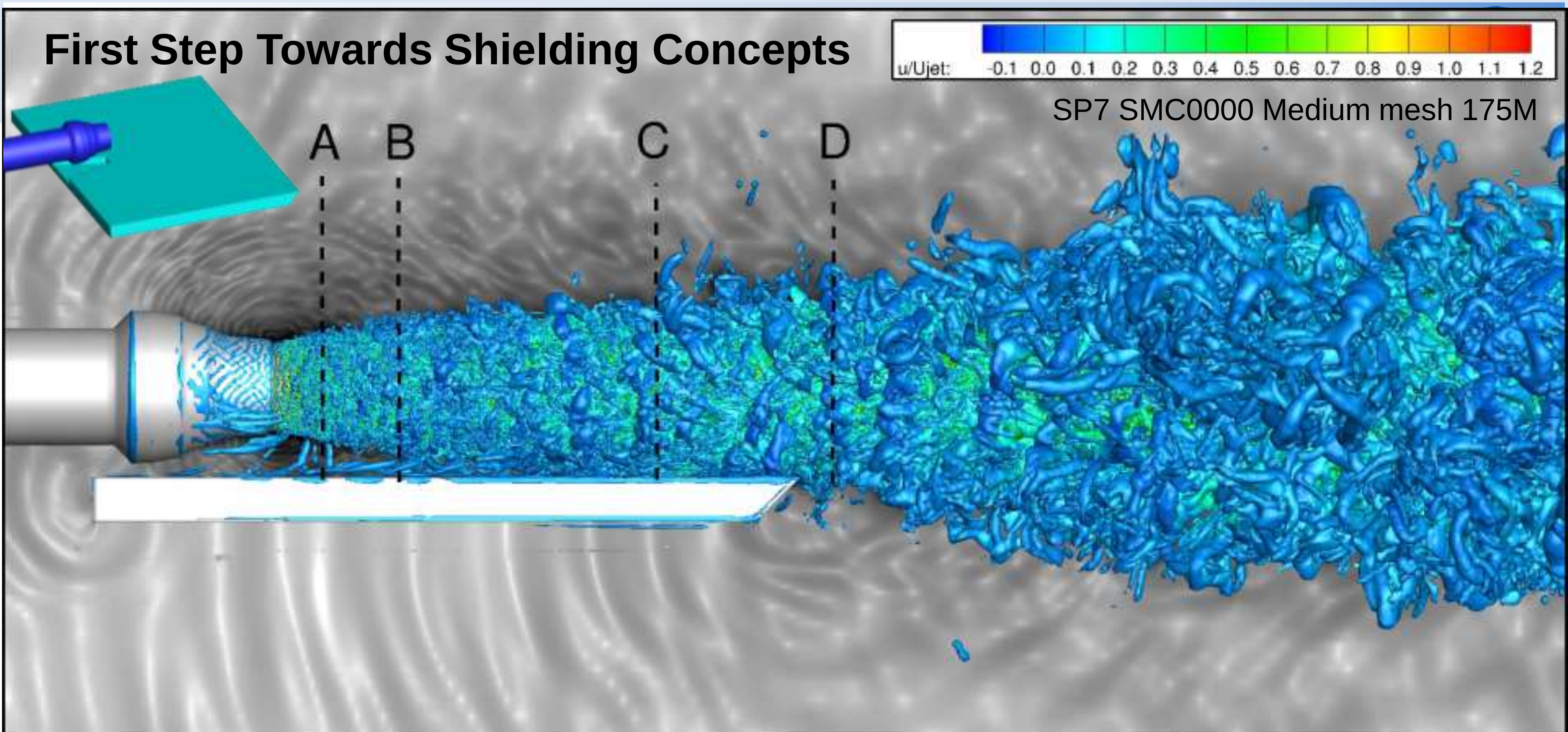


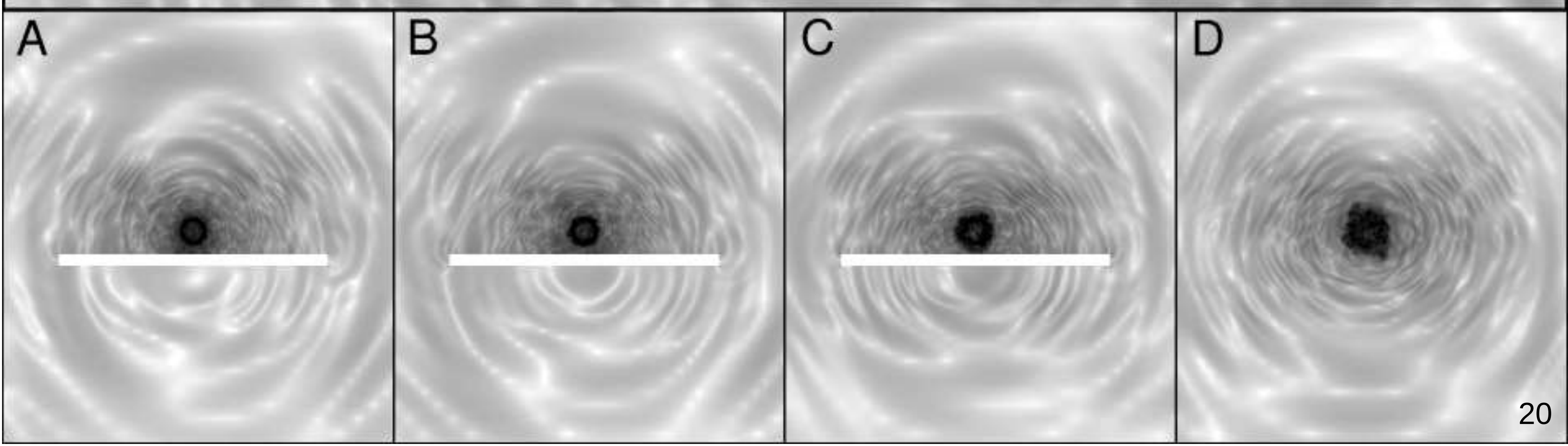






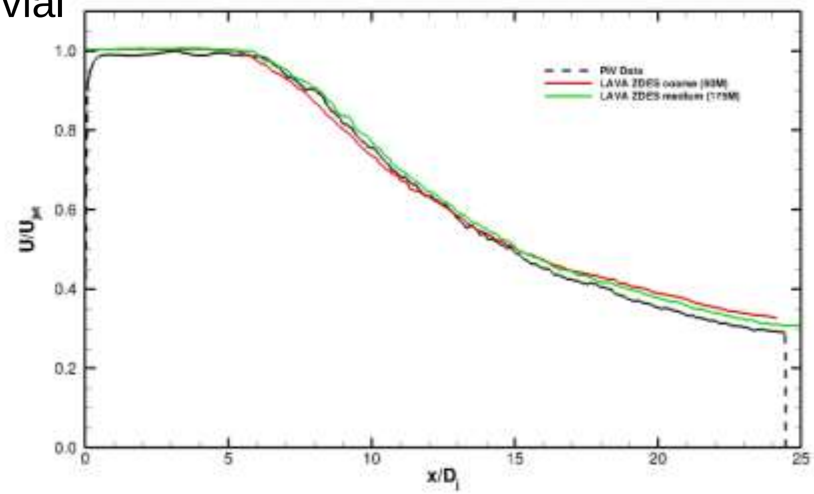
First Step Towards Shielding Concepts

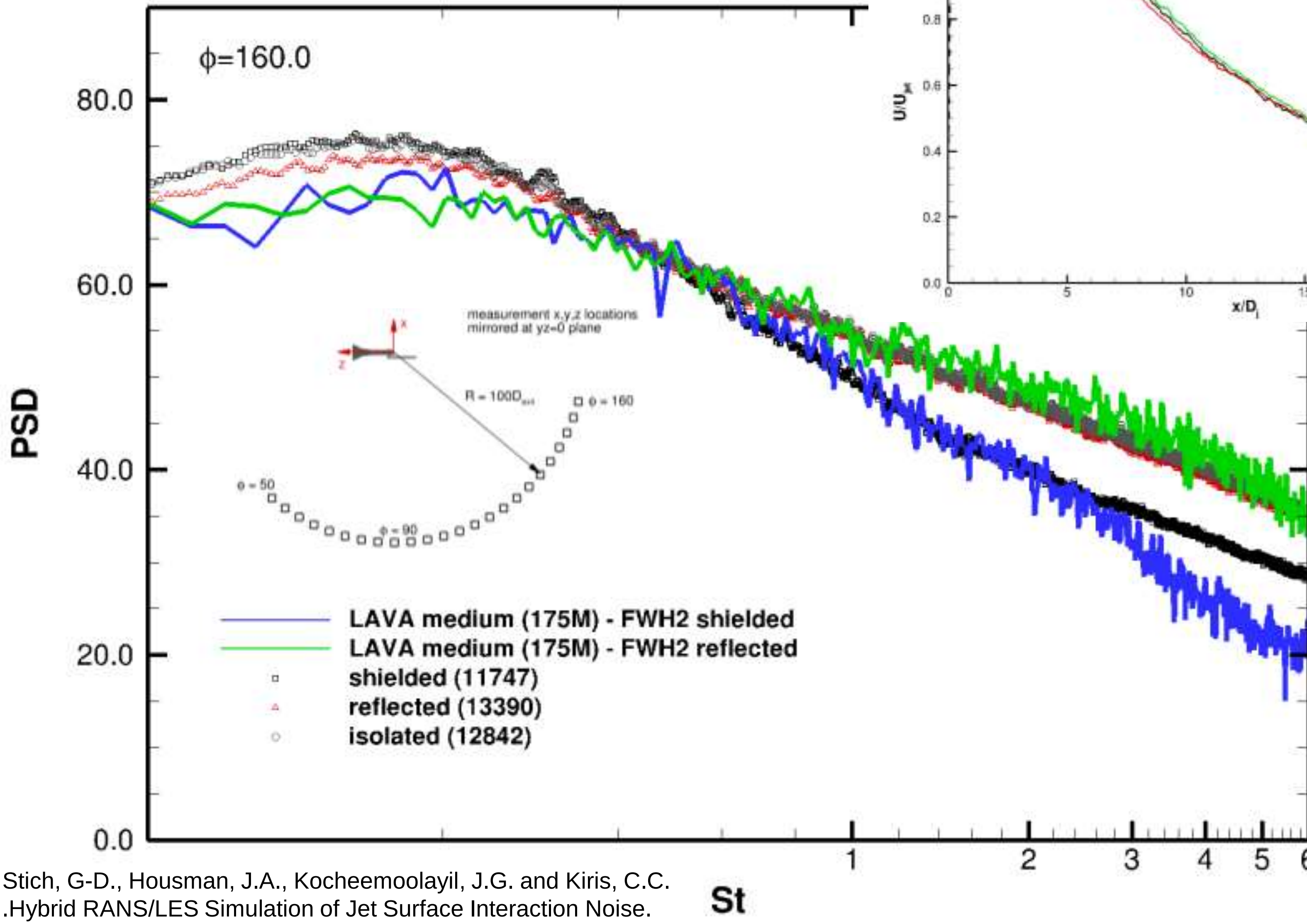




Capturing Shielding Effects

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





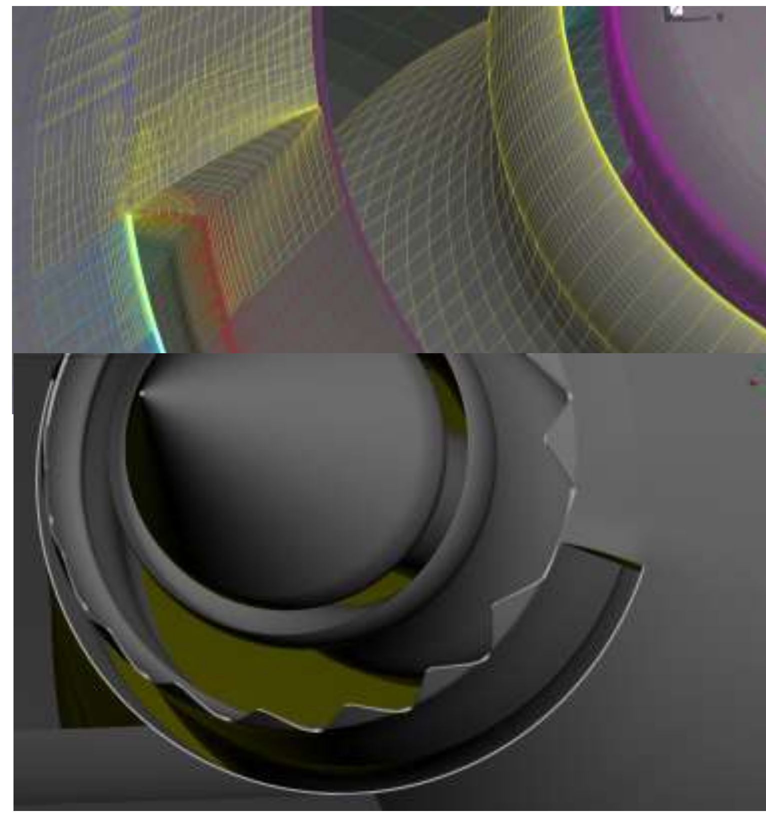
Stich, G-D., Housman, J.A., Kocheemoolayil, J.G. and Kiris, C.C. .Hybrid RANS/LES Simulation of Jet Surface Interaction Noise. AIAA-CEAS 2019. Delft. Netherlands.

Next Step Towards Radical Installation Concepts

Objective:

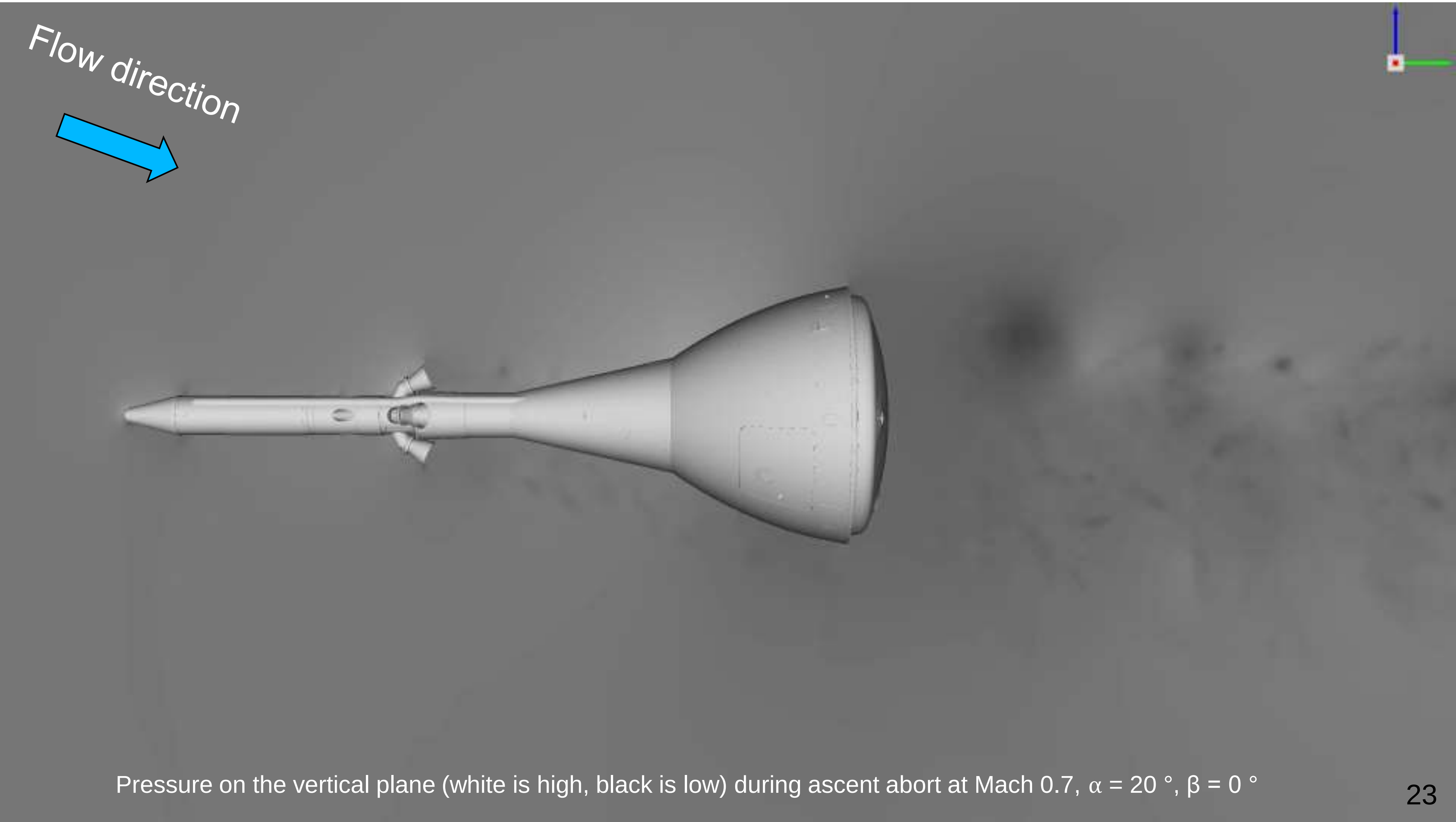
- ✓ Significantly increase complexity (last step before “grand challenge”).
- ✓ Multi-stream nozzle with shielding and installation effects.
- ✓ Comparison with comprehensive experimental database.

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, α = 20 °, β = 0 °

Acknowledgements

- ✓ This work was partially supported by NASA Human Exploration Mission Directorate (HEOMD) projects, along with the NASA Aeronautics Research Mission Directorate's (ARMD) Transformational Tools and Technologies (T^3), Advanced Air Transport Technology (AATT), Commercial Supersonic Transport (CST), and Revolutionary Vertical Lift Technology (RVLT) projects

- ✓ Computer time provided by NASA Advanced Supercomputing (NAS) facility at NASA Ames Research Center