# Launch Ascent and Vehicle Aerodynamics (LAVA)

## A NASA Mission-Critical CFD Solution - Gearing Up for Public Release

Presented by LAVA Team Leads:

**Michael Barad*, Emre Sozer*, Jeffrey Housman*, Jared Duensing***

LAVA Team:

Alexander Aghili**, Josh Anibal*, Chase Ashby*, Austin Bell*, François Cadieux*, Timothy Chau**, Chris DeGrendele*, Ercan Dumlupinar*,
Luis Fernandes**, James Jensen*, James Koch*, Brandon Lowe**, Nguyen Ly**, Daniel Maldonado*, Olivia Martin*, Scott Neuhoff*,
David Craig Penner**, Kiran Ravikumar**, Bram Rodgers*, Victor Sousa**, Gerrit-Daniel Stich**

*Computational Aerosciences Branch (ARC-TNA), NASA Ames Research Center
**Analytical Mechanics Associates (AMA), NASA Ames Research Center

Advanced Modeling & Simulation (AMS) Seminar Series, NASA Ames Research Center, June 12th, 2025

# LAVA Guiding Principles

- Strive for **highly agile** model development to support NASA's most challenging mission-critical needs

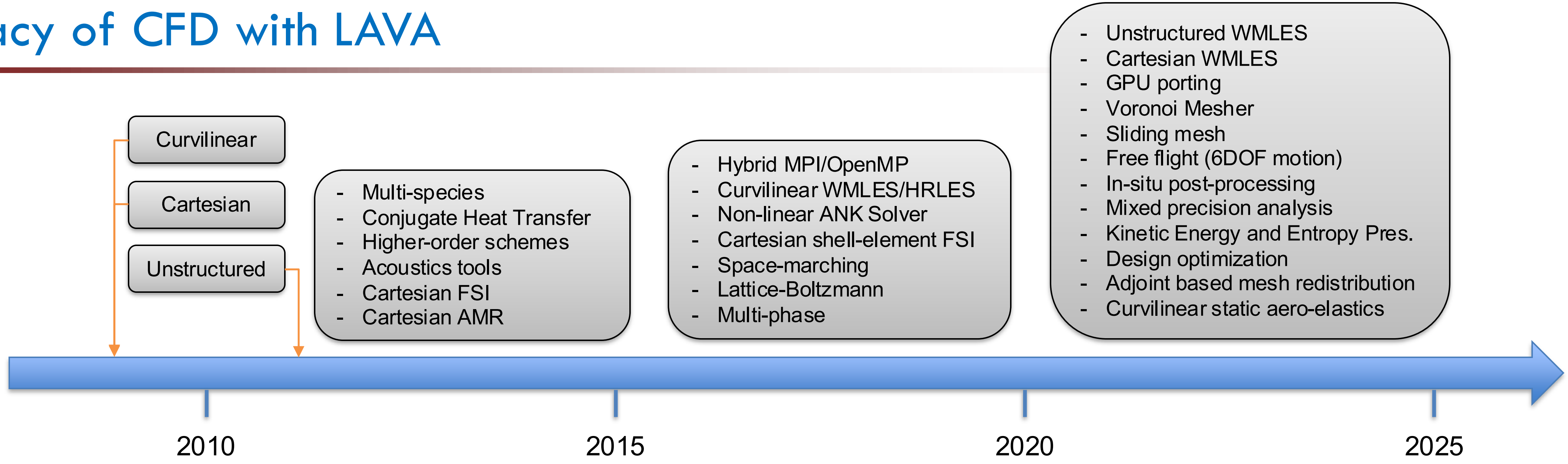
- Focus heavily on **accuracy, performance** and **robustness**
  - Enable large-scale simulations with relatively modest compute resources
  - Provide most efficient and appropriate grid paradigms for the application at hand

- **Reduce user-effort** and improve error-prone aspects of the CFD workflow
  - Automate meshing to the extent possible
  - Provide in-situ and post-processing tools

- Provide a **modern and flexible** software architecture with extensive continuous integration testing at scale

- Push the **state-of-the-art** in CFD and HPC

# Legacy of CFD with LAVA

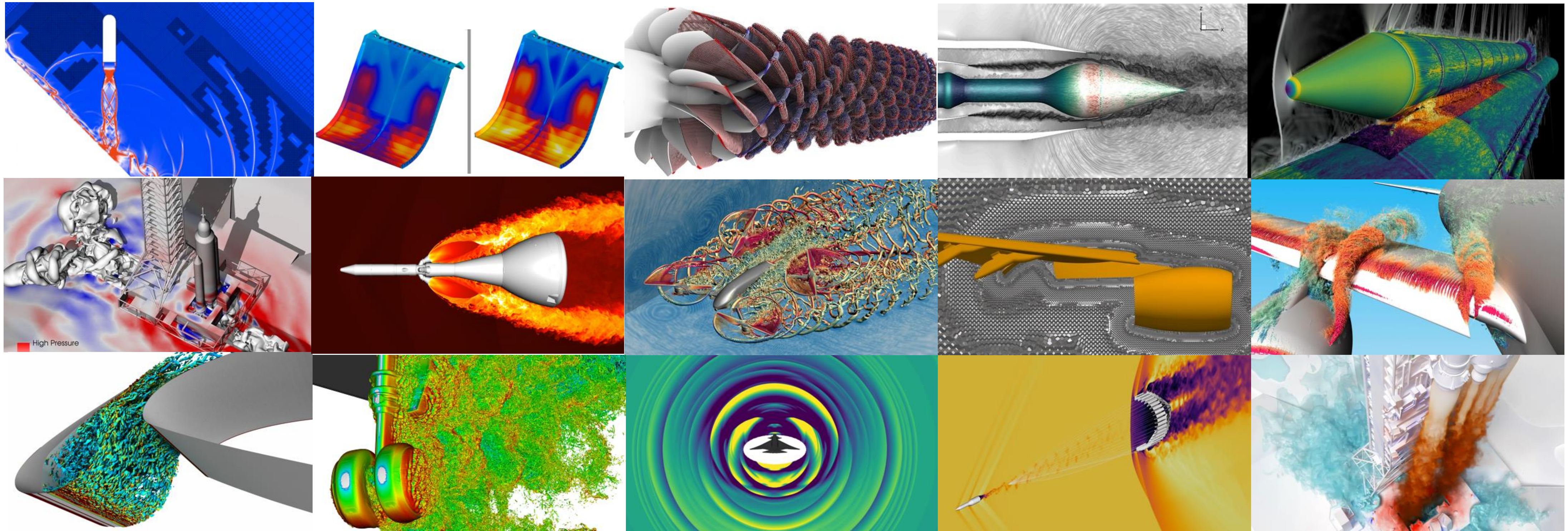


- Curvilinear
- Cartesian
- Unstructured

- Multi-species
- Conjugate Heat Transfer
- Higher-order schemes
- Acoustics tools
- Cartesian FSI
- Cartesian AMR

- Hybrid MPI/OpenMP
- Curvilinear WMLES/HRLES
- Non-linear ANK Solver
- Cartesian shell-element FSI
- Space-marching
- Lattice-Boltzmann
- Multi-phase

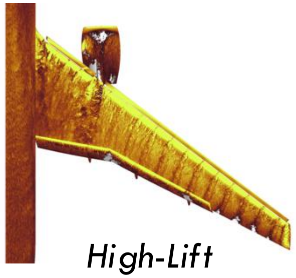
- Unstructured WMLES
- Cartesian WMLES
- GPU porting
- Voronoi Mesher
- Sliding mesh
- Free flight (6DOF motion)
- In-situ post-processing
- Mixed precision analysis
- Kinetic Energy and Entropy Pres.
- Design optimization
- Adjoint based mesh redistribution
- Curvilinear static aero-elastics



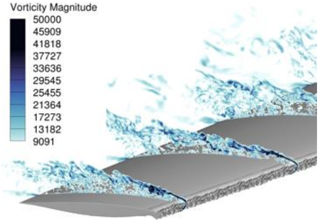
# Role of LAVA in NASA Missions

- LAVA has been utilized successfully across every NASA mission directorate
- Specific capabilities were often developed on-demand for unique simulation needs

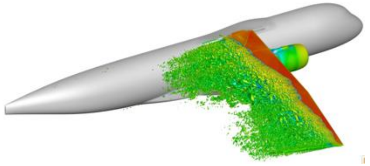
**Aeronautics**



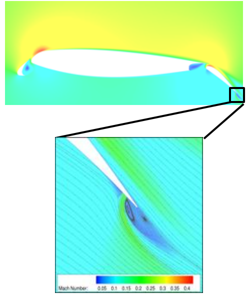
*High-Lift Aerodynamics*



*Iced Wing Aerodynamics*

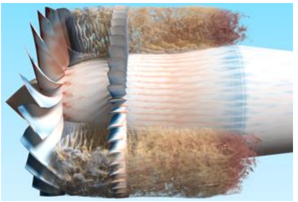


*Transonic Buffet*

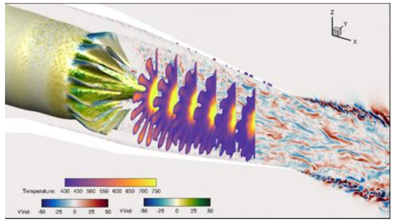


*Active Flow Control*

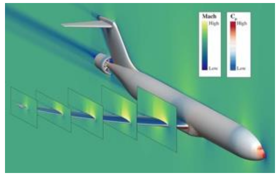
*Aircraft Design*



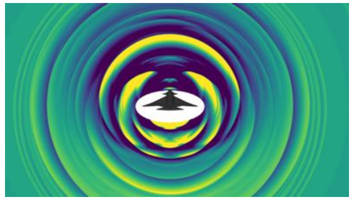
*Rotor Acoustics*



*Jet Acoustics*



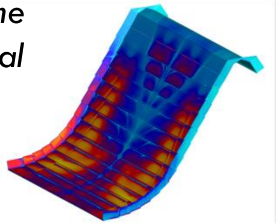
*Propulsion-Airframe Integration*

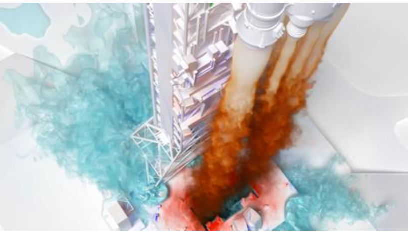


*Sonic Boom*

**Space and Science**

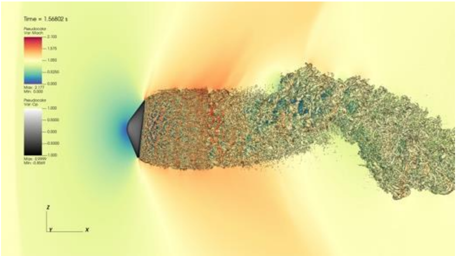
*Launchpad flame deflector thermal analysis*



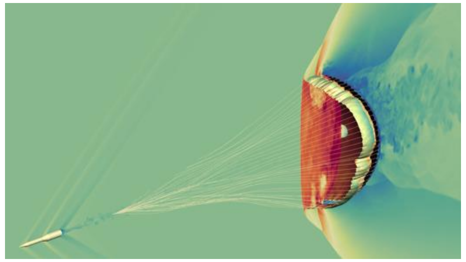


*Launchpad water-plume interactions*

*Orion Ascent Abort Acoustics*

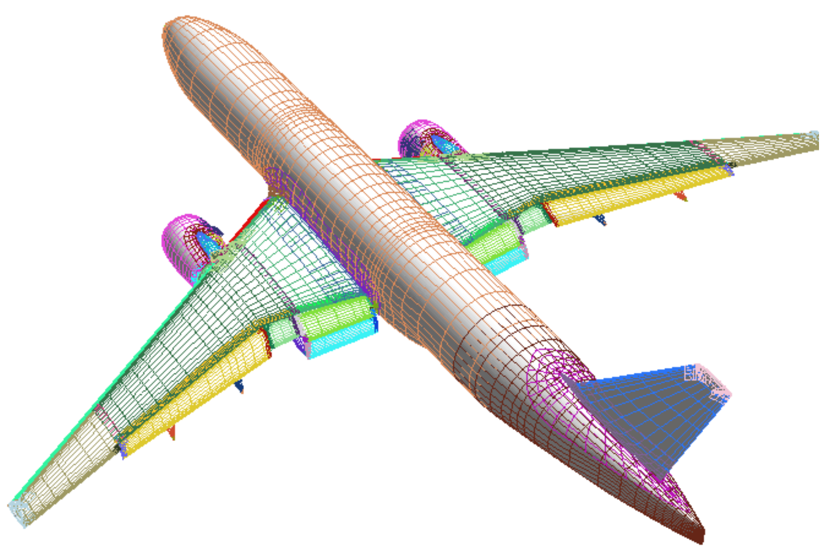
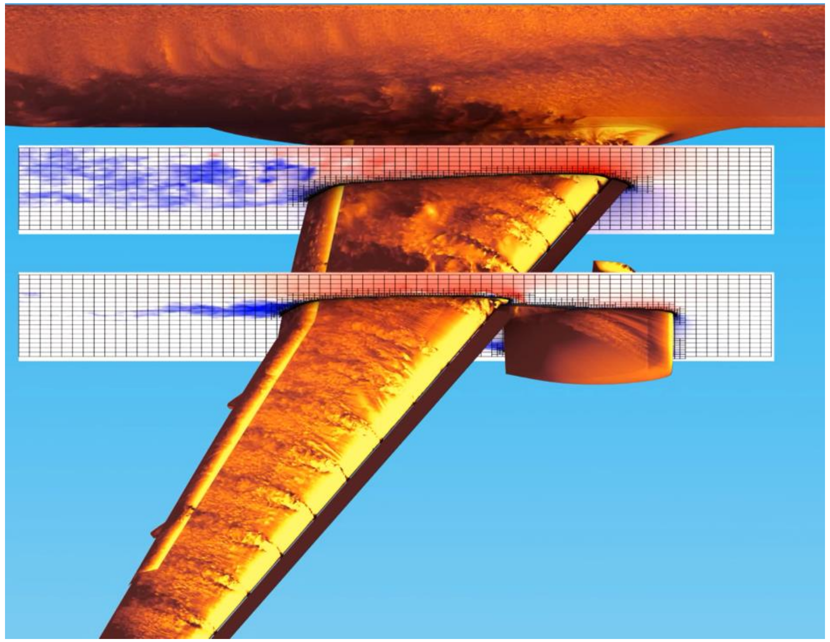
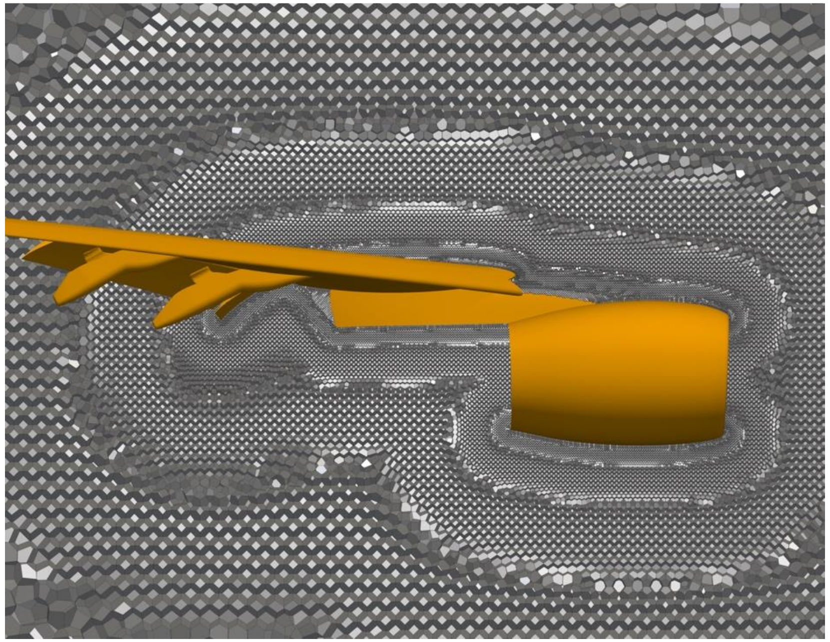


*Capsule Stability Assessments*



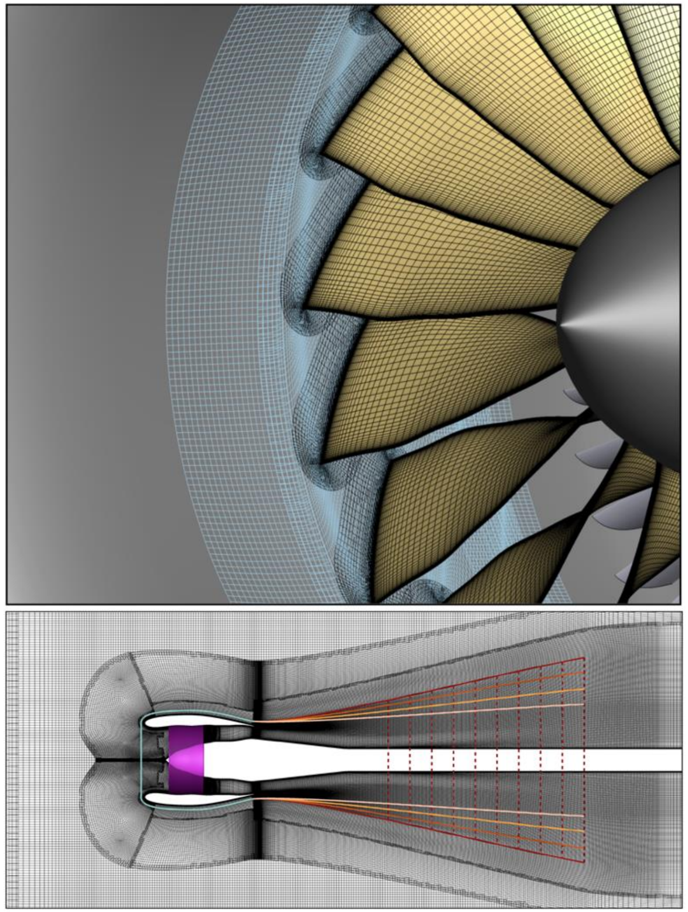
*High-Speed Parachute Dynamics*

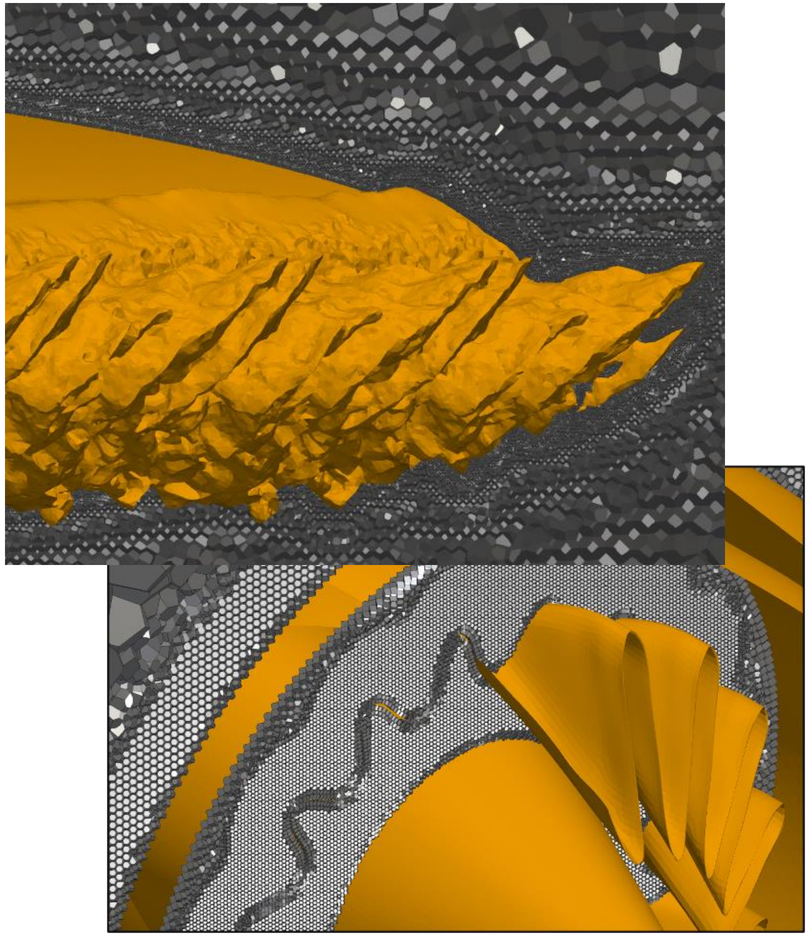
# LAVA supports three mesh types, with in-house meshing tools

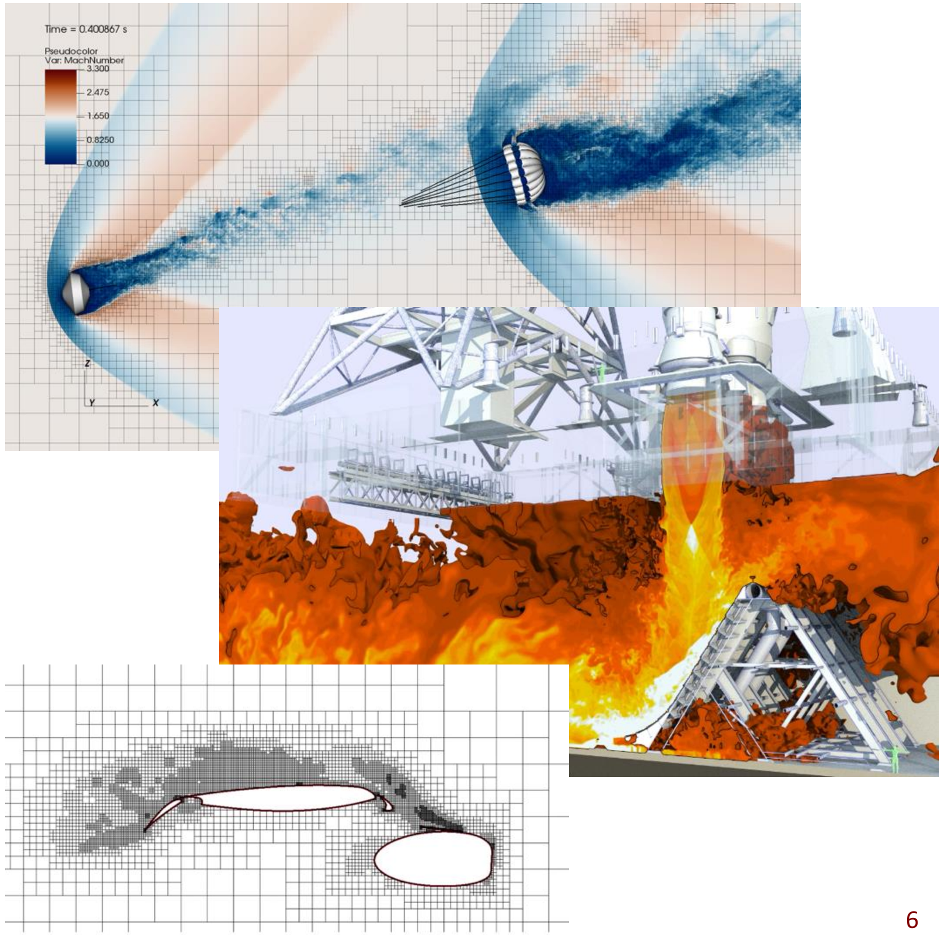
| Structured Curvilinear | Structured Cartesian | Unstructured Polyhedral |
|---|---|---|
|  |  |  |
| Largely manual grid generation | Automatic adaptive grid generation | Automatic grid generation |
| Low computational and memory cost | Low computational and memory cost | Higher computational and memory cost |
| Mature higher order methods | Mature higher order methods | Higher order methods less efficient and mature |
| Overset interpolation: not smooth | Factor of 2 refinements: not smooth | User prescribed mesh smoothness |
| Body-fitted | Immersed boundaries, non-body fitted | Body-fitted |

# Why Support 3 Mesh Types?

- Offers the flexibility to choose the most efficient and accurate type for the:
  - Problem at hand
  - User preference/level of expertise
- Enables code-to-code and mesh type sensitivity studies within a single framework







# LAVA CFD Solvers: Current Major Capabilities

| | **Cartesian** | **Curvilinear** | **Unstructured** |
|---|---|---|---|
| Meshing | Automated/AMR/Parallel | Manual | Automated/Parallel |
| Wall Modeling | Immersed boundaries | Body-fitted | Body-fitted |
| Spatial Discretizations | 2nd, 4th, 5th, 6th order | 2nd, 4th order | 2nd order |
| Time Discretizations | Explicit, 2nd, 3rd, 4th order | Explicit 3rd order or Implicit 2nd order | Explicit 3rd order or Implicit 2nd order |
| Body/Grid Motion | Prescribed, coupled rigid-body dynamics, or deformable (FSI) | Prescribed, FSI | None |
| Physics | Multispecies, multiphase, fluid-structure interaction (FSI), large-eddy simulation (LES), Wall-Modeled LES (WMLES) | Reynolds-Averaged Navier-Stokes (RANS), Hybrid RANS-LES (HRLES), LES, WMLES | Multispecies, RANS, LES, WMLES, Conjugate Heating |
| Mesh transitions | Octree interlevel operators | Overset interpolation or multi-block | Fully conformal |

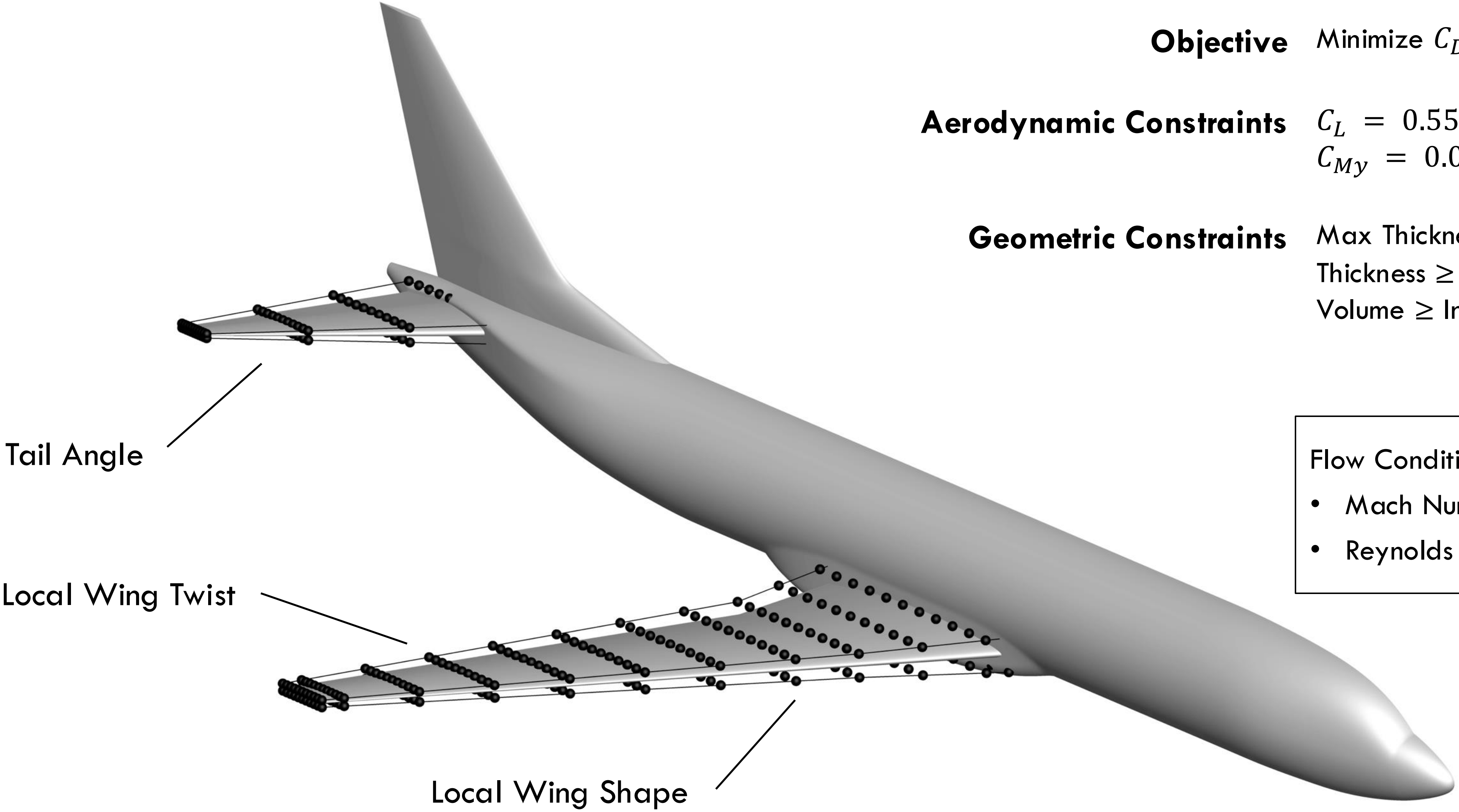
# LAVA MDAO/Design Tools

Featuring:

- Structured Curvilinear

# Gradient-based Aerodynamic Shape Optimization

LAVA's gradient based shape optimization empowered using the discrete-adjoint approach.
We demonstrate this capability with the optimization of a 737-8-like aircraft design.



**Objective** Minimize $C_D$

**Aerodynamic Constraints**

$C_L = 0.556$

$C_{My} = 0.0$

**Geometric Constraints**

Max Thickness-to-Chord Distribution

Thickness ≥ 80% Initial Thickness

Volume ≥ Initial Volume

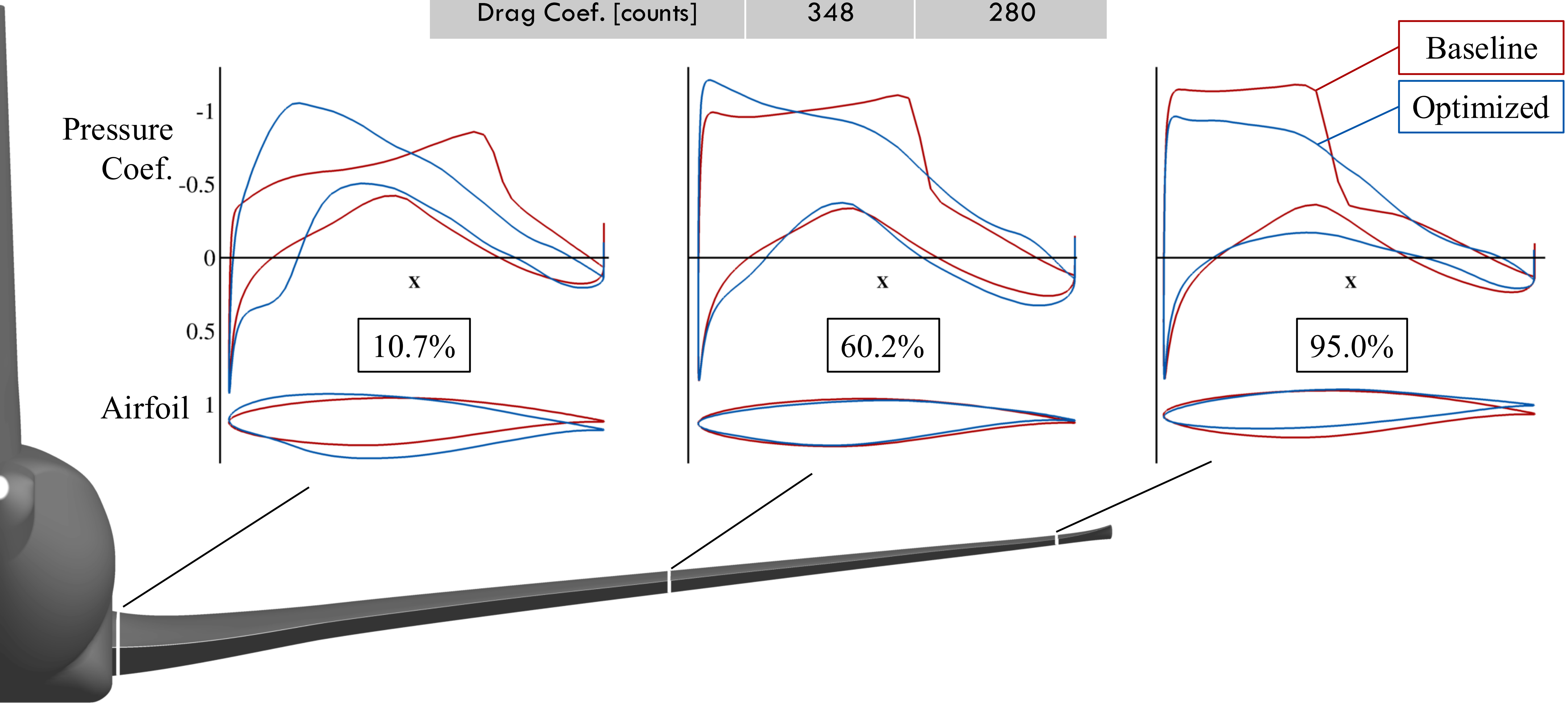
Flow Conditions

- Mach Number: 0.785
- Reynolds Number: 24.1 million

# Gradient-based Aerodynamic Shape Optimization

LAVA successfully reduced the drag of the design and eliminated shocks across the wing while satisfying lift and pitching moment constraints

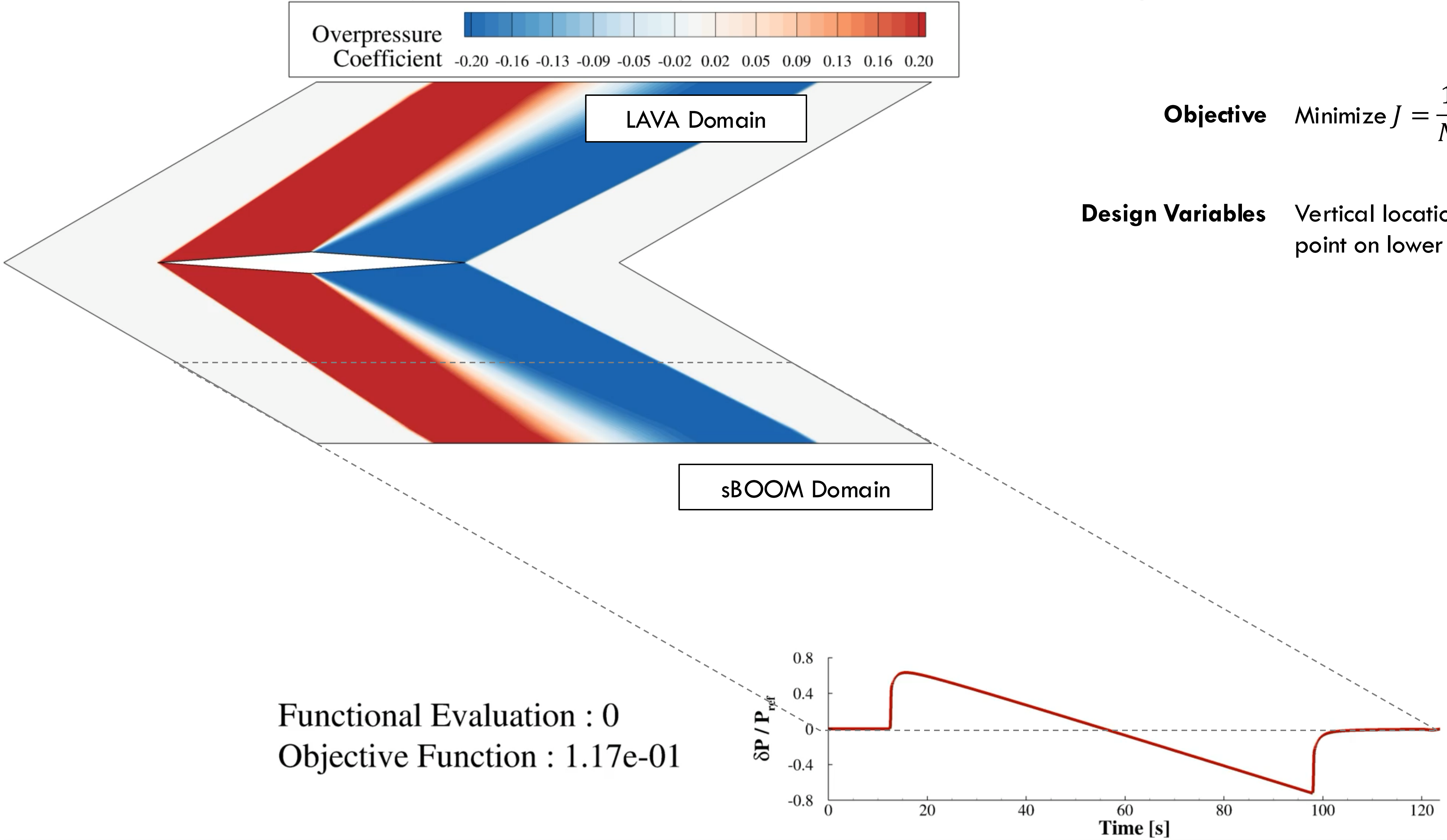
| | **Baseline** | **Optimized** |
|---|---|---|
| Drag Coef. [counts] | 348 | 280 |



# Gradient-based Aerodynamic Shape Optimization

LAVA has been coupled to NASA's advanced sonic boom propagation tool, sBOOM.

This enables RANS based ground-level noise optimization for future low-boom supersonic aircraft



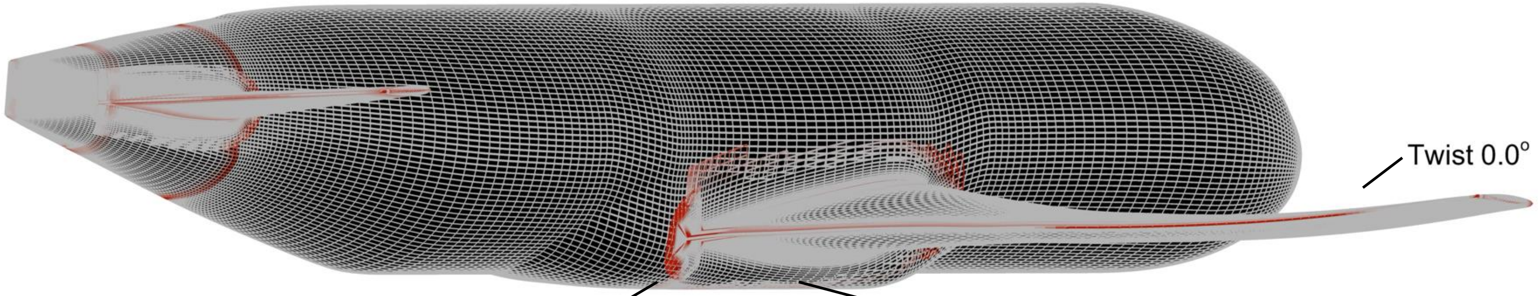
Functional Evaluation : 0
Objective Function : 1.17e-01

**Objective** Minimize $J = \frac{1}{N}\sum_{i}^{N}\left(\frac{\delta P_{i,SB}}{P_{\infty}}\right)^2$

**Design Variables** Vertical location of inflection point on lower surface

# Immersed-boundary Overset Approach

We are working towards the application of an immersed-boundary-overset method to remove the need for collar grids and dramatically increase the freedom of the design space for shape optimization

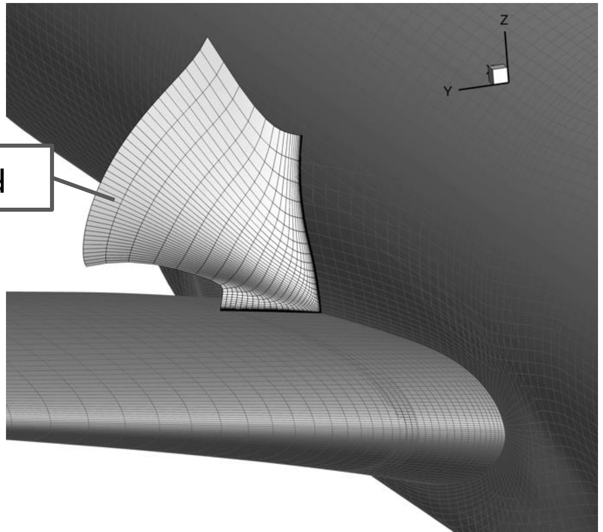


Twist 0.0°

Highly stretched
cells in collar grid

Poor quality cells
due to deformation

**Body-Fitted** method



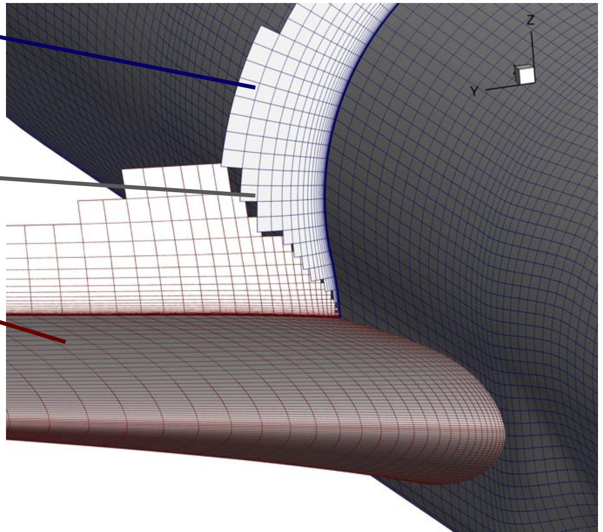
Collar grid

**Immersed Boundary** method

Fuselage Grid

Overset region

Wing Grid



# Immersed-boundary Overset Grid Approach

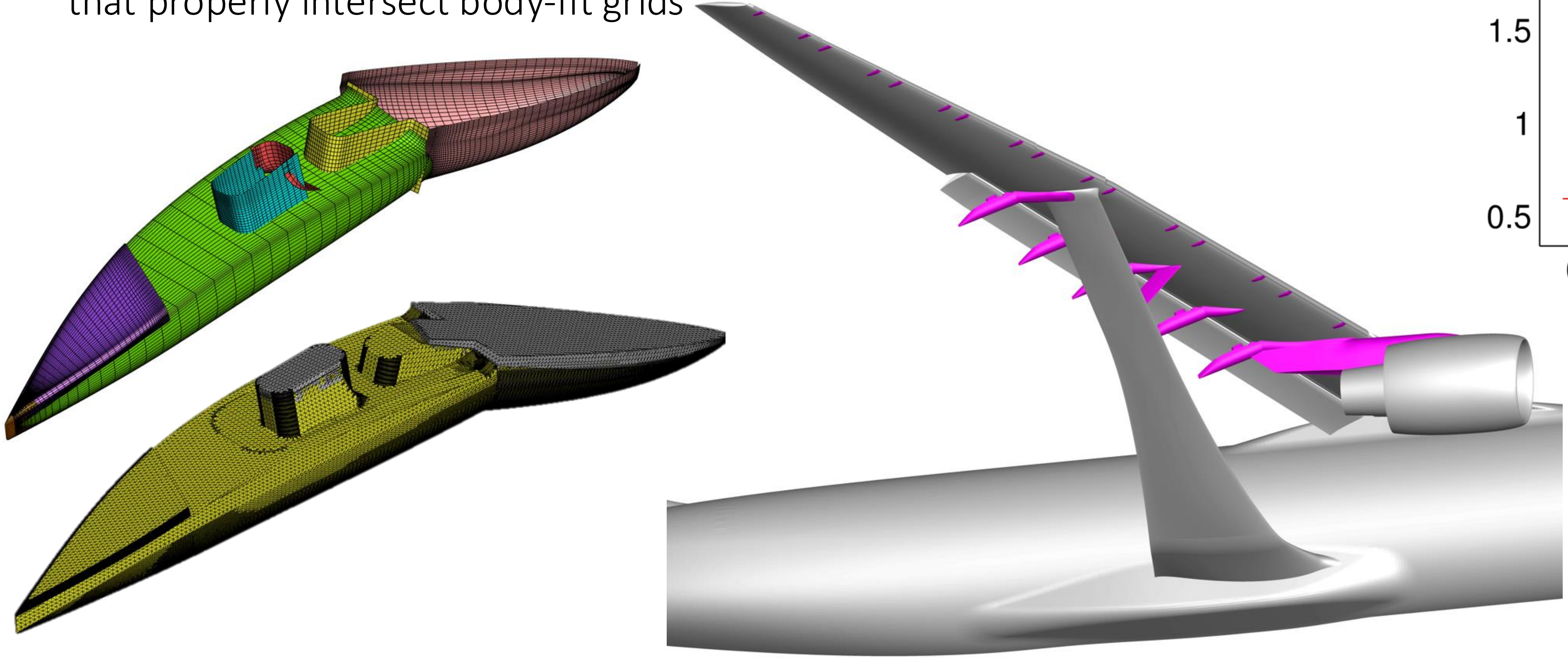
## Approach

Generate standard body-fitted grids on geometrically simple components

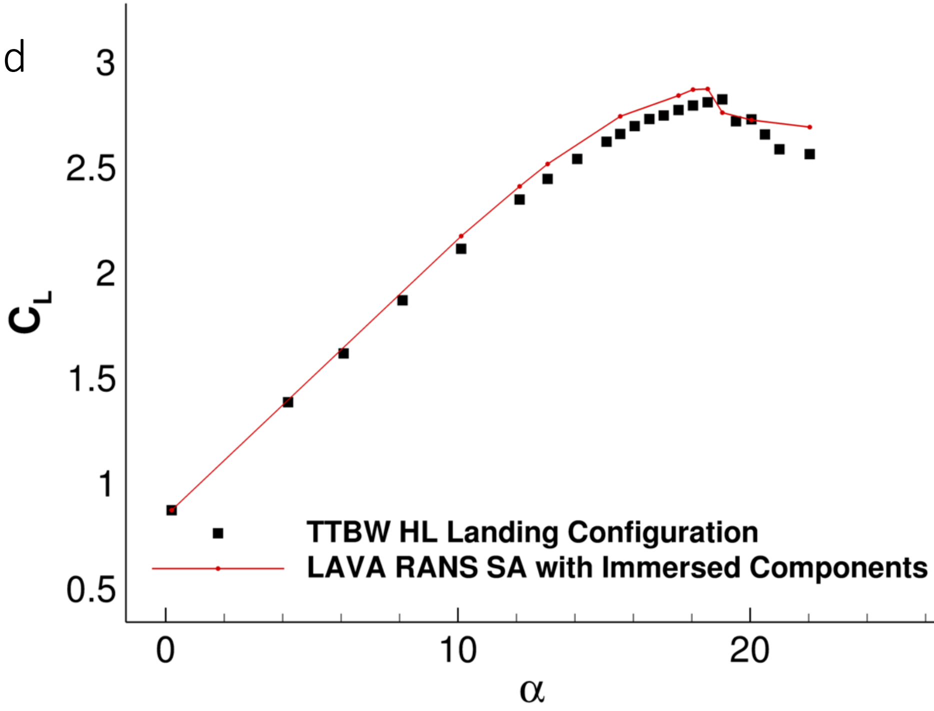
Create ”almost body-fitted” grids around complex geometric components that properly intersect body-fit grids

## Final Grid System

Includes almost-body-fitted immersed grids for complex components and intersections in yellow



## Results

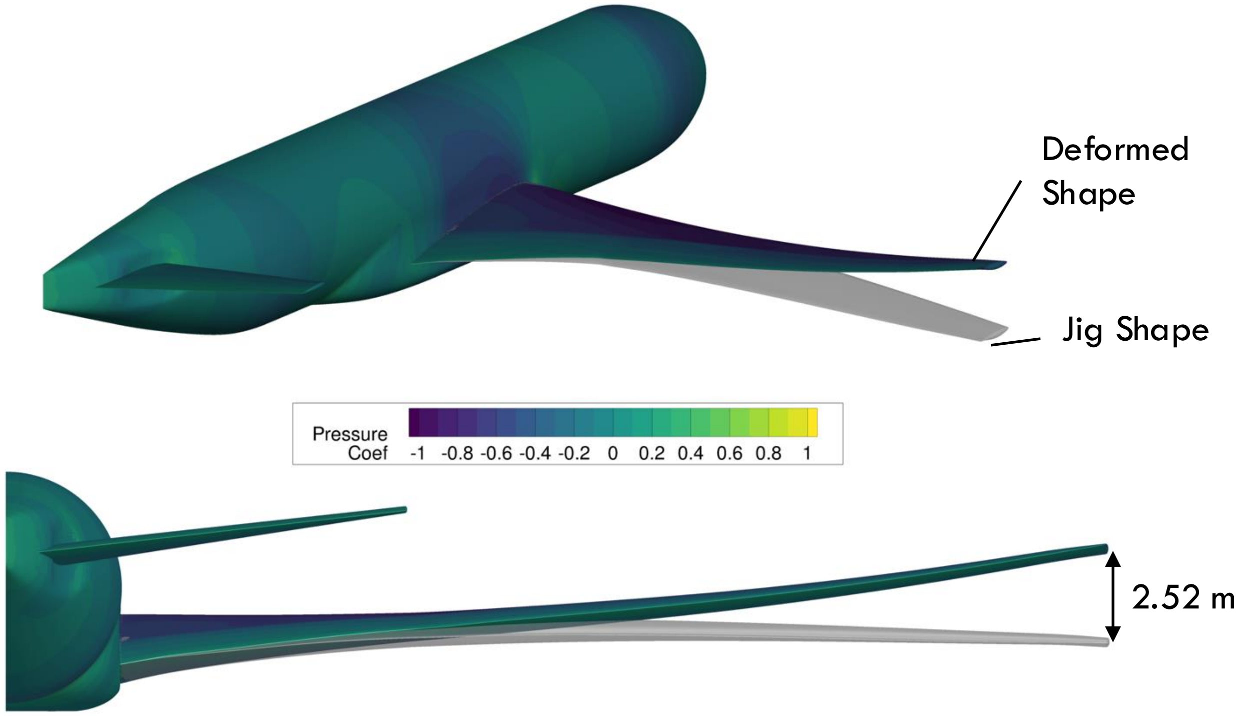


# Multi-disciplinary Optimization and Analysis

The LAVA curvilinear CFD solver has been successfully interfaced with OpenMDAO/MPhys

- OpenMDAO is an existing open-source optimization framework and a platform for building new analysis tools with analytic derivative*
- The LAVA interface allows straightforward coupling to other disciplinary solvers in OpenMDAO platform
  - aerostructural analysis and optimization
  - propulsion airframe integration (PAI)
  - aerothermal analysis and optimization

| | **LAVA + MELD + TACS** | **ADFlow + TACS (Brooks et al. 2018)** | **Relative Difference** |
|---|---|---|---|
| Drag Coef. [counts] (extrapolated) | 223.9 | 223.0 | 0.435% |
| Vertical Tip Deflection [m] (extrapolated) | 2.521 | 2.596 | 2.88% |



LAVA+MELD+TACS aerostructural analysis of the undeflected CRM (uCRM-9) case by Brooks et al. 2018.

---

*https://openmdao.org

# Open-Rotor Aeroacoustics

Featuring:

- Structured Curvilinear with Sliding Mesh

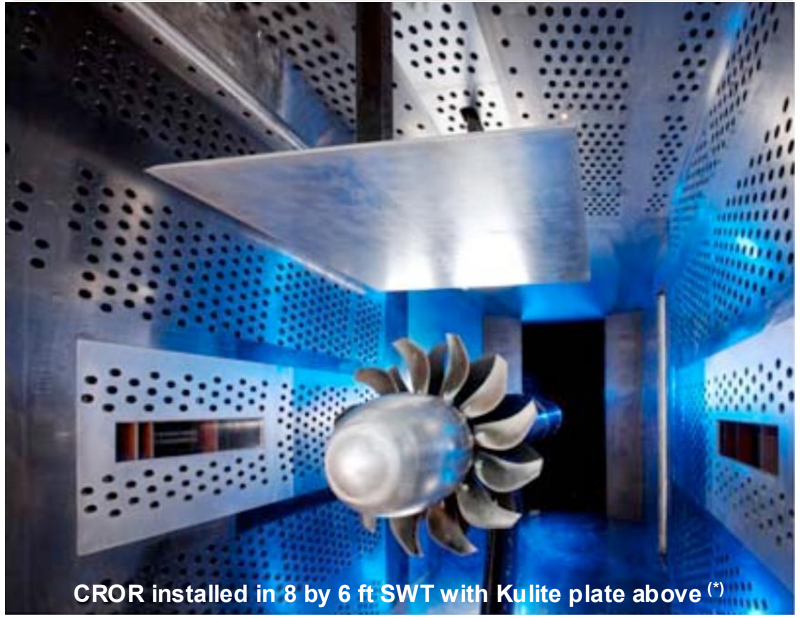
# Open Rotor Aeroacoustics

- Open rotor propulsion systems are potential candidates for future commercial transport aircraft
  - Offer potential for substantial fuel efficiency
  - Significant reduction of $CO_2$ emissions
  - Biggest drawback is acoustic emissions with increases of directional noise up to 30 dB

- Utilizing LAVA's highly efficient ***sliding mesh*** approach allows these complex noise generation mechanisms to be investigated

- Combined with LAVA's Ffowcs Williams-Hawking Acoustic Propagation tool enables the prediction of far-field directional noise

CROR installed in 9 by 15 ft Low Speed Acoustic Wind Tunnel(*)



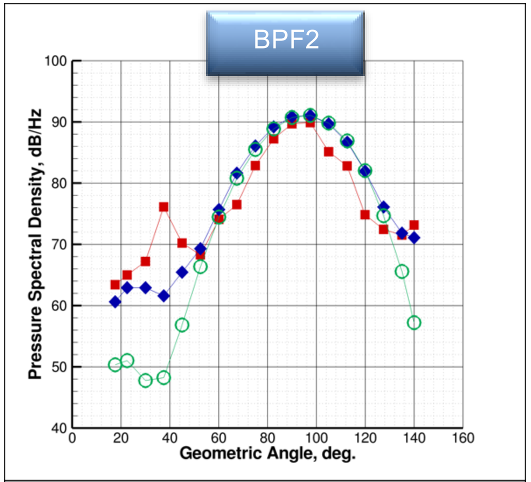
CROR installed in 8 by 6 ft SWT with Kulite plate above (*)

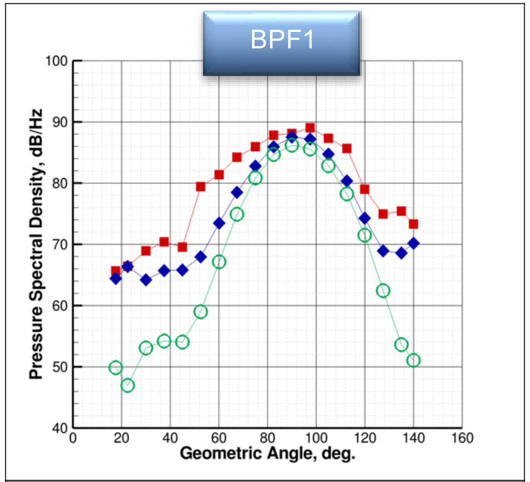
---

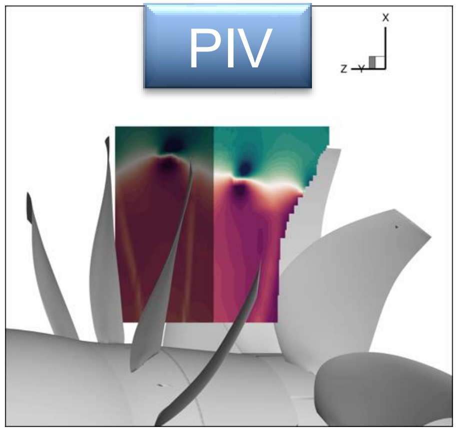
(*)Stephens, D. B., "Data Summary Report for The Open Rotor Propulsion Rig Equipped with F31/A31 Rotor Blades," NASA/TM-2014-216676, 2014.

# Open Rotor Aeroacoustics: Low Speed Validation

- Good agreement in tonal noise predictions are observed at the Kulites
- At larger frequency interaction tones, such as BPF1 + 3BPF2, HRLES is necessary to predict the correct noise amplitudes (compared to URANS)
- PIV comparisons indicate the proper capturing of the forward blade row wake interaction with the aft blade row

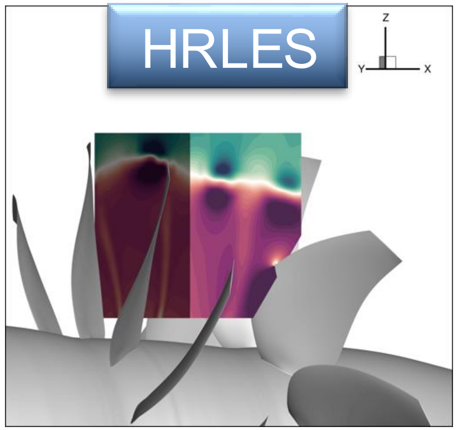


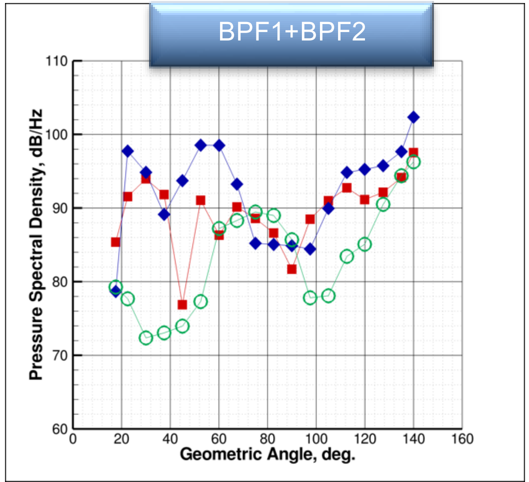


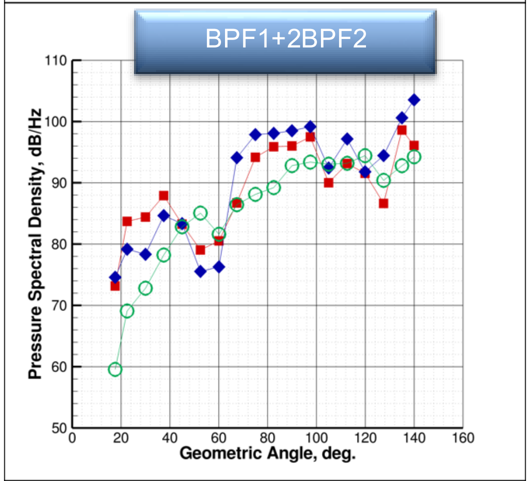


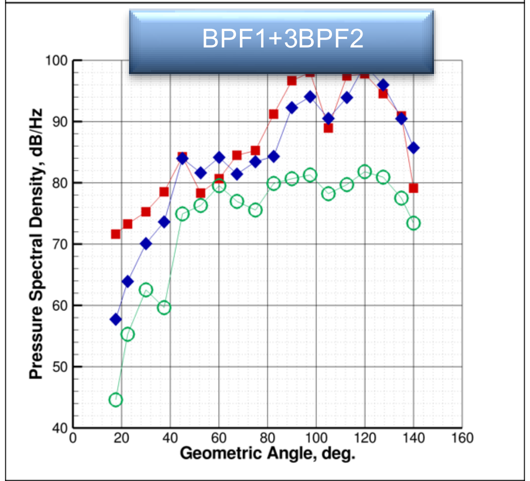
■ Exp. D074 - 470
◆ HRLES
○ URANS

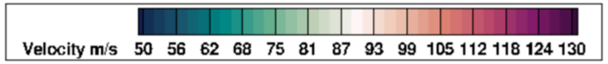
BPF – Blade Passing Frequency





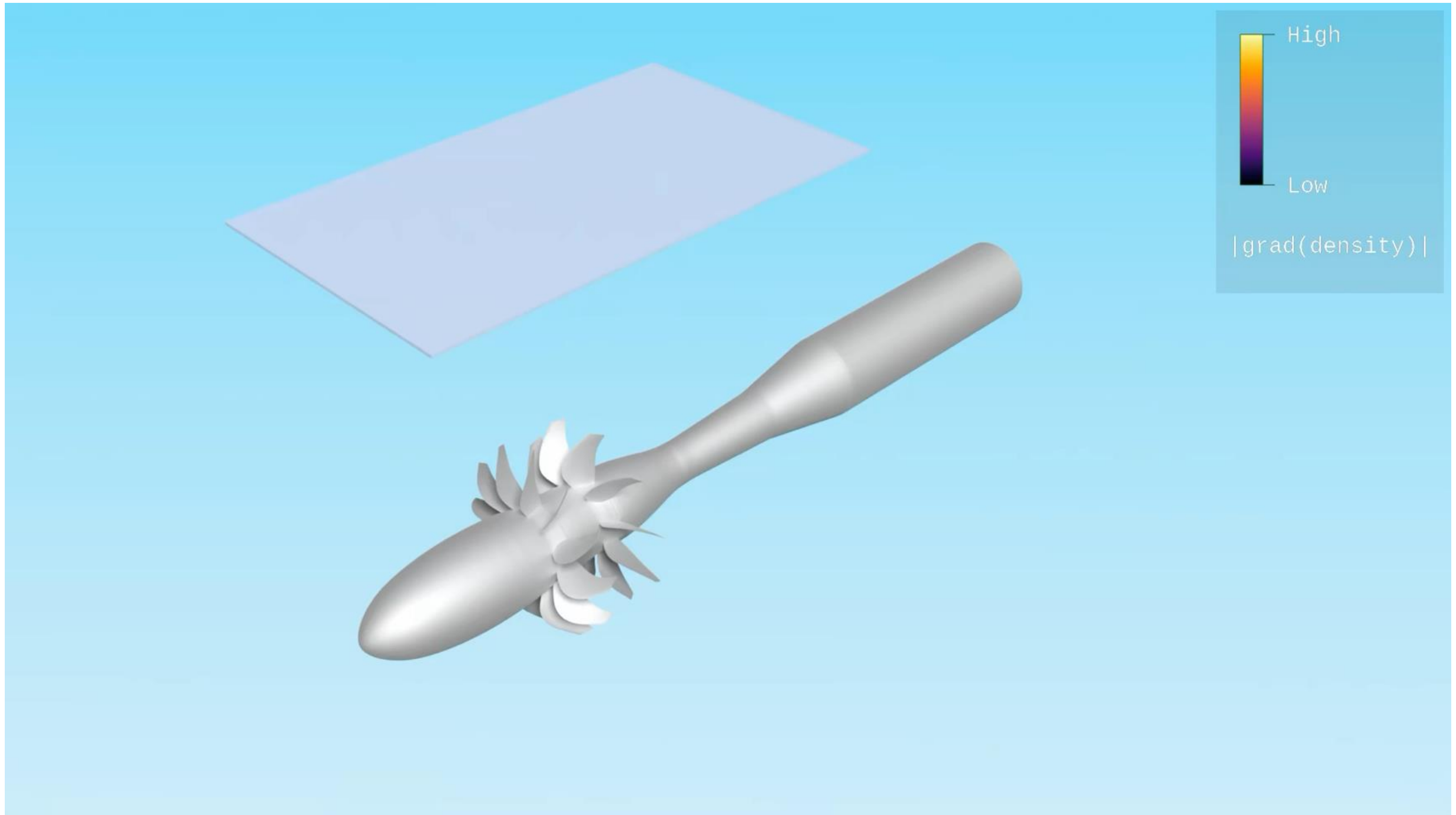


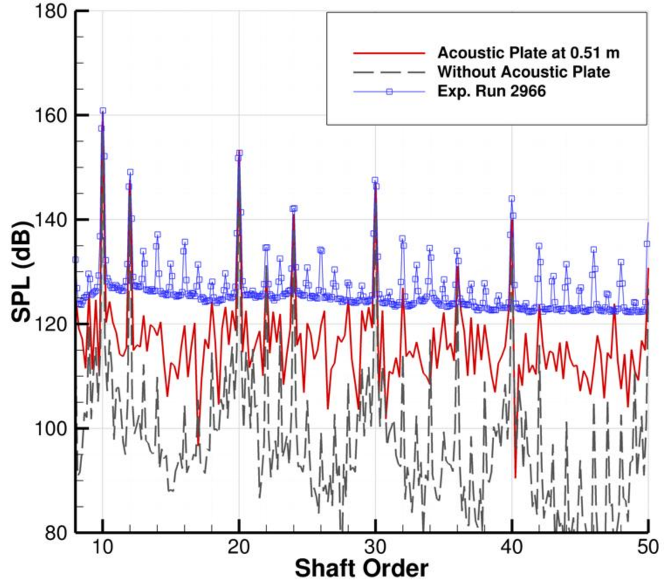




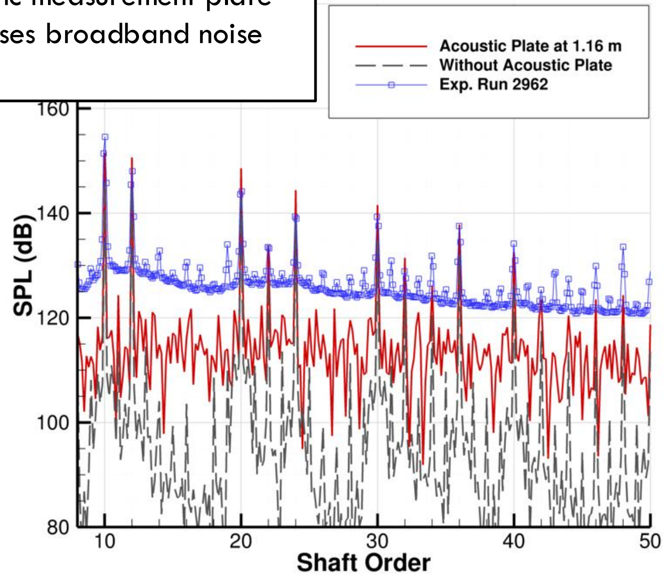
# Open Rotor Aeroacoustics: Effect of Acoustic Measurement Plate

- Sliding mesh approach is not restricted to simple multi-stage analysis (see below) or axisymmetric configurations (see Dumlupinar et al AIAA-2023-0028, AIAA-2024-2807, AIAA-2024-3679 and dos Santos Fernandes et al AIAA-2023-0793, AIAA-2024-3228
- Method currently being applied to new commercial open rotor concepts (E. Dumlupinar) as well as an Open Fan design being developed at NASA Glenn (L. dos Santos Fernandes)





Acoustic measurement plate increases broadband noise levels



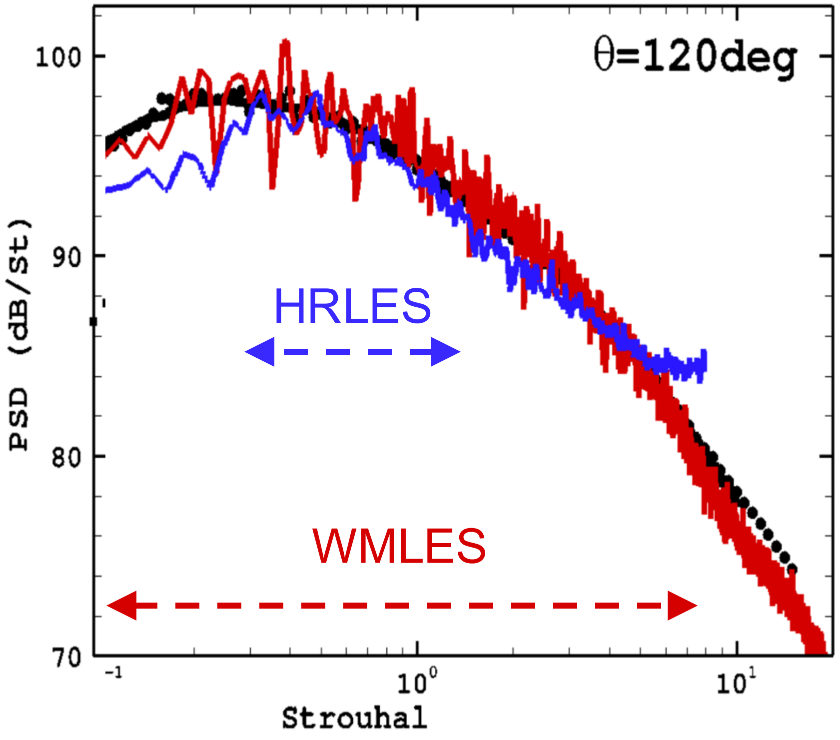
# Jet Noise

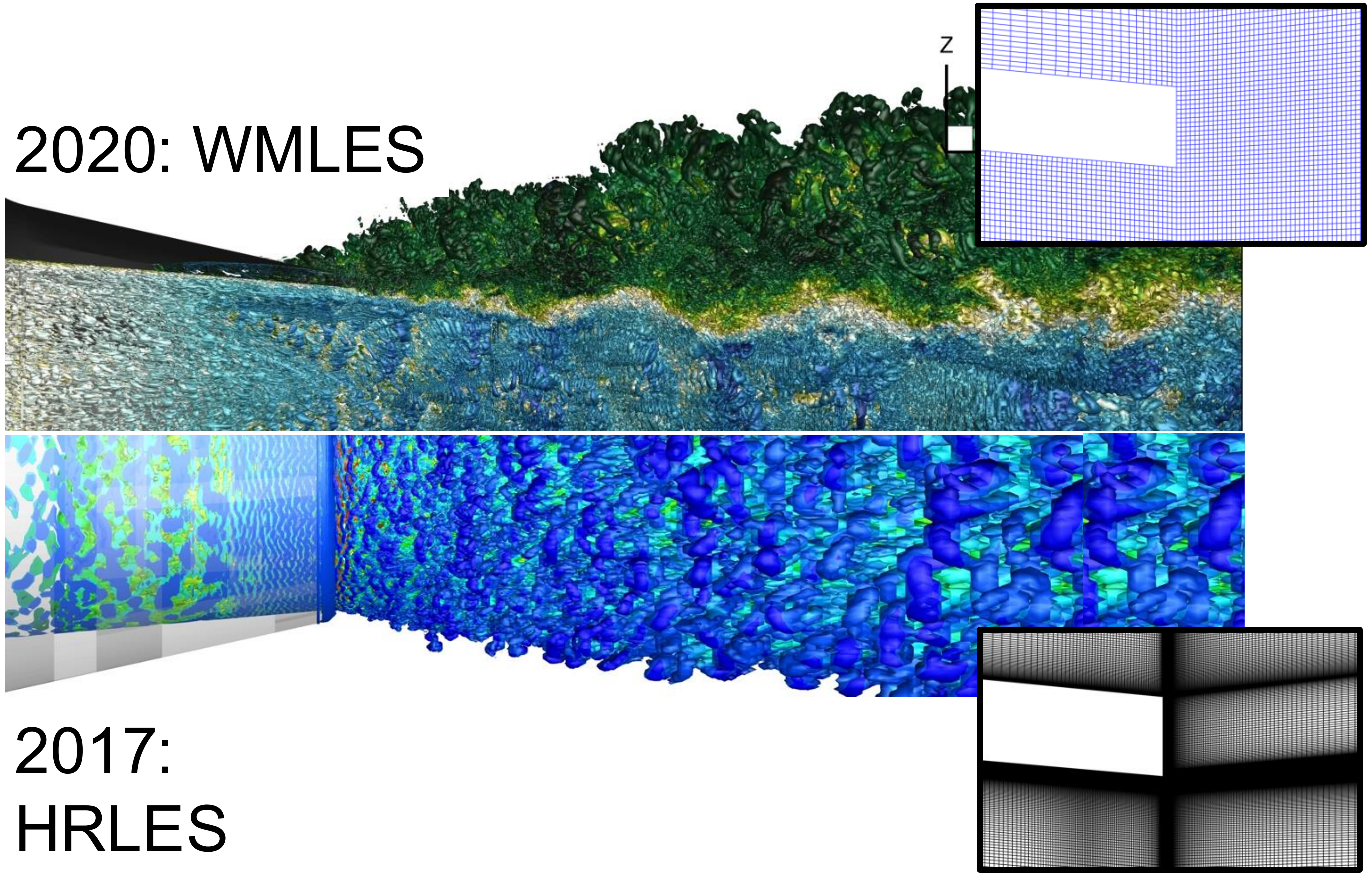
Featuring:

- Structured Curvilinear
- Unstructured Voronoi

# Progress in Jet Noise

- Starting in 2017 with Hybrid RANS-LES we were limited in both the high frequency range (accuracy) and low frequency range (efficiency)
- Introduction of WMLES capabilities into the flow solver extended the upper frequency range by a decade (higher accuracy)



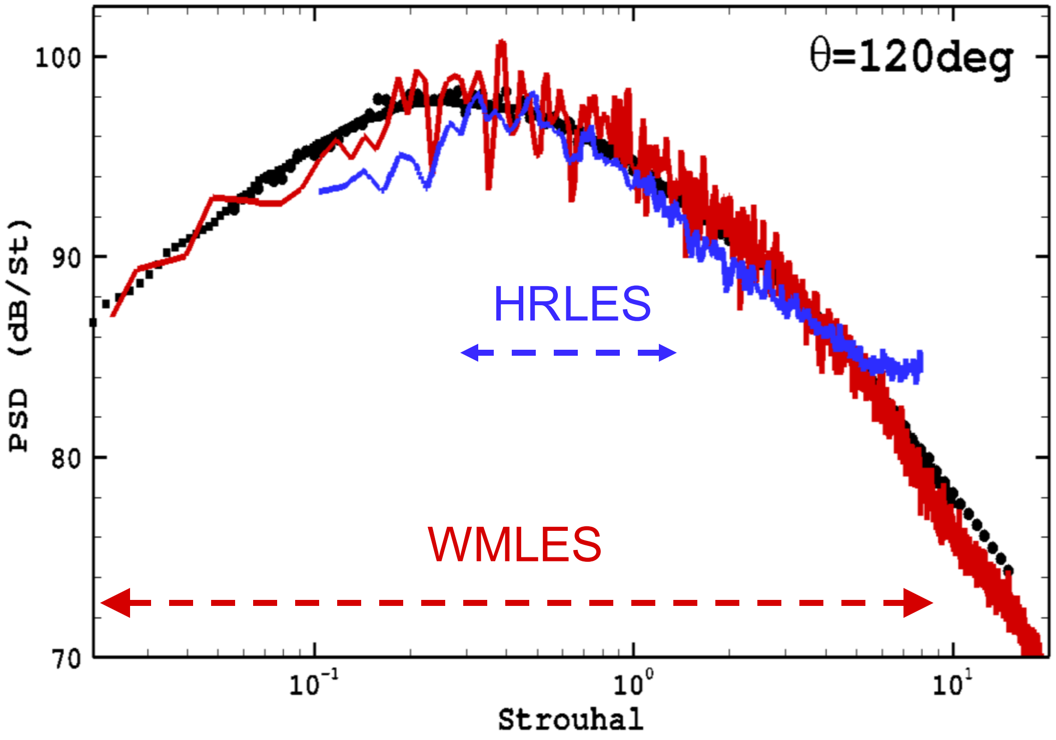


2020: WMLES

2017:
HRLES

# Progress in Jet Noise

- Source code optimizations along with computational hardware improvements reduce the turnaround time for LES simulations resulting in extended low frequency range as well (increase efficiency)



**Path towards a robust, reliable and fast WMLES solver for jet noise database generation**

**November 2019 (Curvilinear CPU)**

| | |
|---|---|
| Hybrid RANS/LES | 6.5 days [100 Broadwell] |

**2024 (Curvilinear CPU)**

| | |
|---|---|
| WMLES + Optimized Code | 14hrs [100 Rome] |

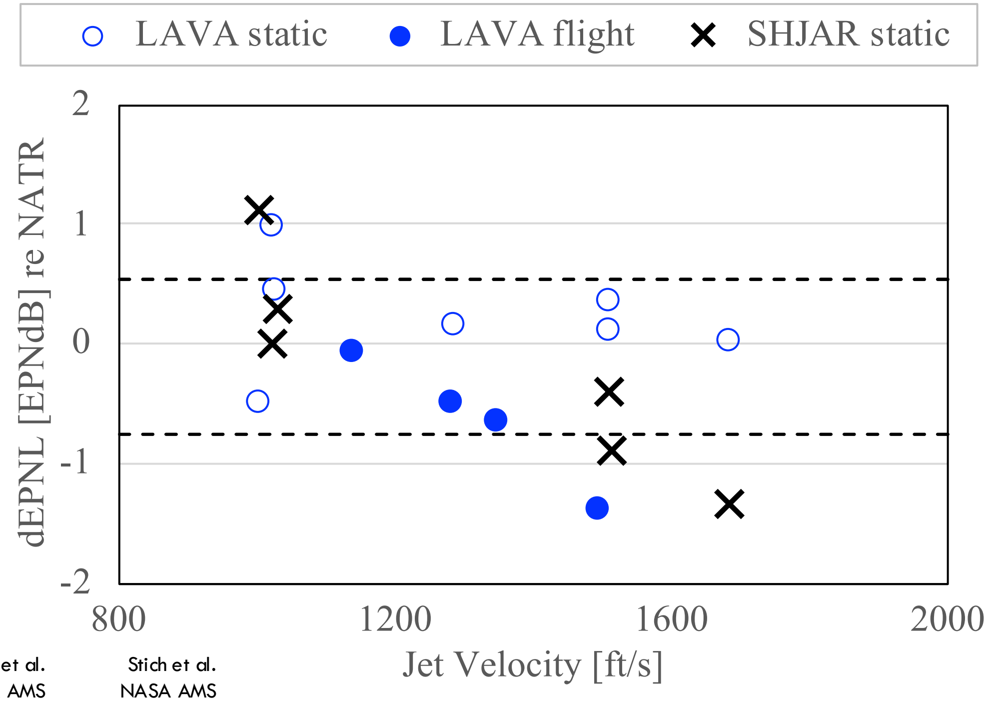
**Current (Voronoi GPU)**

| | |
|---|---|
| WMLES + GPU | 2hr [16 GH200] |

# LES Acoustic Database Generation

- LAVA’s accurate and efficient LES simulation tool enables jet noise database generation
- Discrepancies in component EPNL as a function of jet velocity are summarized in a histogram
- LES-Rig discrepancies are within those observed in Rig-Rig differences for static points

Disparity between LES, NATR, SHJAR



Stich et al.
AIAA2022-3022

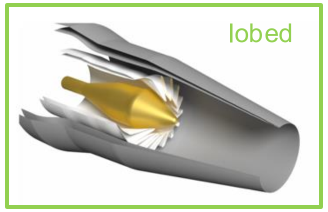
Stich et al.
NASA AMS

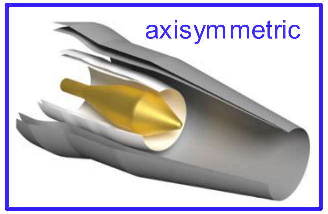
Stich et al.
NASA AMS

LES-Rig vs Rig-Rig

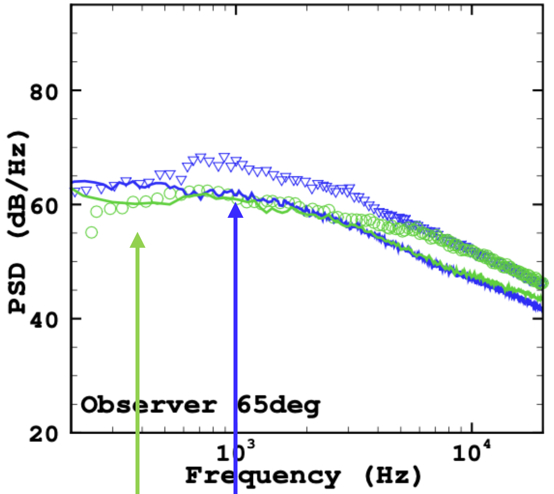
| | dEPNL (dB) | |
|---|---|---|
| setpoint | LES vs Rig | Rig-to-Rig |
| 3 | 4.69 | |
| 23 | 7.66 | |
| 46 | 0.97 | |
| 7 | -0.51 | 1.11 |
| 27 | 0.43 | 0.28 |
| 29 | 0.35 | -0.41 |
| 38 | 0.10 | -0.91 |
| 49 | 0.00 | -1.36 |
| 101240 | 1.55 | |
| **mean*** | **0.41** | **-0.26** |
| **stdev*** | **0.67** | **0.98** |

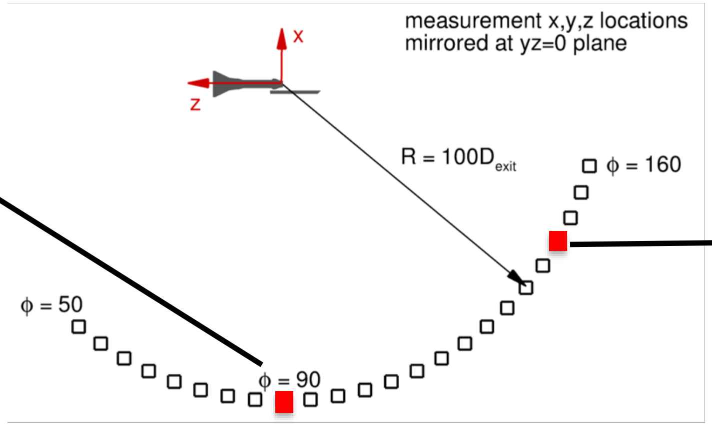
# Open Challenges for Aeroacoustics of Complex Configurations

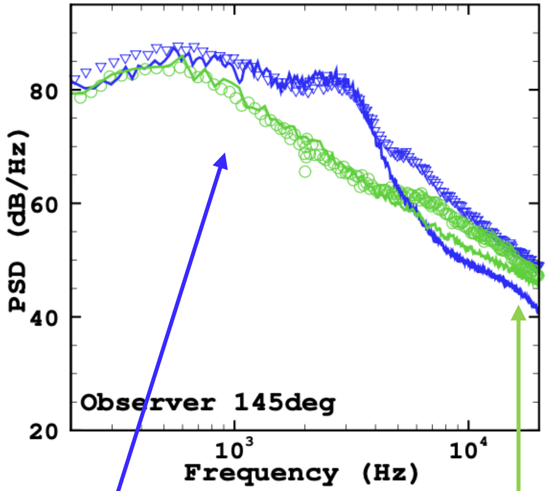




- Experimental campaigns are costly and time-consuming
- LES for complex configurations leaves open questions (see AIAA 2024-3377)







Under-prediction of PSD at lower observer angles for axisymmetric mixer m0

Under-prediction improves towards aft-angles

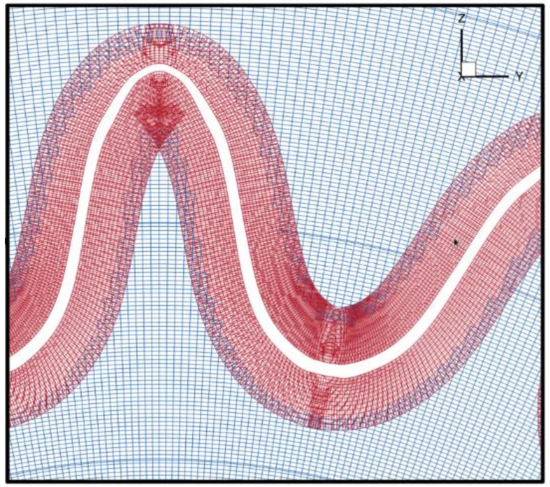
Accurate prediction of noise with lobed mixer m5 at low to mid frequencies for all angles

High-frequency, aft-angle hump in experiments not captured

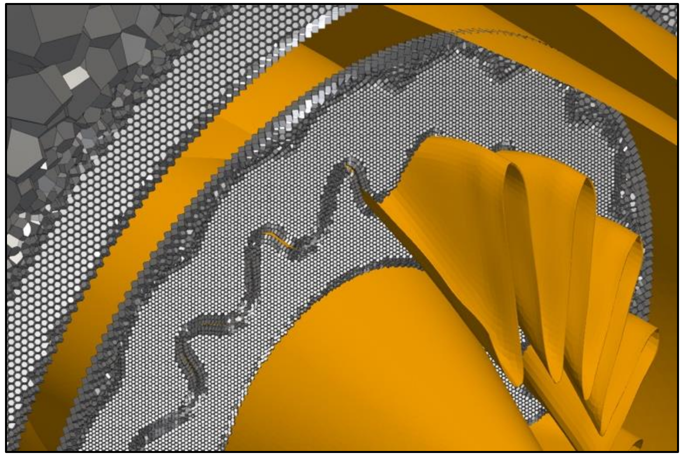
**Further research to understand difference between experiment and simulation needed**

# Improving Turnaround Times by Automated Voronoi Meshing

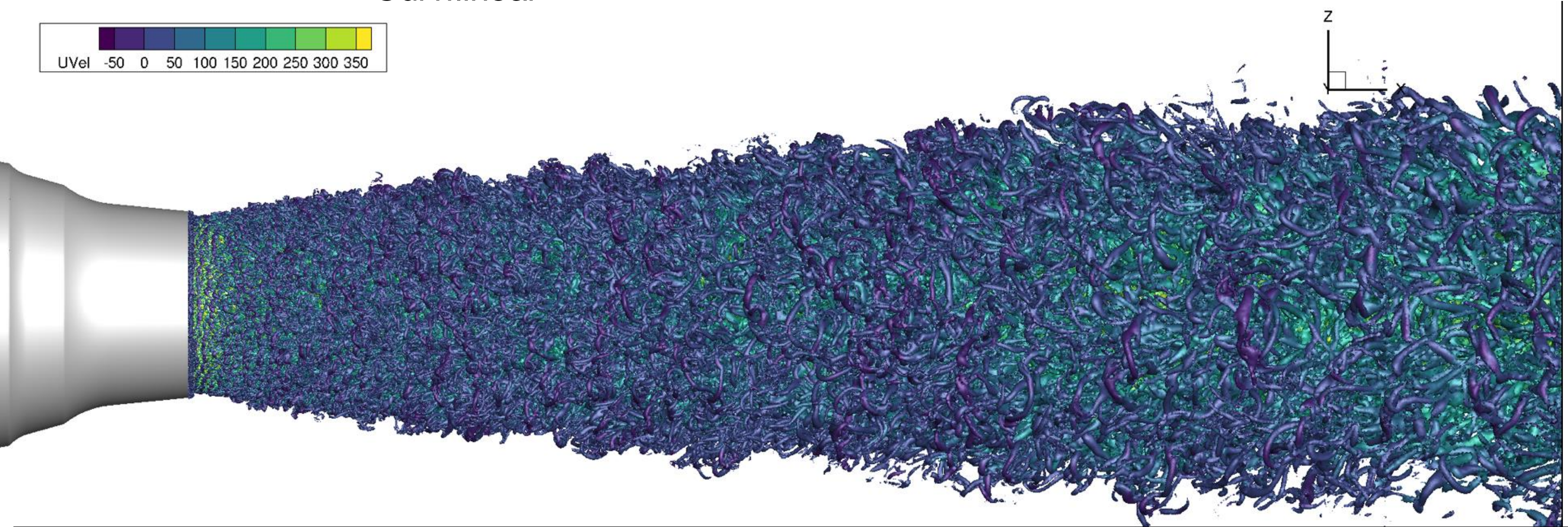
- Curvilinear meshing for acoustics difficult and time-consuming



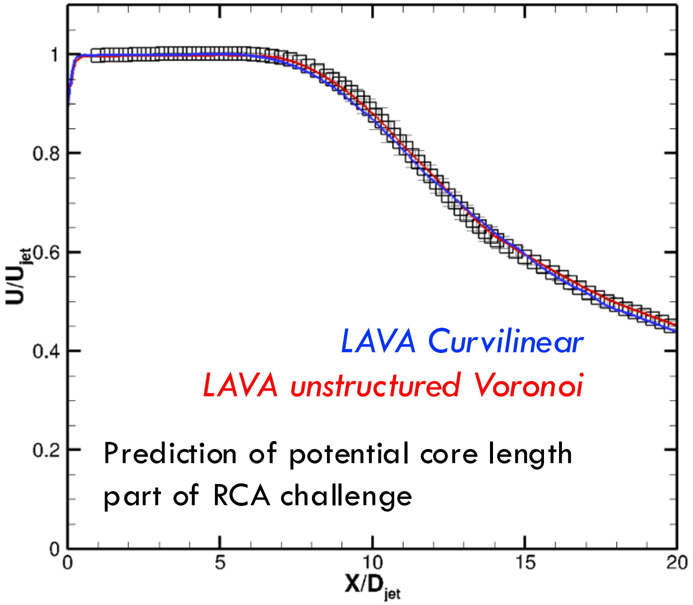
Curvilinear



Voronoi

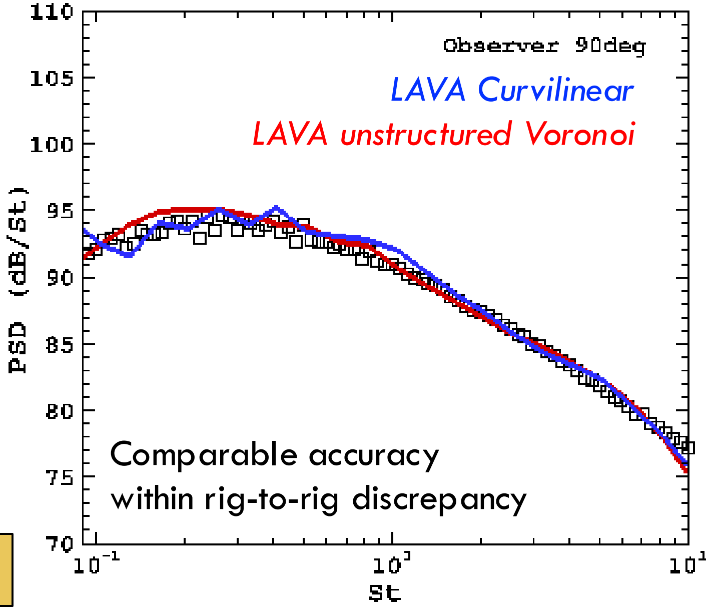


Near-field Lipline Velocity



Prediction of potential core length part of RCA challenge

Farfield noise spectrum at 100D



Comparable accuracy within rig-to-rig discrepancy

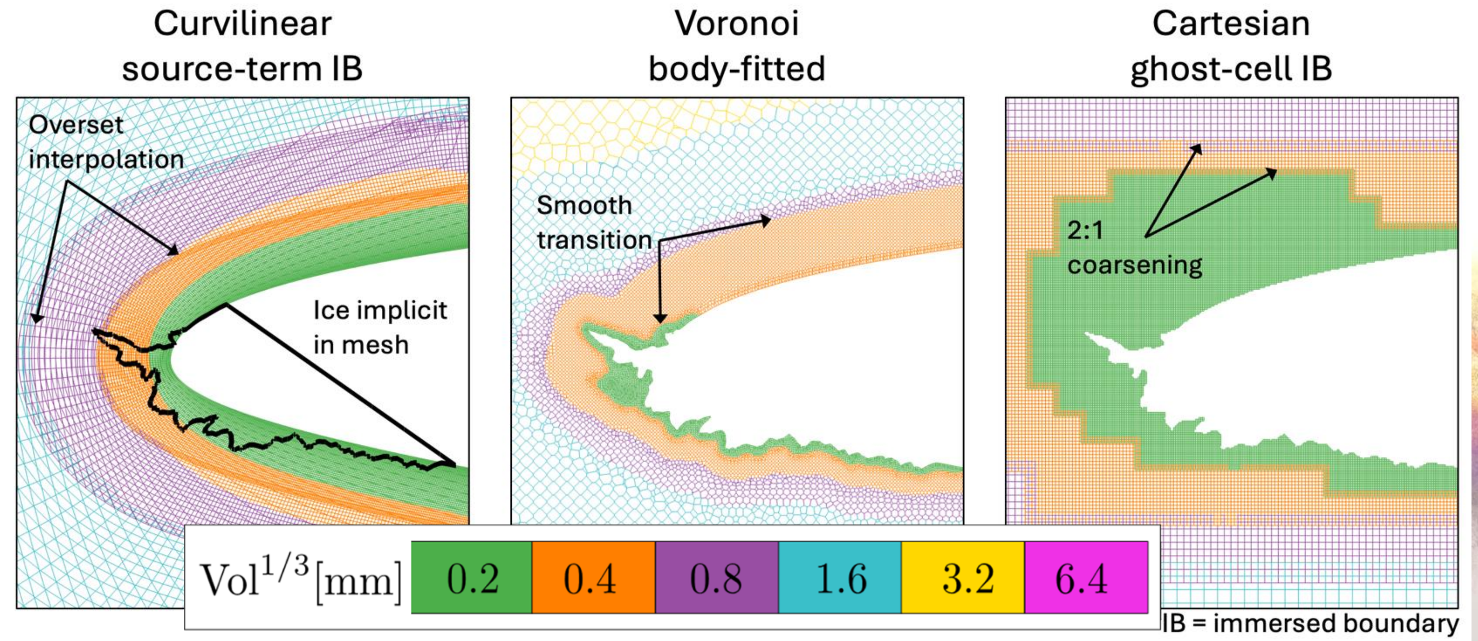
**Demonstrated Comparable Accuracy Between Voronoi/Curvilinear as well as Rig-Rig**

# Icing Aerodynamics

Featuring:

- Curvilinear, Unstructured, and Cartesian WMLES

# WMLES of Challenging Swept Wing with 3D Ice Buildup



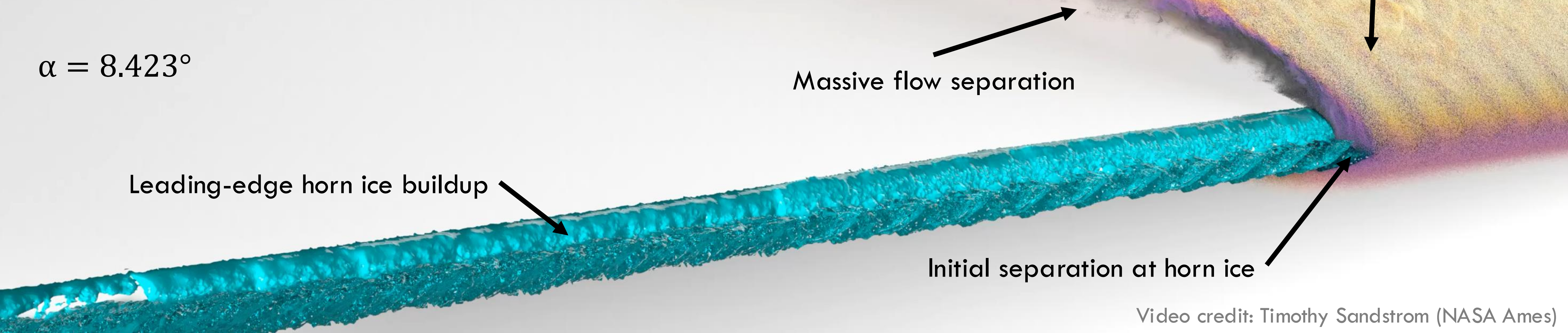
IB = immersed boundary

Craig Penner et al.
SciTech 2025

Craig Penner et al.
Aviation 2024

Wong et al.
SciTech 2023

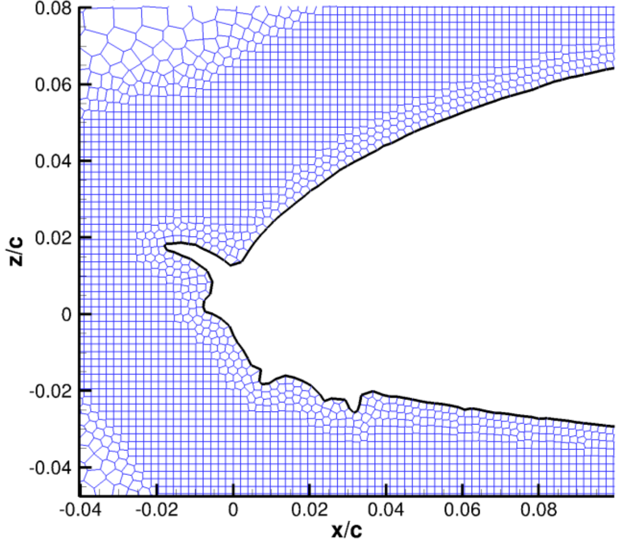
$\alpha = 8.423°$



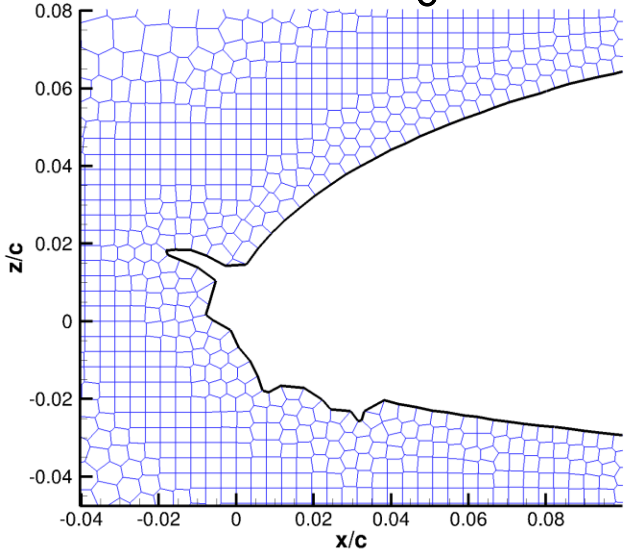
Video credit: Timothy Sandstrom (NASA Ames)

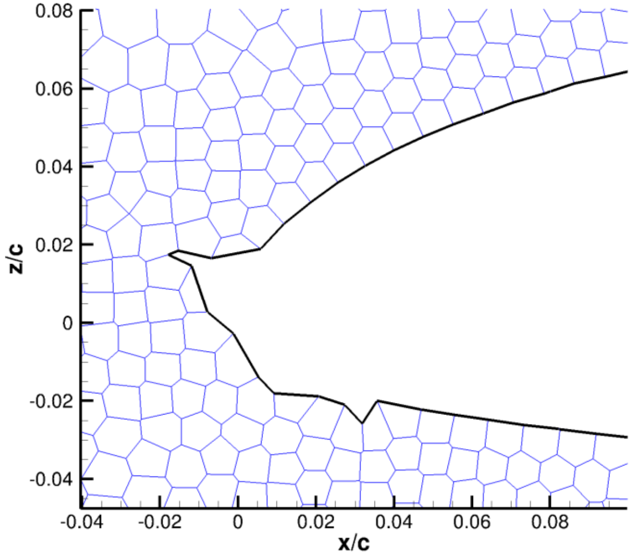
# LAVA Meshing Paradigms Particularly Well-Suited Including Body-Fitted

Example using the automatic surface defeaturing capabilities in the LAVA Voronoi unstructured meshing software

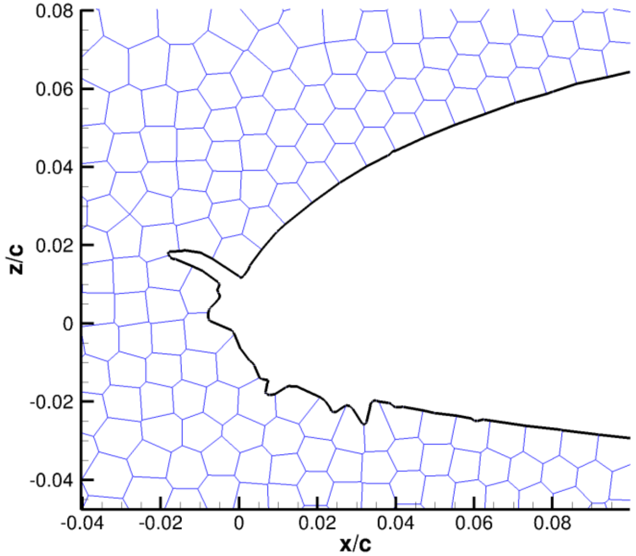


Option to filter geometric features to match coarse mesh resolution

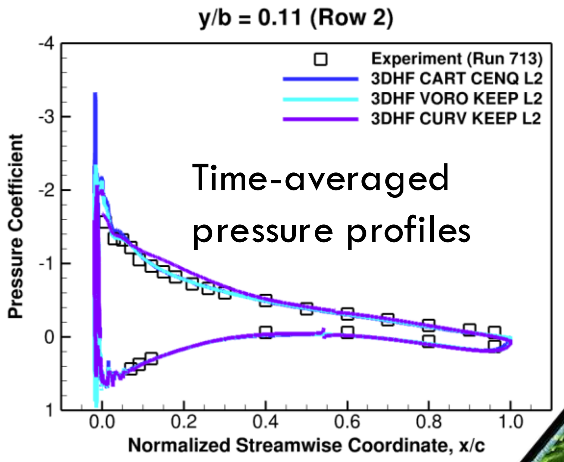




Option to preserve detailed geometric features on coarse meshes



# Accurate Results and Flow Topologies For Complex 3D Ice Shapes

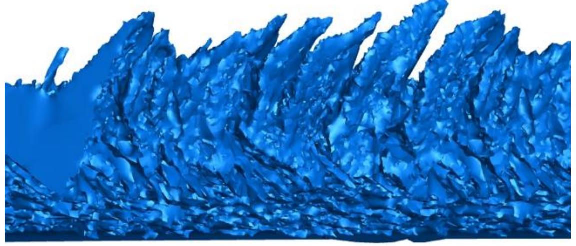


Time-averaged pressure profiles

Curvilinear timing comparison

| Solver Paradigm | Solve Nodes (Million) | Computational Resources | MUPS/Node (FP64) | Wall-Clock Hours per CTU (FP64) |
|---|---|---|---|---|
| Curv CPU | 504 | 60 Rome | 30 | 5.16 |
| Curv GPU | 504 | 35 Grace Hopper | 213 | 1.25 |

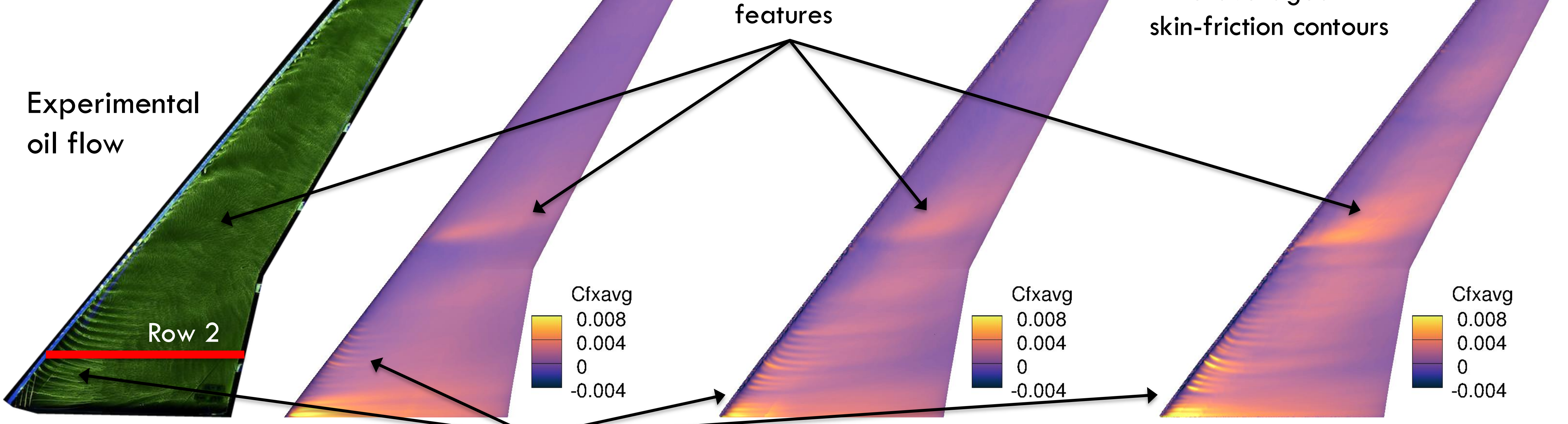
Results shown with "high-fidelity" ice at $\alpha = 8.423°$



Curvilinear L2

Voronoi L2

Cartesian L2



Similar midboard features

Time-averaged skin-friction contours

Experimental oil flow

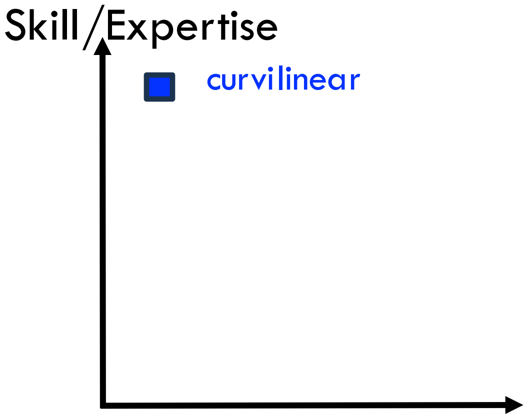
Similar inboard streamwise streak structures

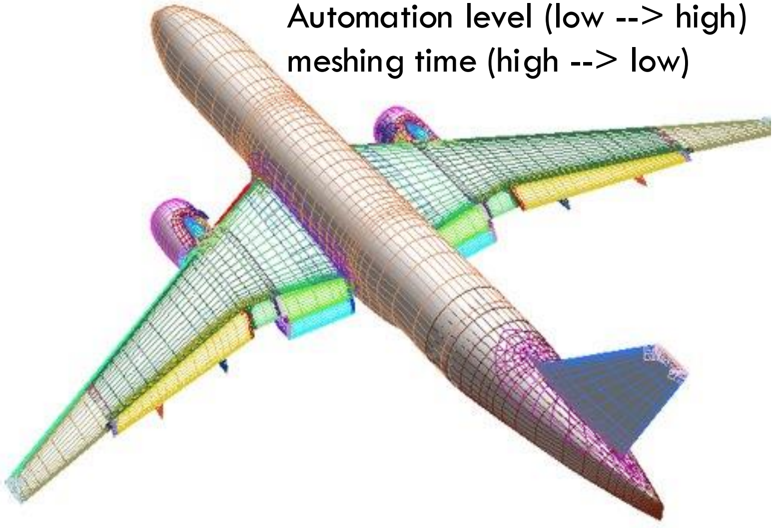
# High-Lift CRM

Featuring:

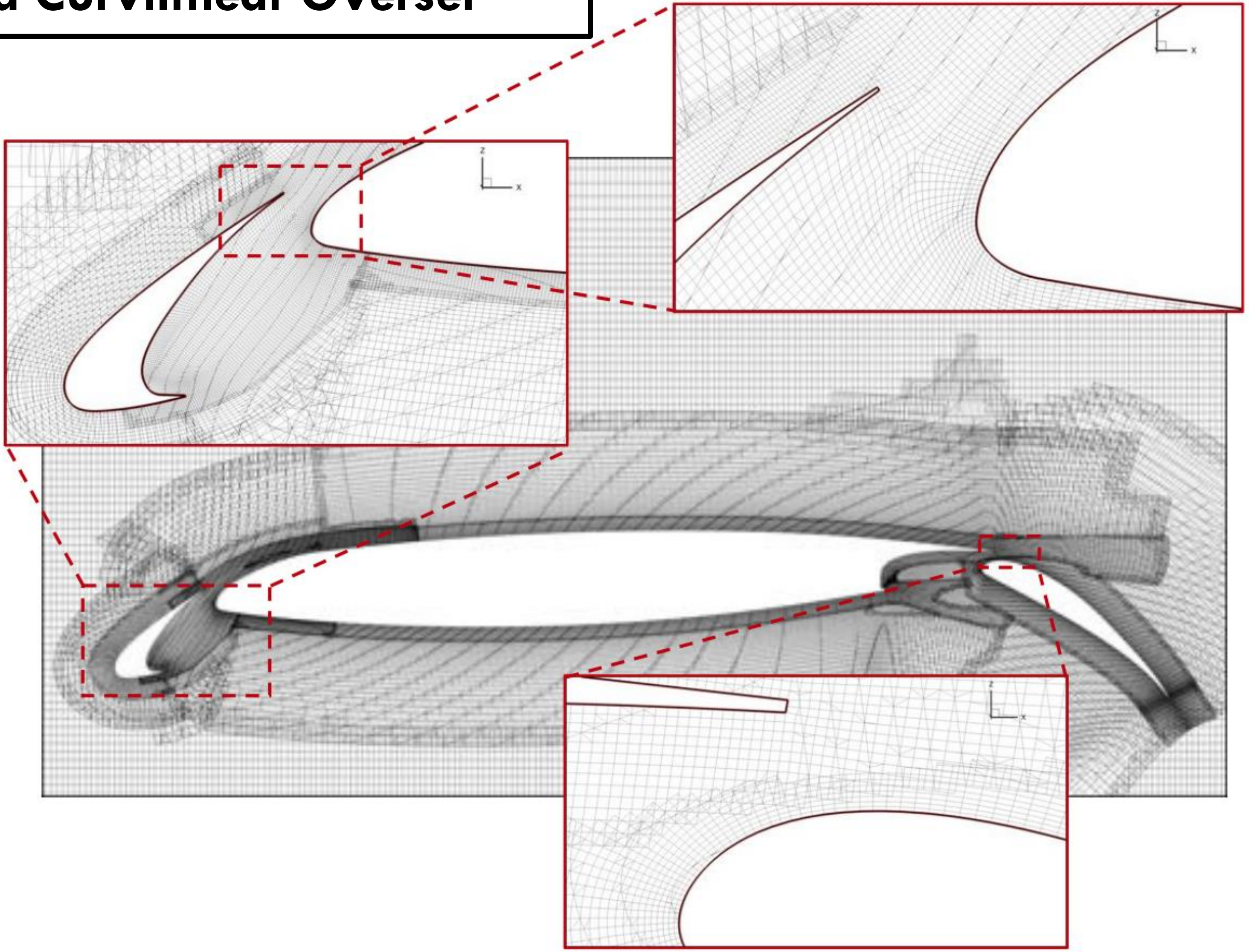
- Voronoi Meshing
- Unstructured WMLES
- Cartesian WMLES with AMR

# Fully Manual Mesh Generation – Domain Expert Required





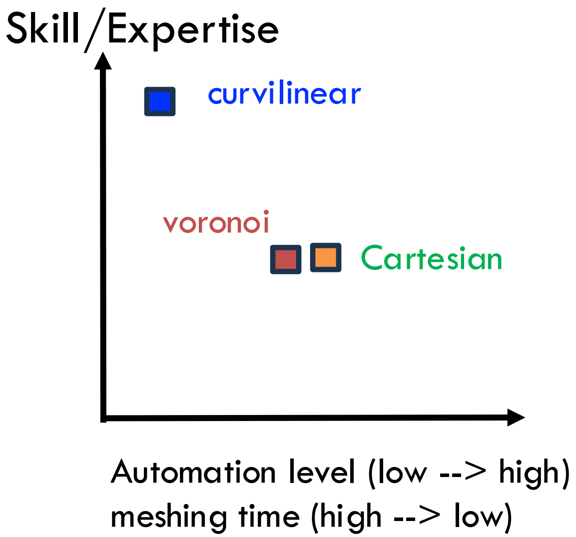
## Structured Curvilinear Overset



- Precise control over mesh placement
- High-quality grids but **labor-intensive**
- Challenging for complex geometries

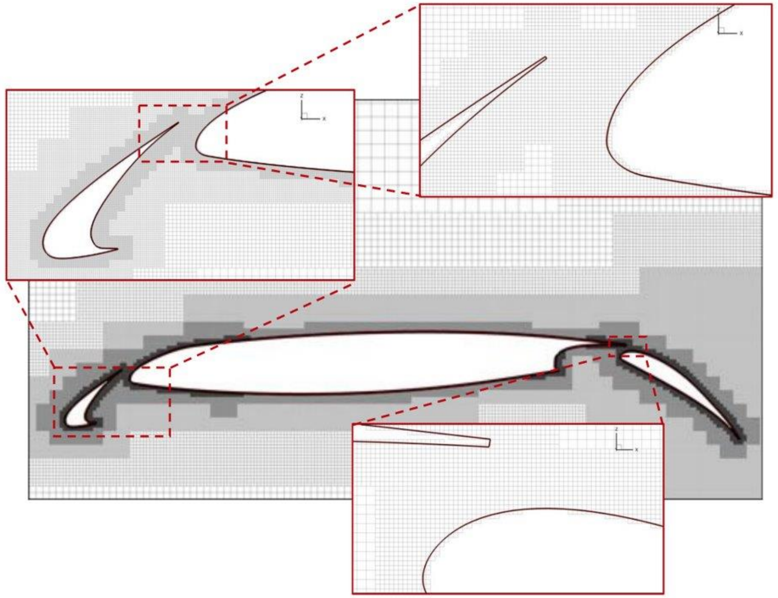
***Challenge: Time consuming O(month) and requires strong domain expertise***

# Semi Automated Mesh Generation – Expert Informed Mesh



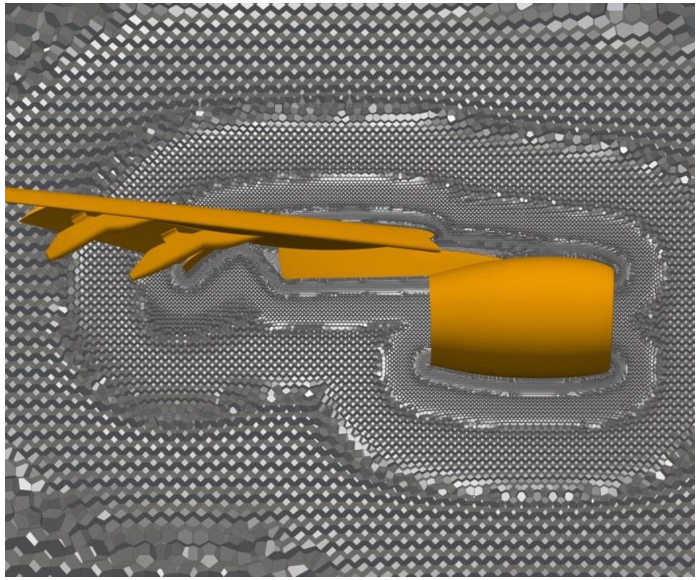
**User with expert knowledge of flow physics defines refinement region in input file**

## Structured Cartesian



- small memory footprint, highly scalable
- Allows for highly complex geometries (thin geometries, sub-grid size)

## Unstructured Voronoi

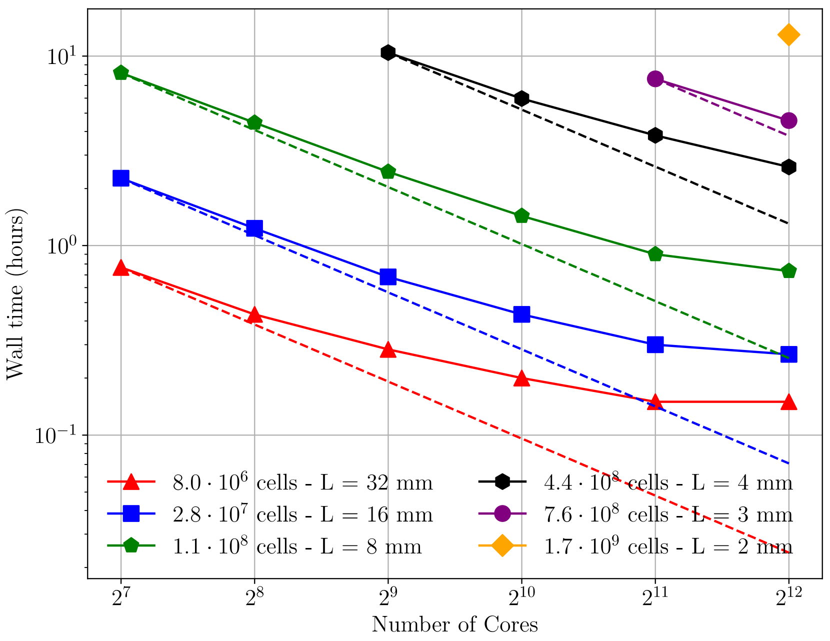


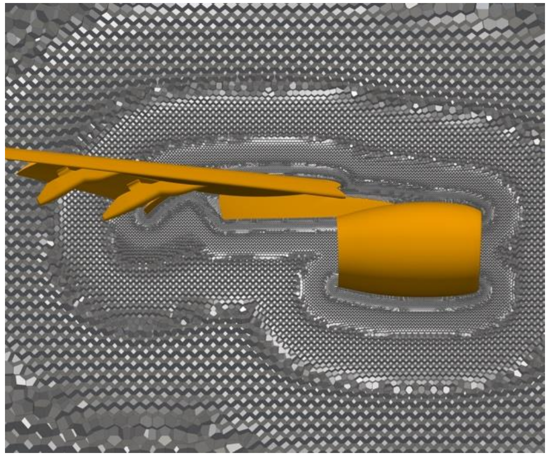
- Smooth transition between regions
- body-fitted with automated built in surface defeaturing capabilities

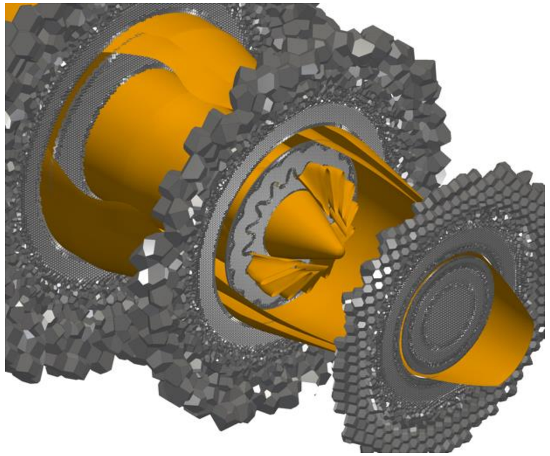
***Manual mesh generation time reduced from O(month) to O(minutes/hours)***
***(demonstrated for 100+ billion Cartesian cell grid on NASA systems)***

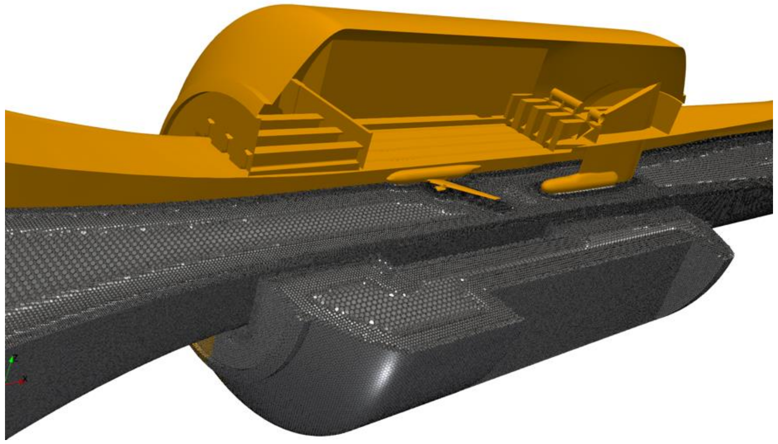
# LAVA Voronoi Mesh Generation

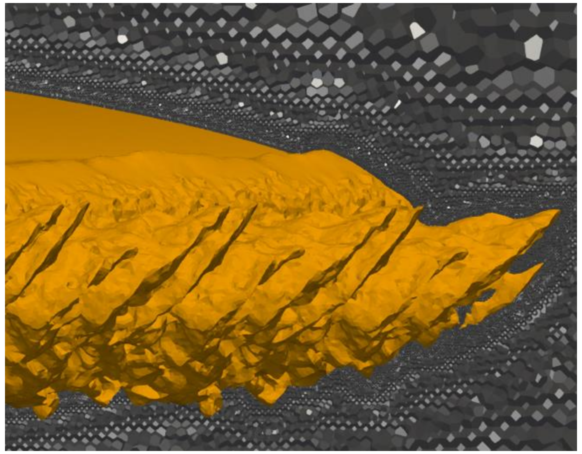
- Inherently high-quality meshes, suitable for scale-resolving simulations
- Developed in-house from ground up
- Highly automated and simple to use, with powerful sizing capabilities
- Distributed memory parallelism
  - Can scale to generate large meshes, demonstrated with a 1.7B cell mesh
- In progress: wall anisotropy and Voronoi RANS meshes
- Received AIAA best paper award in Aviation 2024




CRM-HL

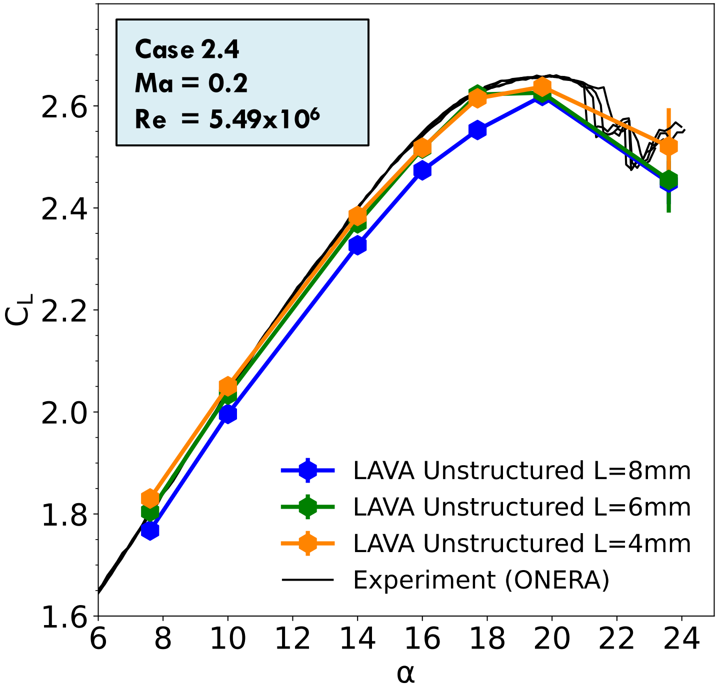

Supersonic jet with lobed mixer

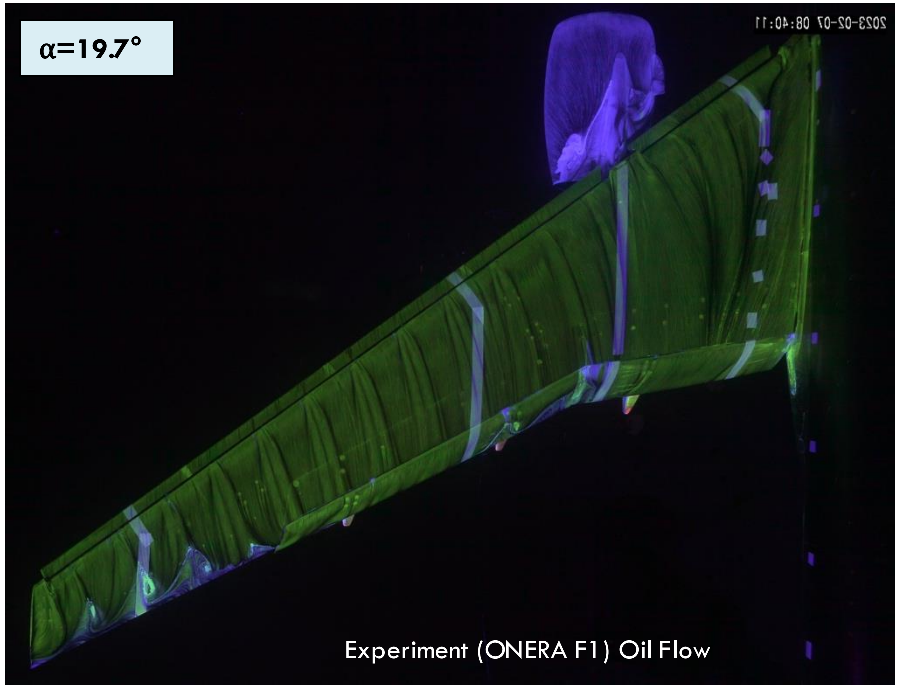

NTF wind tunnel


Iced wing

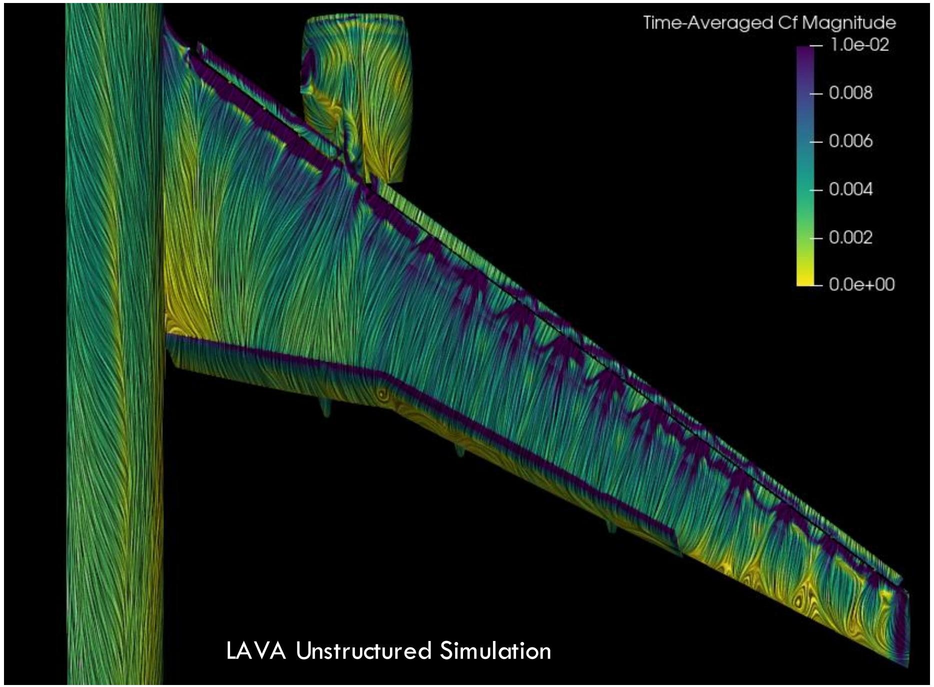
# LAVA Unstructured – AIAA 5th High-Lift Prediction Workshop

- Participated in AIAA HLPW5 using the Voronoi Unstructured WMLES capability
- Results were among the best in terms of both accuracy and efficiency
  - Excellent reproduction of force and moments as well as flow topology throughout the angle of attack range
- Identified leading edge transition as a major source modeling error
- Published results in AIAA SciTech 2025





Experiment (ONERA F1) Oil Flow

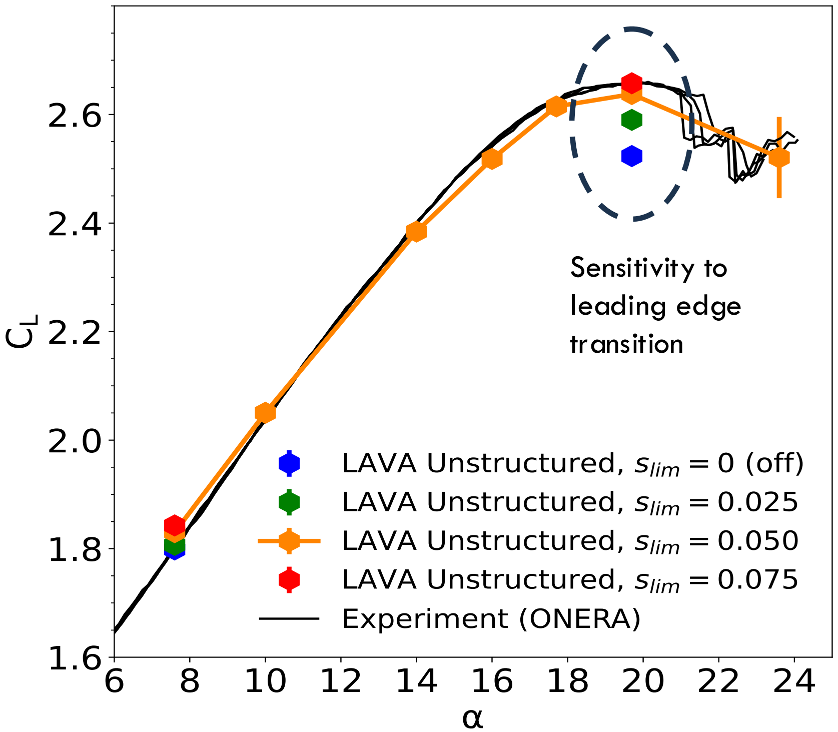


LAVA Unstructured Simulation

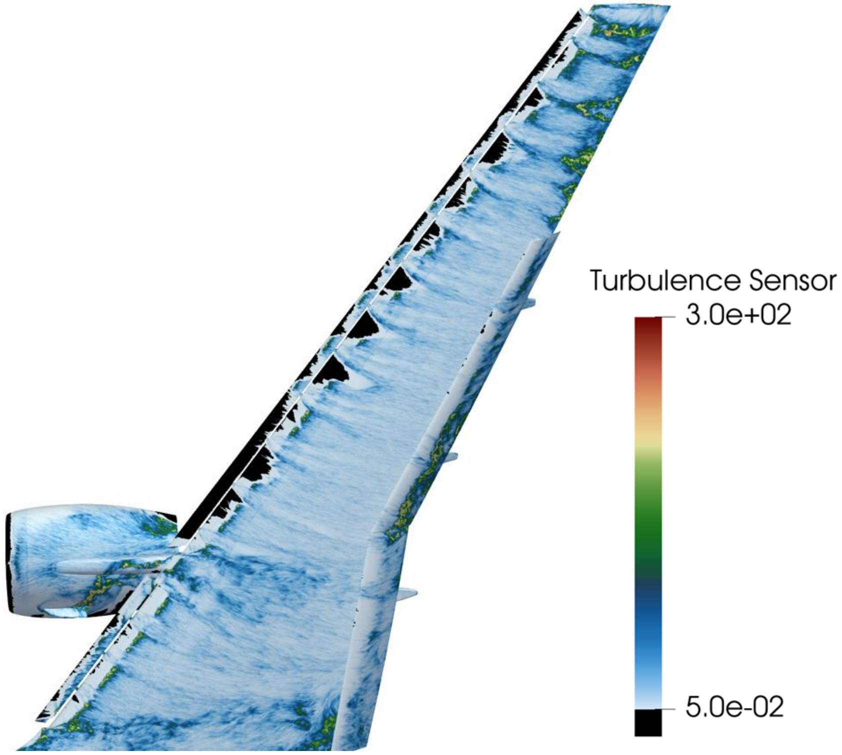
# LAVA Unstructured – AIAA 5th High-Lift Prediction Workshop

- A shortcoming of traditional WMLES: Lack of regard for the transitional leading-edge regions
  - Wall function typically computes fully turbulent wall stress even if the flow hasn't transitioned yet
  - This is a significant error and can lead to loss of momentum and premature flow separation

- During the workshop, we adopted a sensor-based approach to remedy this with low computational cost
  - Based on Larsson et al.* with our modifications
  - The sensor measures the resolved turbulent content at the wall



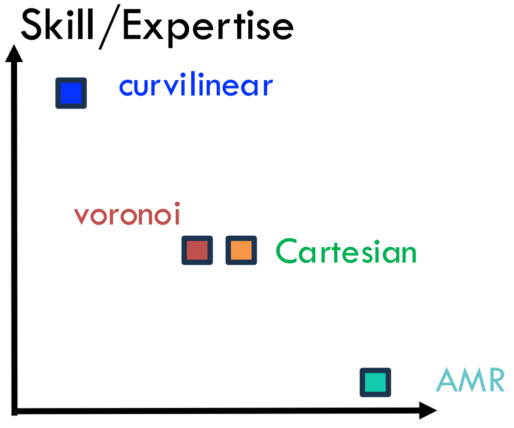
Sensitivity to leading edge transition



---

* Larsson, J., Kawai, S., Bodart, J., and Bermejo-Moreno, I., "Large Eddy Simulation with Modeled Wall-Stress: Recent Progress and Future Directions," *Mechanical Engineering Reviews*, Vol. 3, 2015. https://doi.org/10.1299/mer.15-00418.

# Automated Adaptive Mesh Generation – Solution Informed Mesh


Skill/Expertise

curvilinear

voronoi

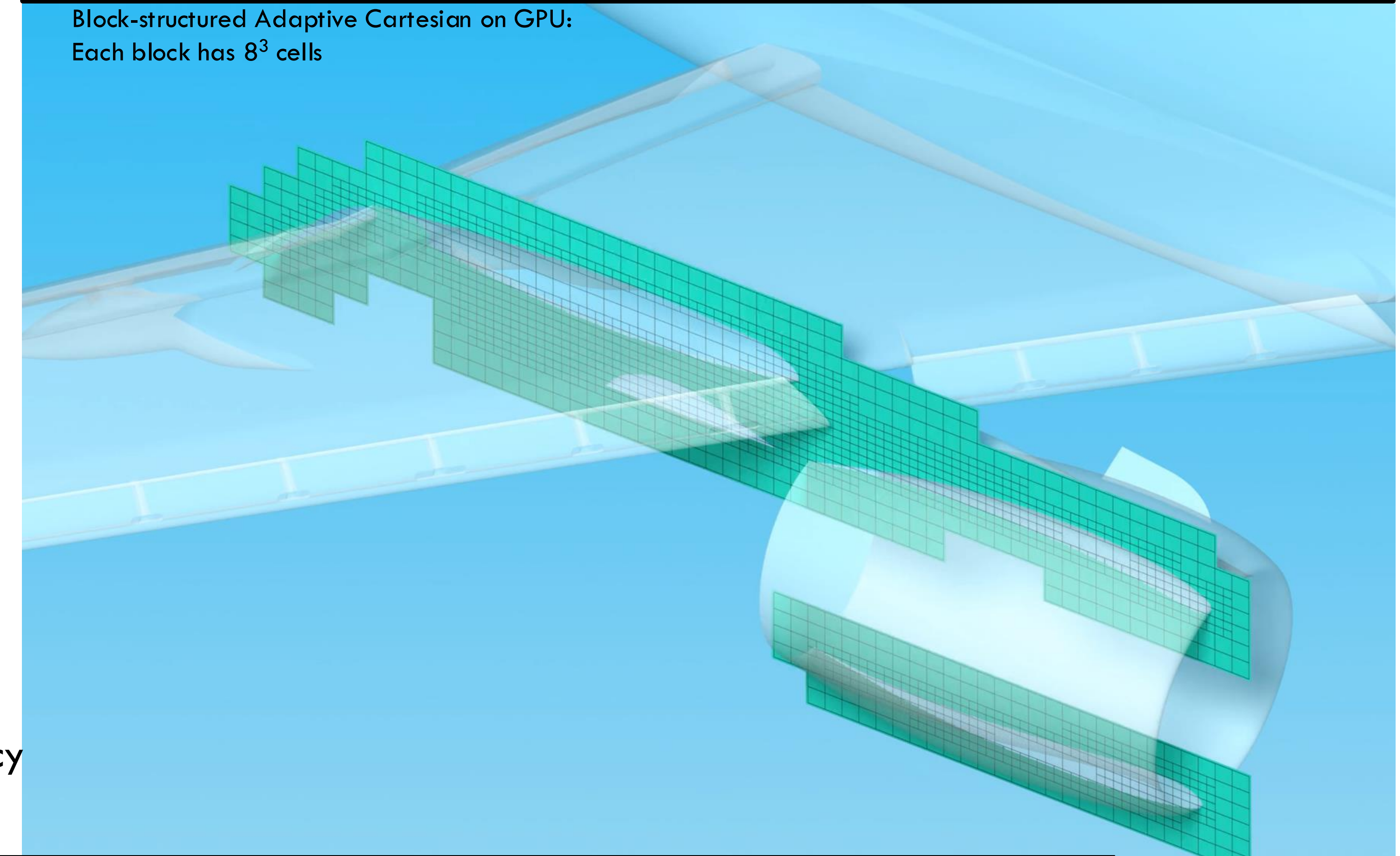
Cartesian

AMR

Automation level (low --> high)
meshing time (high --> low)

- Reduced computational cost by refining only in necessary areas
- Cartesian approach allows for fast re-gridding
- **Primary challenge:**
Optimizing refinement criteria for accuracy vs. cost

## Adaptive Mesh Refinement (AMR)


Block-structured Adaptive Cartesian on GPU:
Each block has $8^3$ cells

***Physics informed refinement - minimum user intervention/expertise required***

# Some Details on LAVA Cartesian AMR

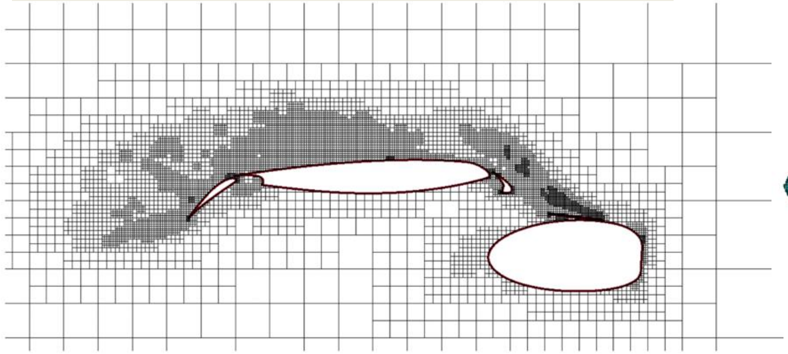
**LAVA Cartesian Refinement Criteria:**

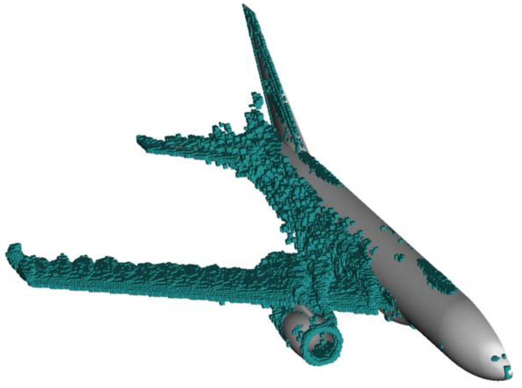
- Supports volume and surface error metrics, solution-based (e.g., Laplacian, vorticity), and user-defined geometry metrics.

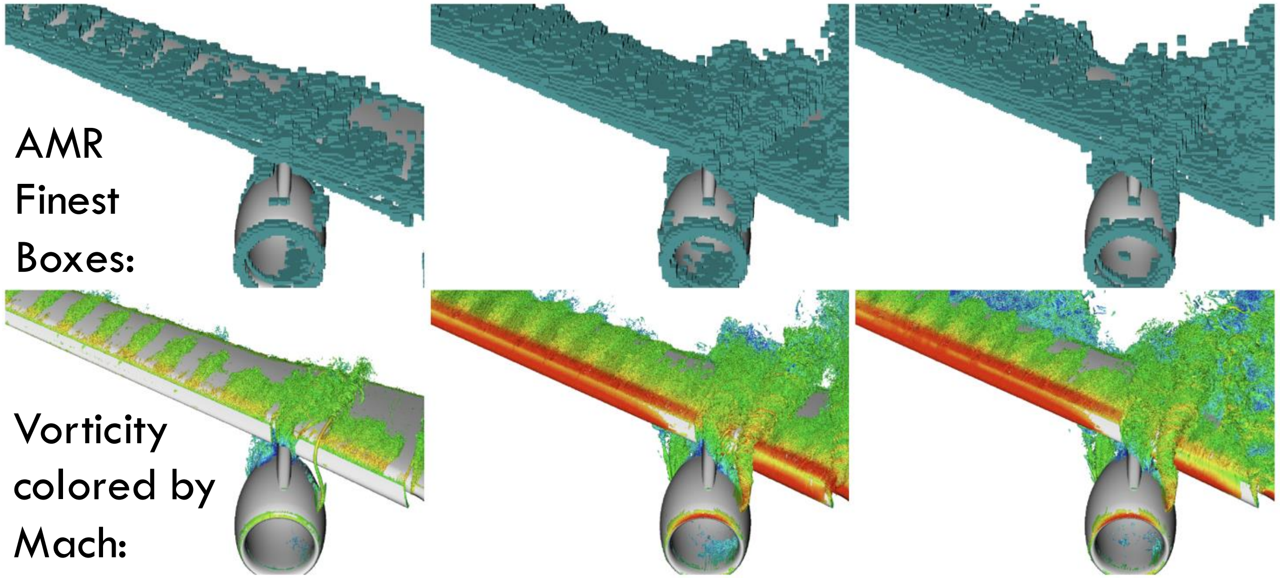
**AMR Benefits:**

- Improves gradients and FP32 results
- Lowers user expertise needed
- Mesh adapts to local flow (see alpha sensitivity on right)
- Fast unsteady adaption; minimal slowdown, often reduces mesh size. Best practices evolving.

Toosi & Larsson AMR Metric:







AMR Finest Boxes:

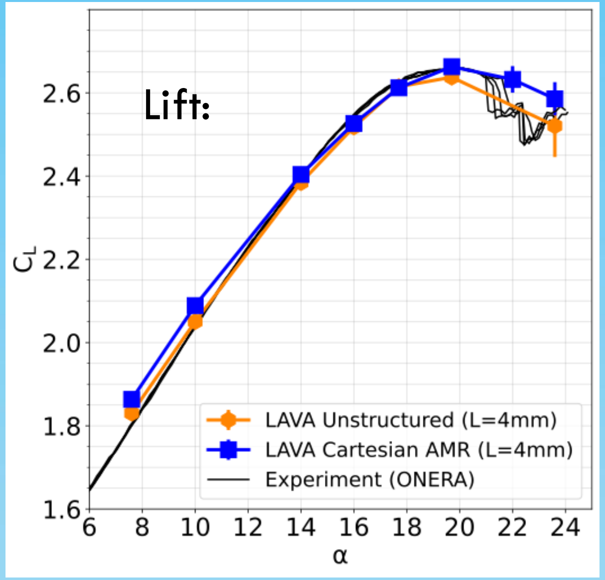
Vorticity colored by Mach:

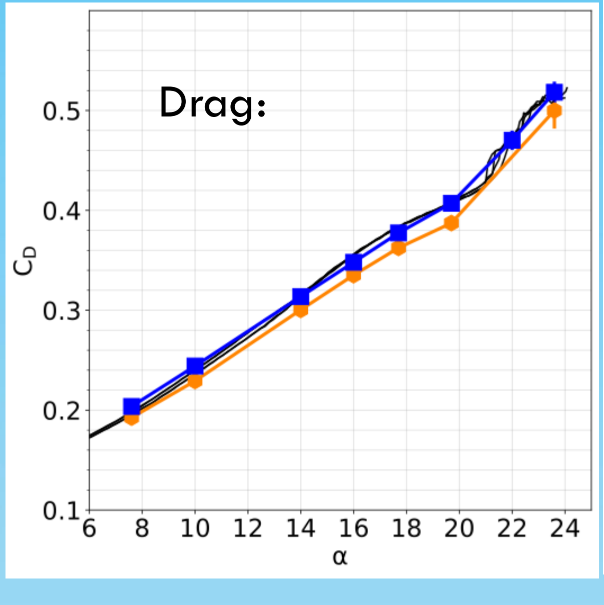
$\alpha = 7.6$ $\alpha = 19.7$ $\alpha = 23.6$

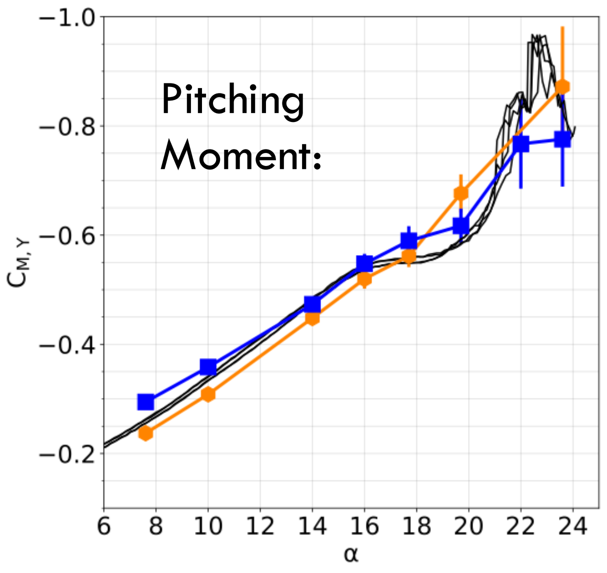
# HLPW5 Benchmark with Adaptive Cartesian

***High-Lift Prediction Workshop 5:***

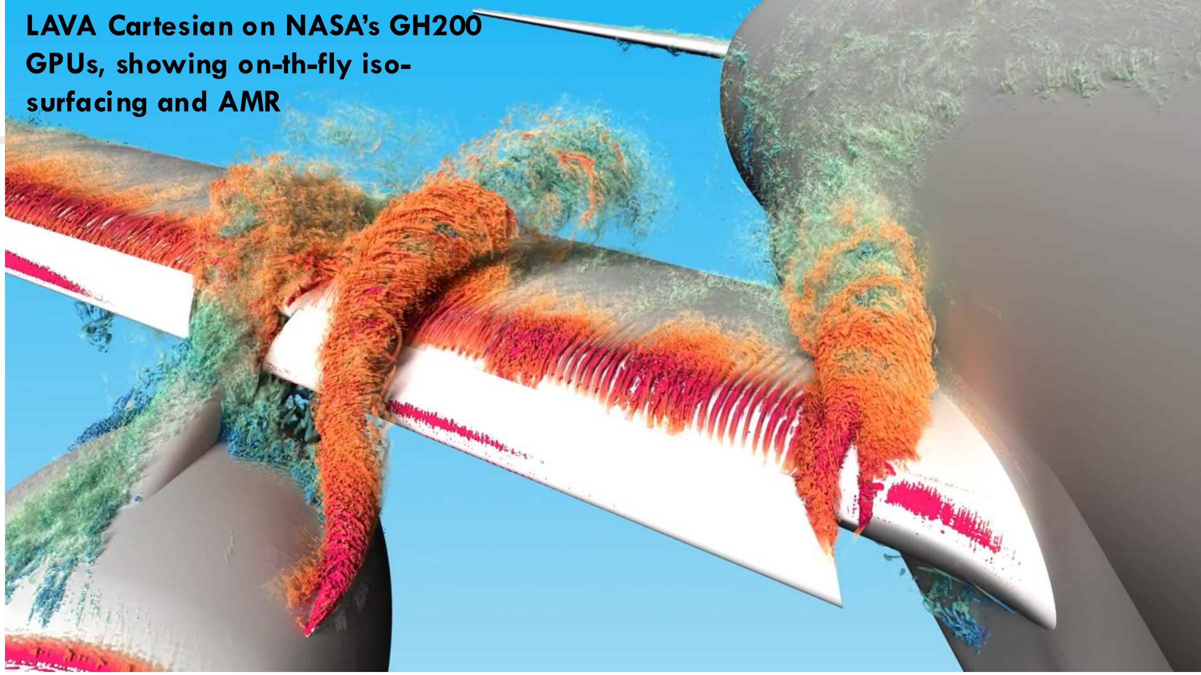
- Computed using LAVA Cartesian with AMR on NASA's A100 GPUs (FP32)
- Movie shows velocity magnitude and mesh adaption, for Mach=0.2 and stall angle=23.6°:







# Computational Performance

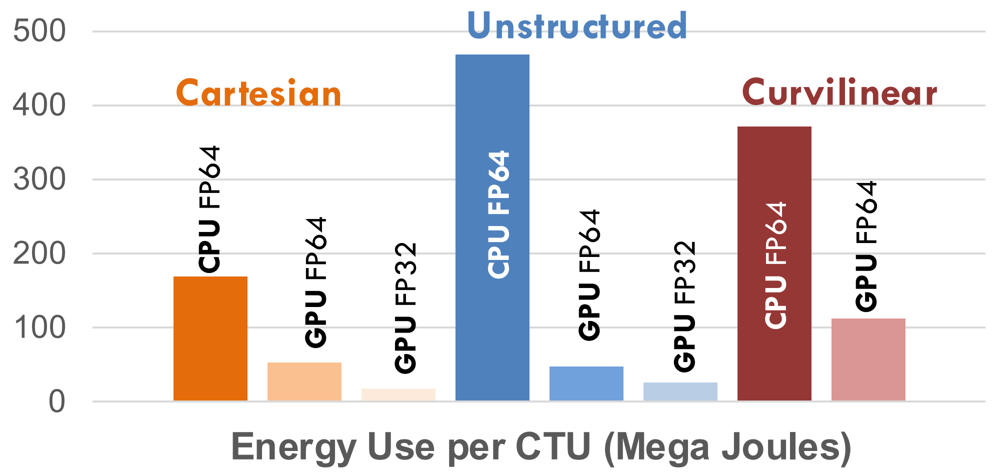

LAVA Cartesian on NASA's GH200 GPUs, showing on-th-fly iso-surfacing and AMR

**Benchmark: High Lift Prediction Workshop 5 (HLPW5)**

- Target arch: AMD Milan CPU + 4 NVIDIA A100 GPUs
- Performance measures:
  - MUPS: millions of updates per second
  - Energy usage: measure of megajoules per convective time unit (MJ/CTU)
- Performance at scale: 325-1400 million cells, ~10x more energy efficient compared to CPUs

| HLPW5 Performance | Cartesian | | | Unstructured | | | Curvilinear | |
|---|---|---|---|---|---|---|---|---|
| Nodes (Rome/A100) | 100 CPUs | 64 GPUs | **64 GPUs** | 200 CPUs | **64 GPUs** | 64 GPUs | 40 CPUs | **24 GPUs** |
| Precision | FP64 | FP64 | **FP32** | FP64 | **FP64** | FP32 | FP64 | **FP64** |
| Solve cells | 736M | 1400M | **1400M** | 325M | **325M** | 325M | 800M | **800M** |
| MUPS/node | 45 | 554 | **1562** | 19.1 | **192** | 335 | 48 | **358** |
| Energy (MJ/CTU) | 168 | 52 | **18.4** | 467 | **46.4** | 26.6 | 370 | **113** |

Numbers in **bold** represent the current HLPW5 best-practice for accuracy.



**1 Mega Joule:**

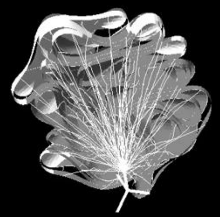
- Roughly the kinetic energy of a one-ton vehicle moving at 100 mph.
- Roughly the energy needed to heat 10 liters of water from 0°C to 100°C.

# Entry Systems Modeling

Featuring:

- Cartesian WMLES with AMR
- Fluid-Structure Interaction for Parachutes
- Supersonic Retropropulsion

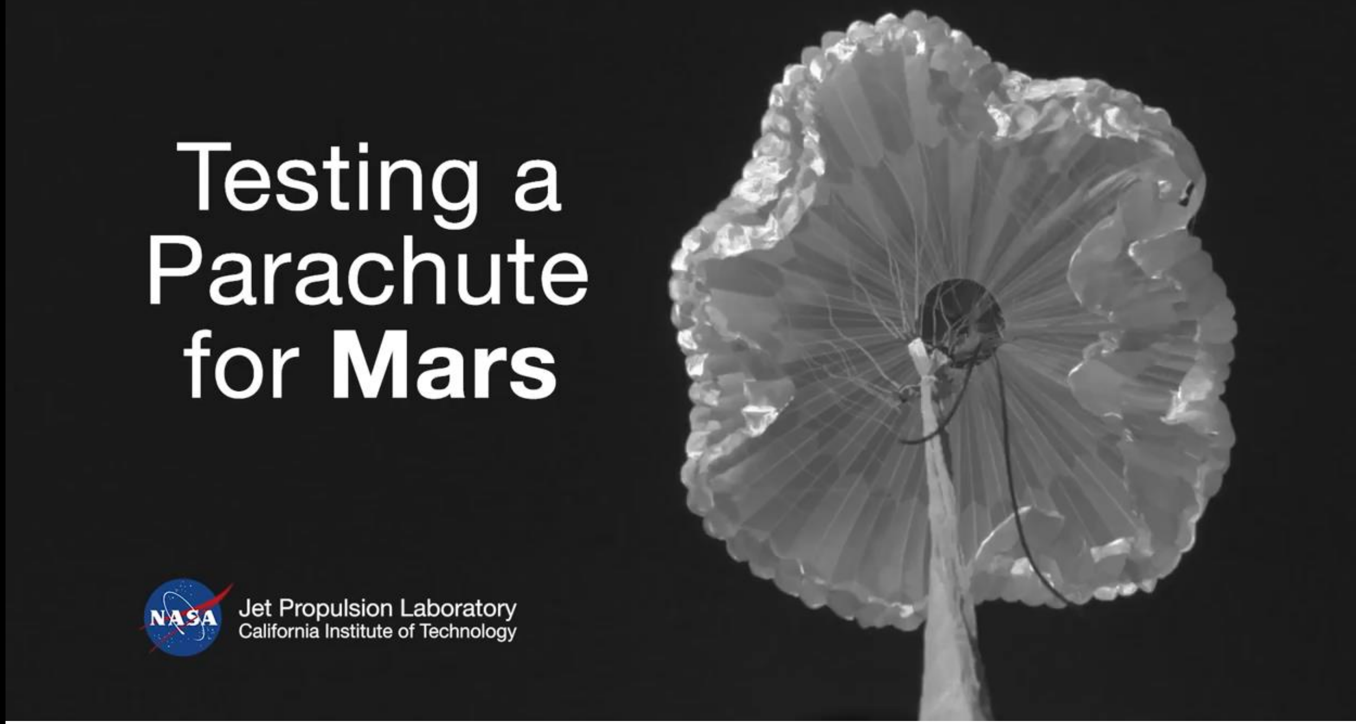
# Qualitative Comparison to ASPIRE SR03



Rendering of FSI parachute system meant to mimic the high-speed video from flight (right).

**_Credit: NASA/JPL-Caltech_**
https://www.nasa.gov/feature/jpl/third-aspire-test-confirms-mars-2020-parachute-a-go

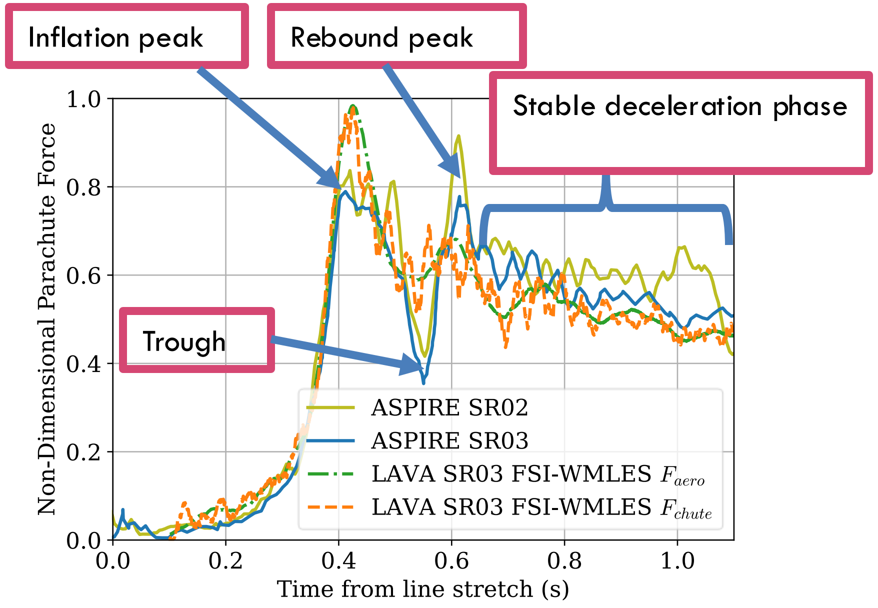
Advanced Supersonic Parachute Inflation Research Experiments (ASPIRE)



- Canopy fabric porosity modeled through immersed boundary
- Parachute structural dynamics modeled via finite elements with hyper-elastic model
- Physics-based contact mechanics
- Payload deceleration coupled to parachute system drag through free flight module

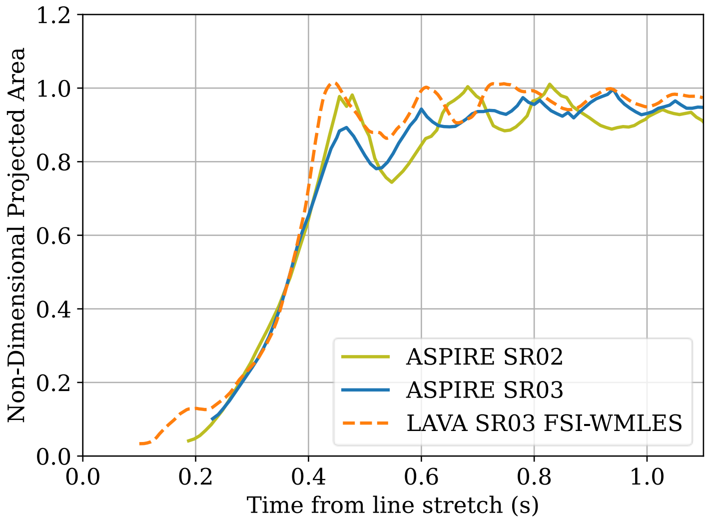
# ASPIRE Parachute FSI Validation

## Parachute Force:



- Over-predicts inflation peak drag by 17%, but within family when compared to SR02 rebound peak
- Match downward slope of flight test during stable deceleration phase
- Predicts suspension line mode of ~27 Hz (~0.038 s) in close agreement with flight tests for $F_{chute}$

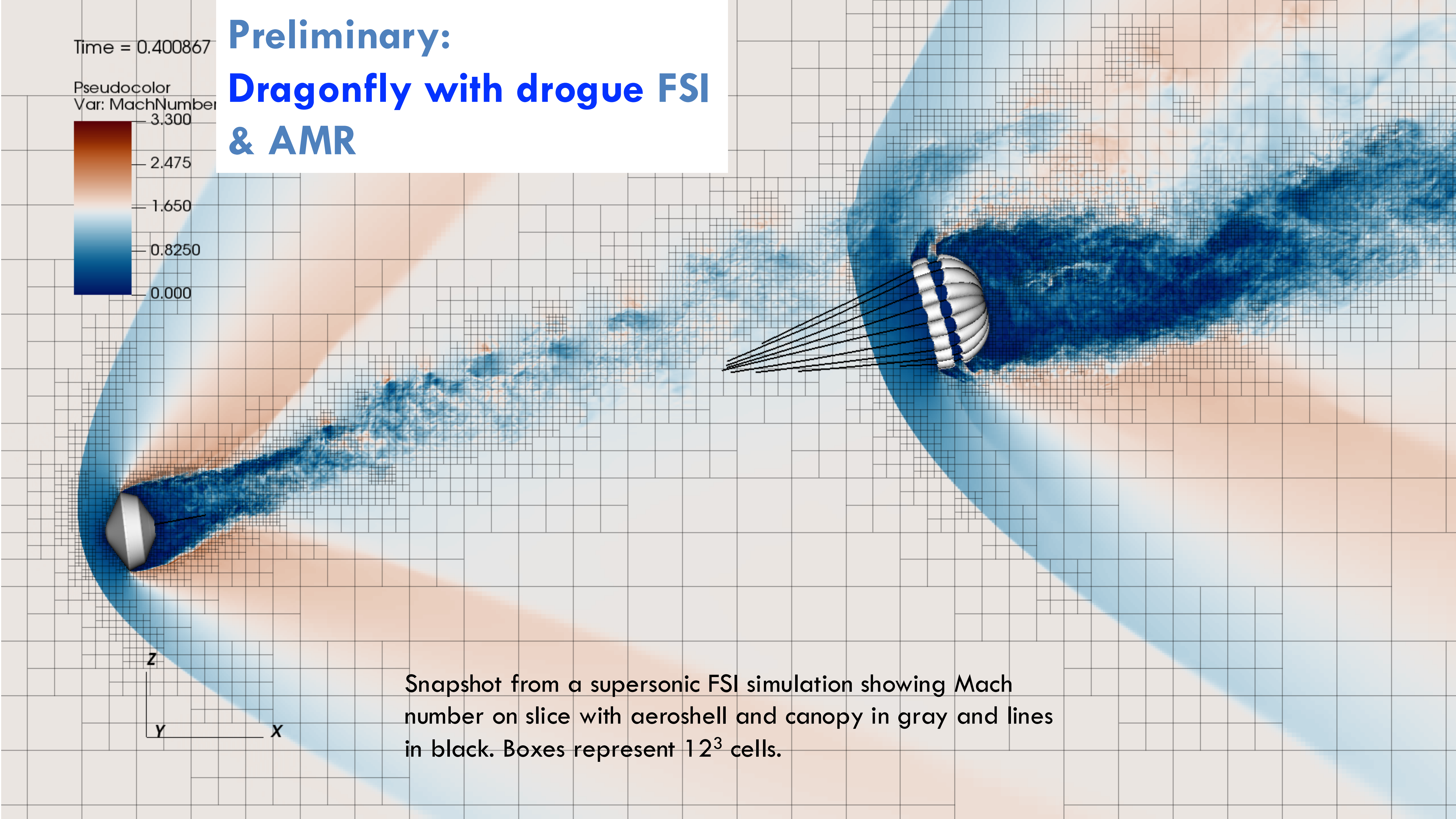
## Projected Parachute Area:



- Inflation rate matches well until 0.4s after which FSI parachute model predicts faster inflation
- Over-predicts first area peak by 12% compared to SR03, but within 5% of SR02
- Displays area “breathing” mode in good agreement with SR03

Cadieux, F. and Barad, M., 2024, July. *Wall-Modeled Large-Eddy Simulation of Supersonic Parachute Inflation.* In 12th International Conference on Computational Fluid Dynamics (ICCFD12) (No. ICCFD12-2024-C000159).

# Preliminary:
# Dragonfly with drogue FSI & AMR



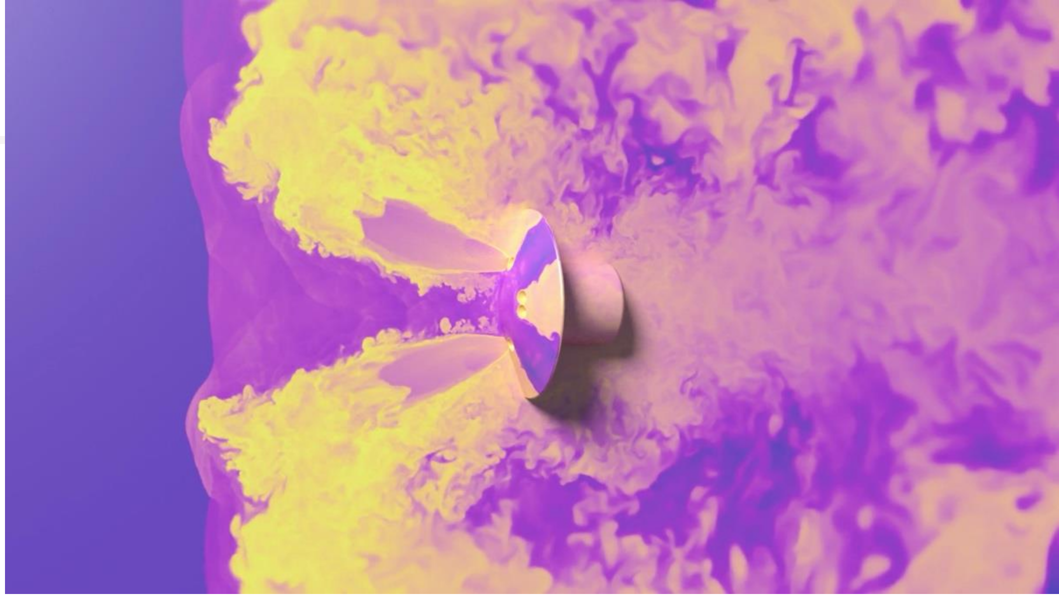
Snapshot from a supersonic FSI simulation showing Mach number on slice with aeroshell and canopy in gray and lines in black. Boxes represent $12^3$ cells.

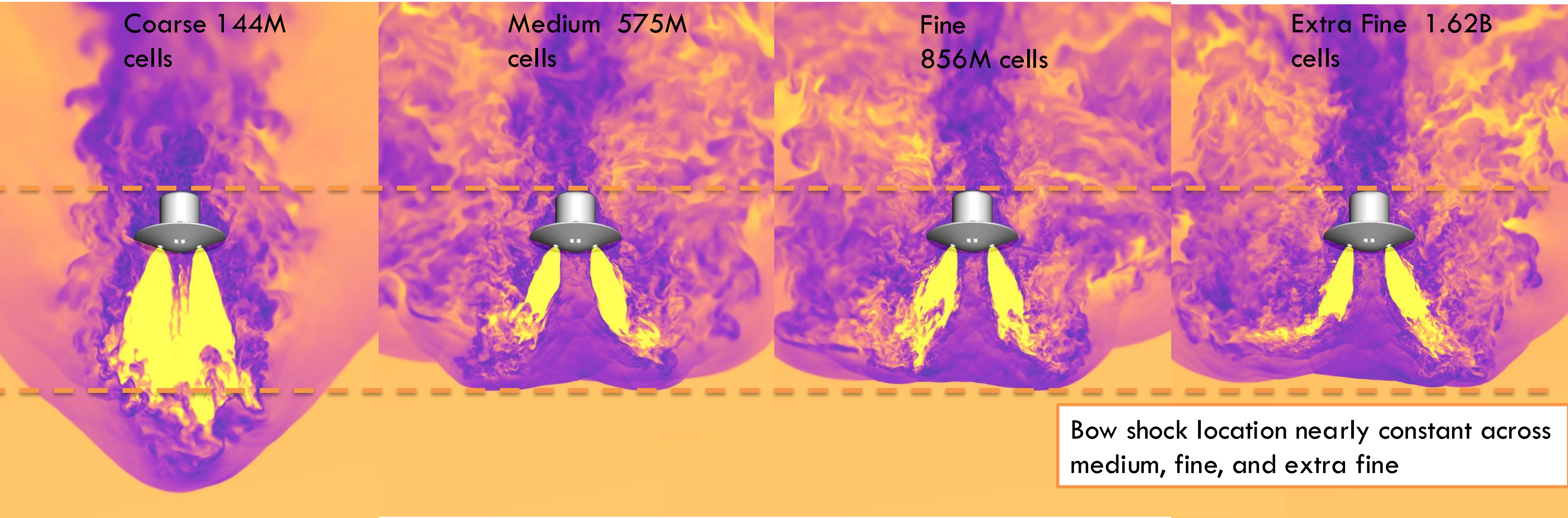
# Preliminary: Dragonfly with drogue FSI & AMR

Animation from a supersonic FSI simulation showing density on a slice with aeroshell and canopy in gray and lines in black.

# Supersonic Retropropulsion

- High-order WENO, SSPRK33, 2 species
- Block-structured with octree based local-refinement
- Up to 1.62 billion cells
- Grid Generation Cost: **seconds**
- 2021 resources: **70-100 Sky/Rome CPU nodes, 0.5-7 days**
- **2025 estimated resources: 32 GH200 Nodes at NAS, 1 day**





Bow shock location nearly constant across medium, fine, and extra fine

# Launch Environment

Featuring:

- Cartesian AMR
- Multi-species and Multi-phase

# KSC LC39B Launch Environment Simulations in LAVA

**Background:**

- LAVA Cartesian solver is ideal for analysis where the geometry may be rapidly changing between design iterations.
- The LAVA solver was used extensively for the redesign efforts of the KSC launch pad/tower for SLS starting in 2012.

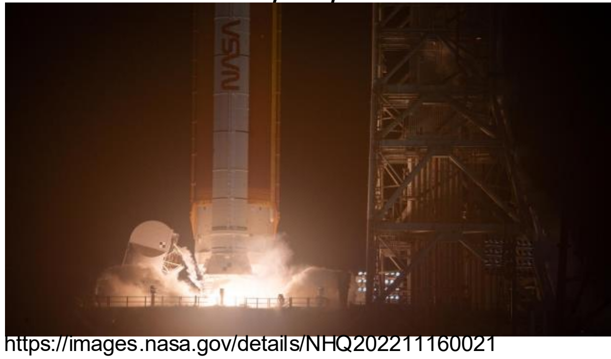
**Numerical Methods:**

- A range of numerical schemes are available, including WENO5, WCNS and energy preserving schemes
- Multi-species and multi-phase options available.
- Ghost-cell immersed boundaries for the highly complex geometry
- Static or adaptive mesh refinement

**LC39B Water System Test:**

https://www.nasa.gov/image-article/artemis-ii-water-deluge-test/

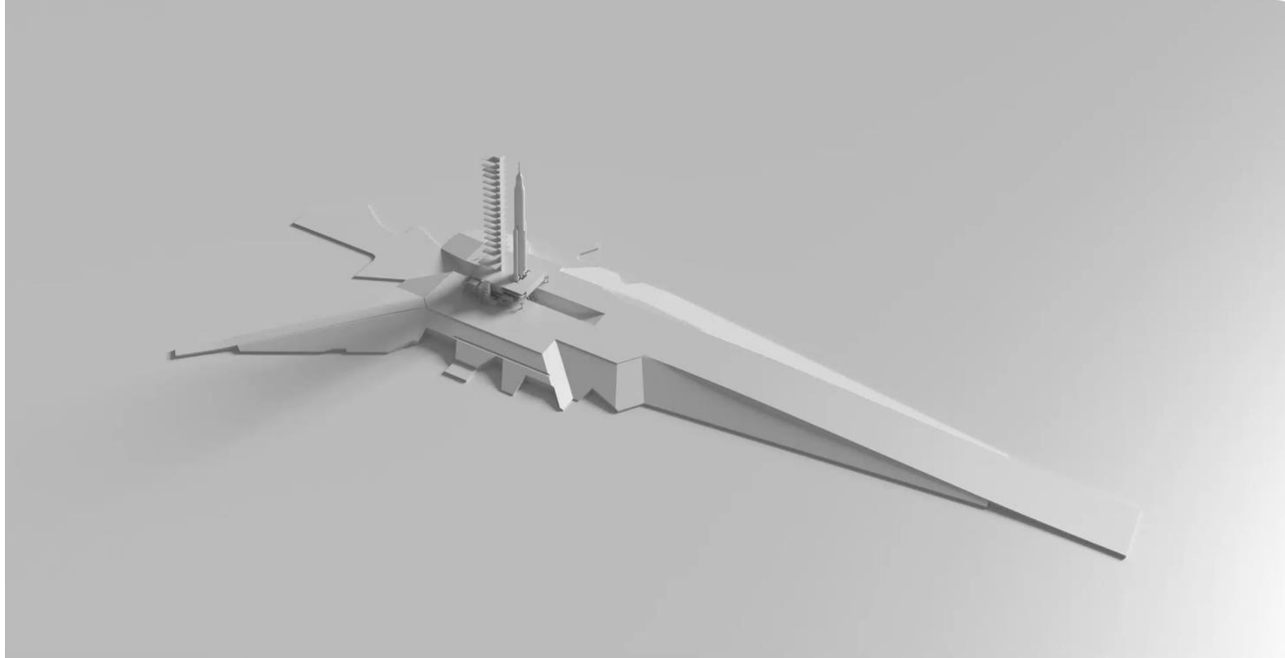
**Artemis I Launch 11/16/2022:**



https://images.nasa.gov/details/NHQ202211160021

**Multi-Species Dry Simulation:**

**Multi-Phase Simulation Including Water Systems:**



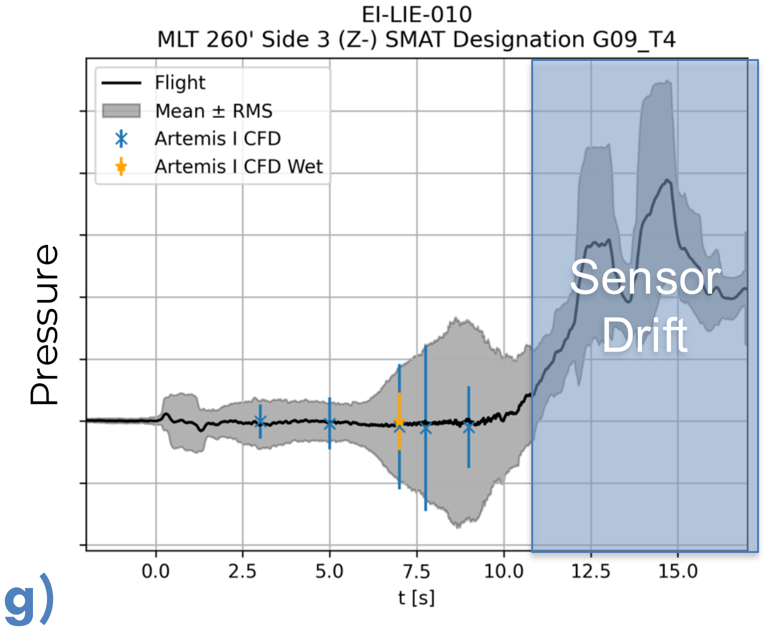
# Lofted Artemis Launchpad Simulations

Plume dynamics of last 2 seconds of Artemis I case (wet). Rendering of water liq/vap in teal. Launch pad surfaces colored by pressure. Exhaust gas rendered in yellow/orange

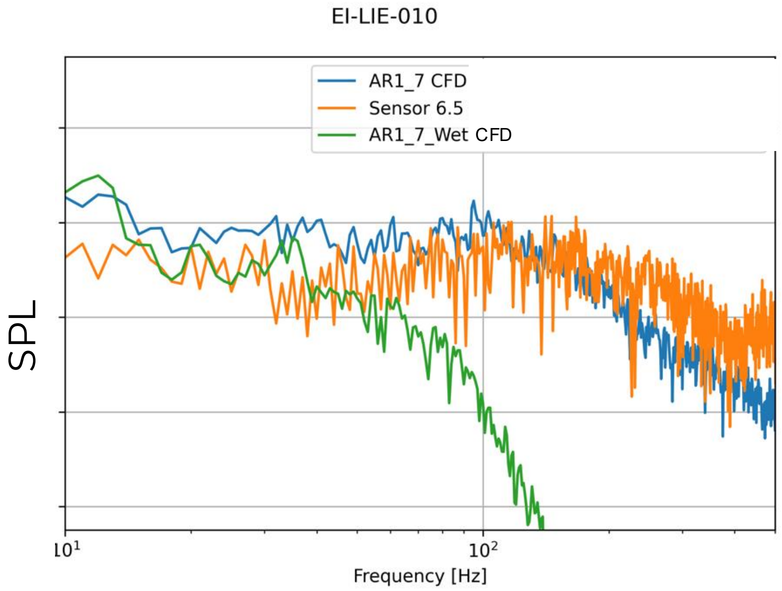
| Cells (M) | Node Type/Count | Wall Clock Time |
|---|---|---|
| 628.0 | 180 AMD Rome | 18 Days |

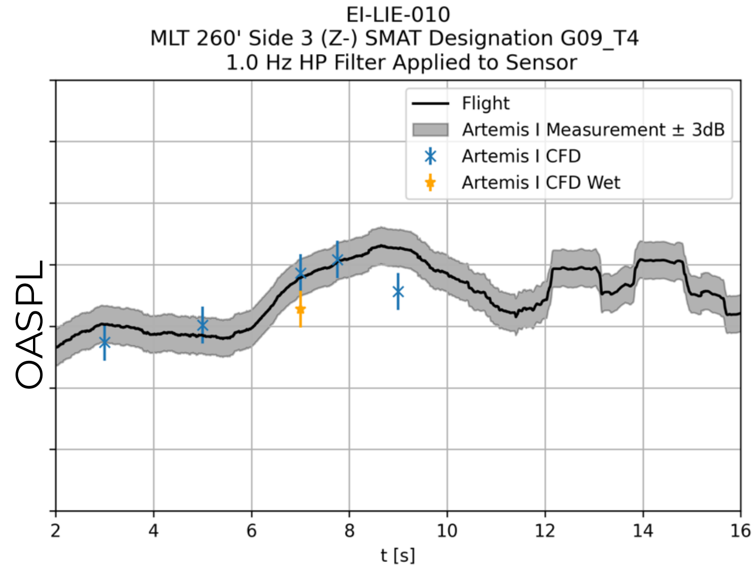
# Artemis I: Validation

## Comparison to measurement: North face (not plume facing)



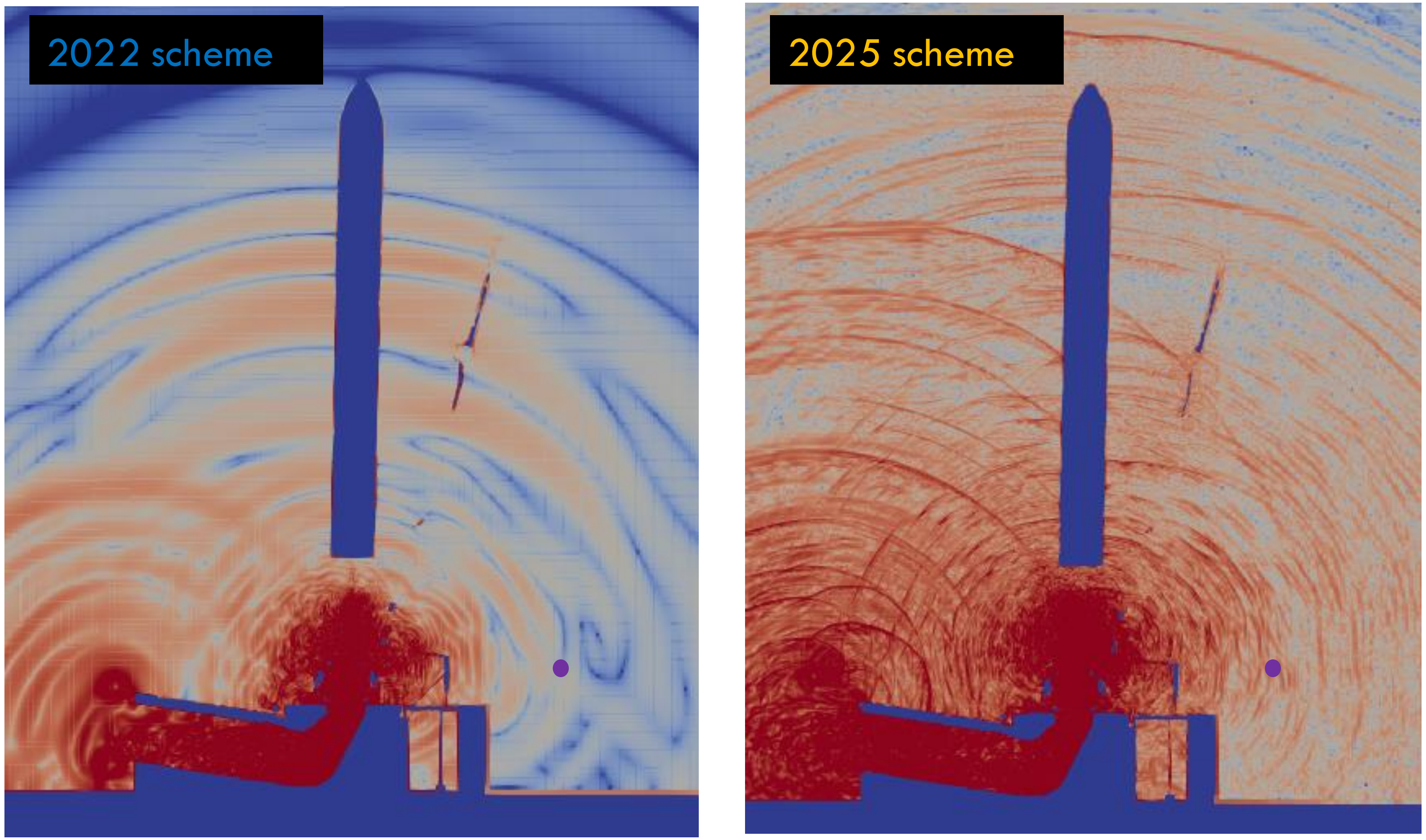
*Last-second gauge pressure averages for each simulation compared to ML tower measurements. Error bars indicate +/-std. (Z-) indicating north face. Some drift is evident at later times in the measurements.*



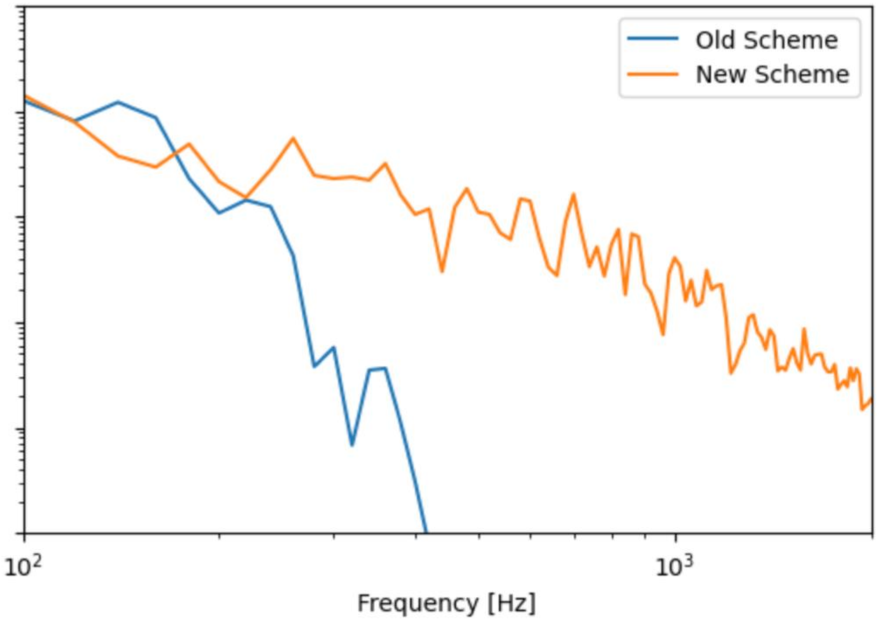


# Recent Developments : Improved Wet Launch Acoustics

- Significant improvement in acoustic resolution on the same mesh
- Important to multiphase: Robustness and accuracy of simulation is maintained
- GPU porting mostly done, still testing and optimizing



Pressure Gradient Visualization


Pressure Probe Frequency Spectrum

# Ascent Environment

Featuring:

- Cartesian WMLES with AMR

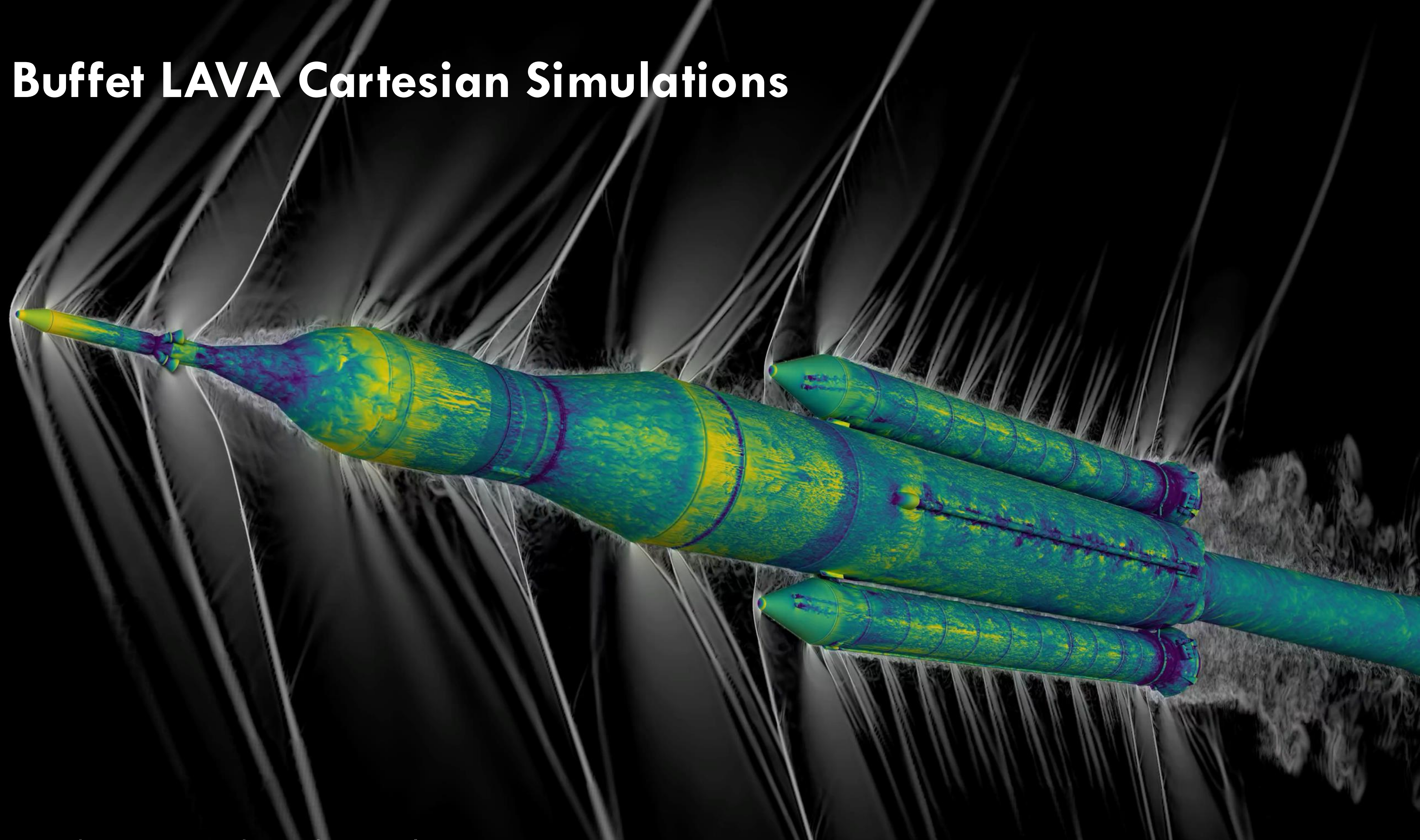
# LAVA Cartesian Proof of Concept for Space Vehicle Buffet Analysis

WMLES is a critical capability to analyze launch vehicles during ascent, particularly at transonic and low supersonic conditions, where unsteady flow physics poses risks to the vehicle

- The LAVA team simulated the SLS launch vehicle at buffet conditions as tested in the NASA Ames Unitary Plan WT.
- The LAVA team was able to setup (~1day) and run (~1day) a few prototype ~4 billion cell simulations on 72 GH200
- Validation with experimental data is underway

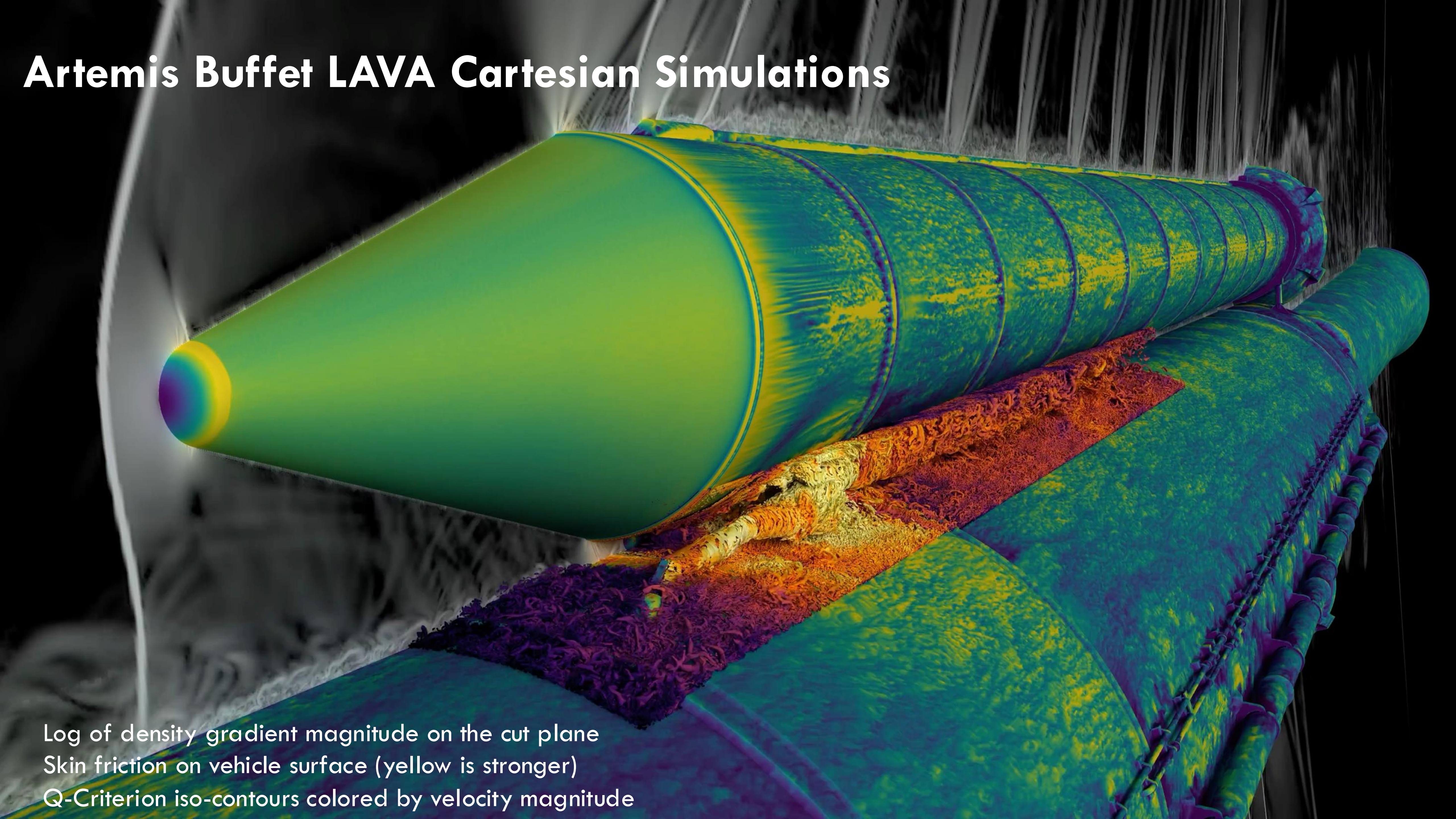
https://www.nasa.gov/image-article/artemis-i-launch-4/

# Artemis Buffet LAVA Cartesian Simulations



Log of density gradient magnitude on the cut plane
Skin friction on vehicle surface (yellow is stronger)

# Artemis Buffet LAVA Cartesian Simulations

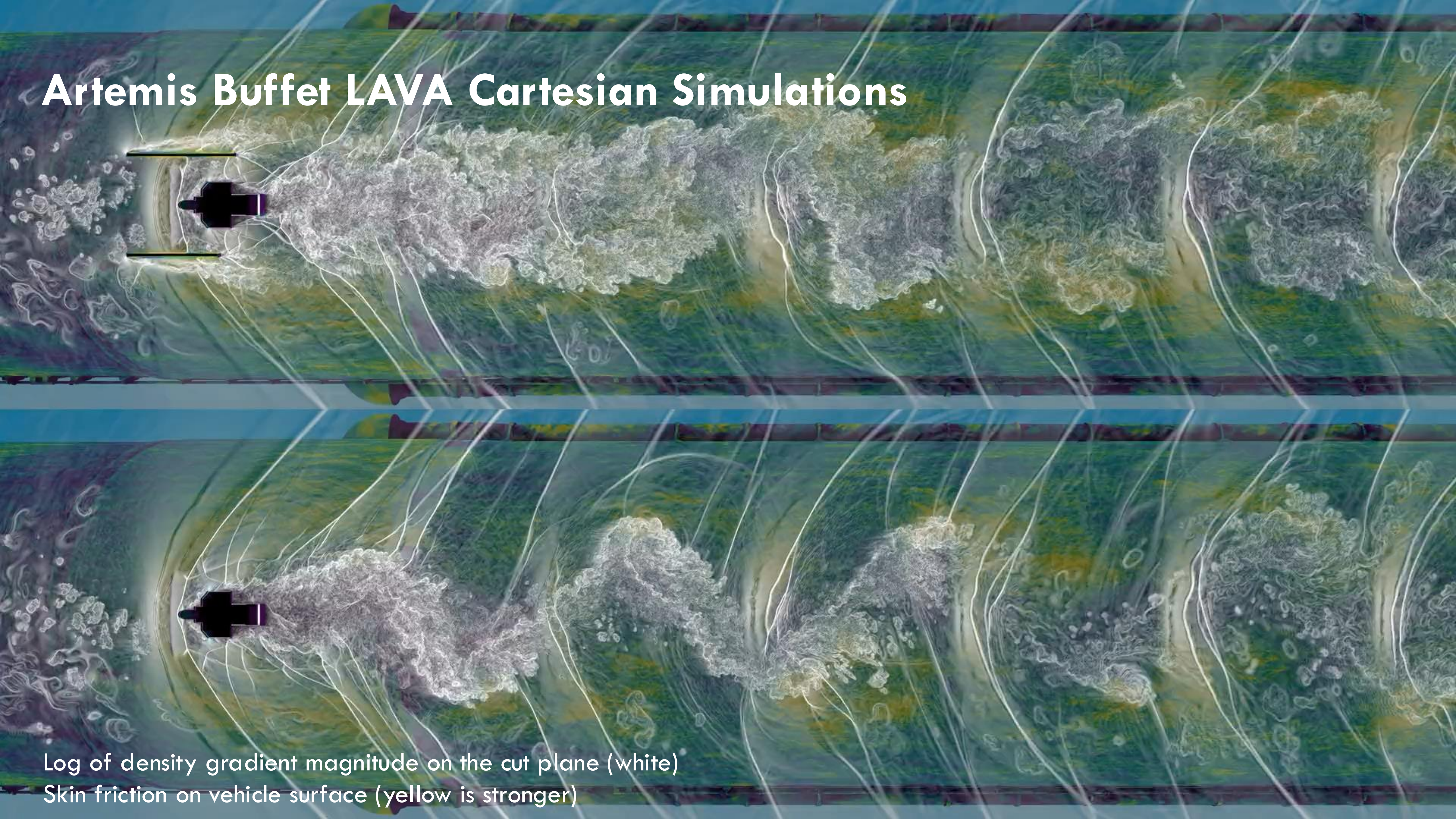


Log of density gradient magnitude on the cut plane

Skin friction on vehicle surface (yellow is stronger)

Q-Criterion iso-contours colored by velocity magnitude

# Artemis Buffet LAVA Cartesian Simulations

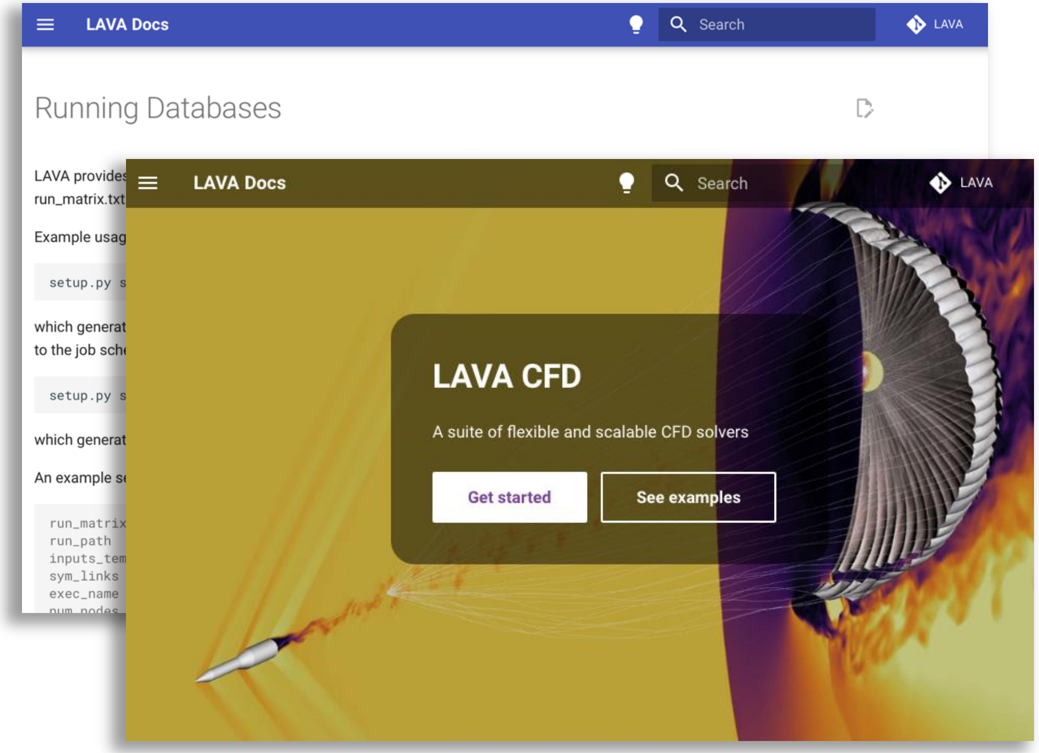


Log of density gradient magnitude on the cut plane (white)
Skin friction on vehicle surface (yellow is stronger)

# Future Plans for LAVA

- Continue working on **peak portable performance,** ranging from workstations to exascale clusters
- Further **AMR** efforts and optimizations
- Improve **WMLES closure and wall models,** addressing transition and smooth-body separation
- Expand high-fidelity **design optimization** and **multi-disciplinary analysis** for flight vehicles
- Introduce new **multi-physics modeling** capabilities as needed
- Continue to support an expanding user base

# Progress Towards Release



Running Databases

LAVA provide
run_matrix.txt

Example usag

```
setup.py s
```

which generat
to the job sch

```
setup.py s
```

which generat

An example s

```
run_matrix
run_path
inputs_tem
sym_links
exec_name
num_nodes
```

LAVA CFD

A suite of flexible and scalable CFD solvers

Release LAVA software so others can use it too!

Email jared.c.duensing@nasa.gov to be added to our future user list. Target public release date will be October 2025.

**100%**

1. Consult with experienced NASA CFD software developers familiar with the release process

---

**100%**

2. Work with select NASA groups and train/assist them in using LAVA
3. Create LAVA modules on NAS systems and release to all NASA users
4. Develop user documentation and tutorials

---

**75%**

5. Follow NASA software release process
6. Implement issue tracking system and community forum
7. Finish outstanding critical development tasks
8. Conduct user training sessions

---

9. Release the LAVA framework to users external to NASA (commercial, academia, etc.)

# Concluding Remarks

- LAVA has become a **go-to CFD option** for many of the agency's most complex applications.

- LAVA provides many unique capabilities with support for **three distinct mesh types**: Curvilinear, Unstructured, and Cartesian.

- LAVA enables **routine scale-resolving simulations** of complex problems with modest resources, often within a day.
  - GPU acceleration on NAS demonstrated ~**10x energy reduction** relative to CPU.
  - Reduces mission risk in difficult-to-test scenarios (e.g., supersonic parachute deployment on re-entry)
  - Enables more efficient and informed designs by incorporating high-fidelity CFD in the loop
  - Supplements / provides unique insight for physical testing, and supports certification by analysis goals

- LAVA has consistently demonstrated stand-out accuracy for complex **aerodynamic** and **aeroacoustic** environments

- LAVA's new MDAO capability enables uniquely robust geometric freedom along with efficient RANS based design optimization

# Acknowledgements

- Funding for LAVA has been provided through programs/projects across multiple NASA mission directorates. Enclosed application examples were funded by NASA's ARMD/TTT, ARMD/AATT, ARMD/CST, STMD/ESM, and ESDMD/EGS projects
- The authors would like to extend their gratitude to Mujeeb Malik, James Bridges, Melissa Carter, Sriram Rallabhandi, Andy Broeren, Shishir Pandya, Cliff Brown, Tony Washburn, Aaron Brandis, Justin Haskins, Michael Harris, Brandon Marsell, Craig Fortier, David Chesnutt, and William Dziedzic for their support, guidance, and collaboration

- Lucas Erlandson, David Appelhans and the NVIDIA team for their guidance when optimizing LAVA
- STC and AMA for providing excellent mission support throughout the AEMMS and ASSESS contract
- Computational resources are provided by the NASA Advanced Supercomputing (NAS) facility at NASA Ames Research Center
- The NAS Visualization Team for providing high-quality and insightful CFD visualizations over the years
- Dr. Cetin Kiris for his founding and key contributions to LAVA's success
- Past LAVA Team members for their contributions to solver framework development and applications

**THANK YOU!**

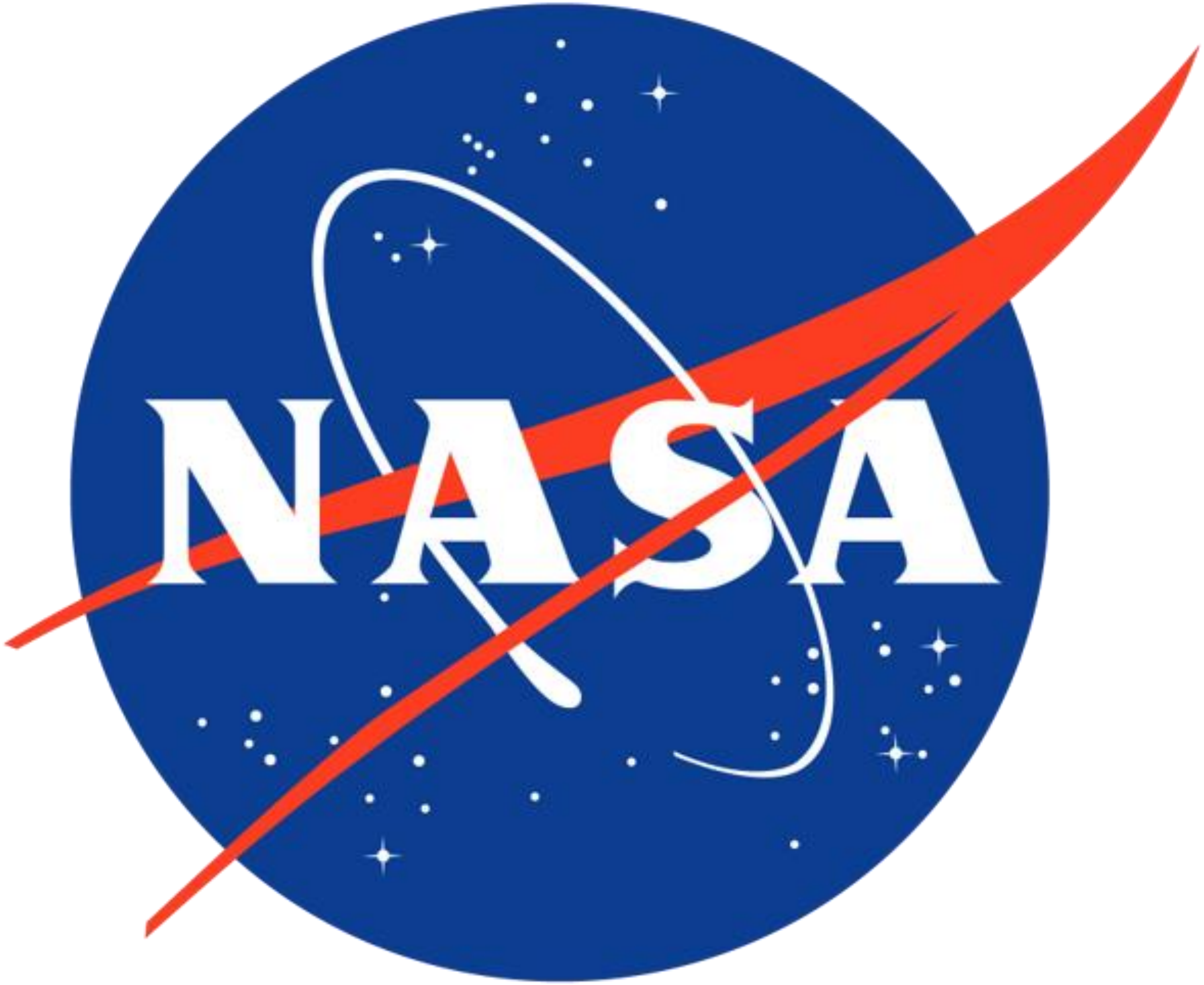
# Acknowledgements

LAVA Team members, who have won a

**2024/2025 NASA Honor Award—Group Achievement Award**

*For enhancing the LAVA Framework to include efficient scale-resolving CFD and high-fidelity design, strengthening NASA's ability to advance next-generation flight vehicles.*

**CONGRATULATIONS!**


NASA