



Scale-Resolving Simulations for Jet Noise Prediction

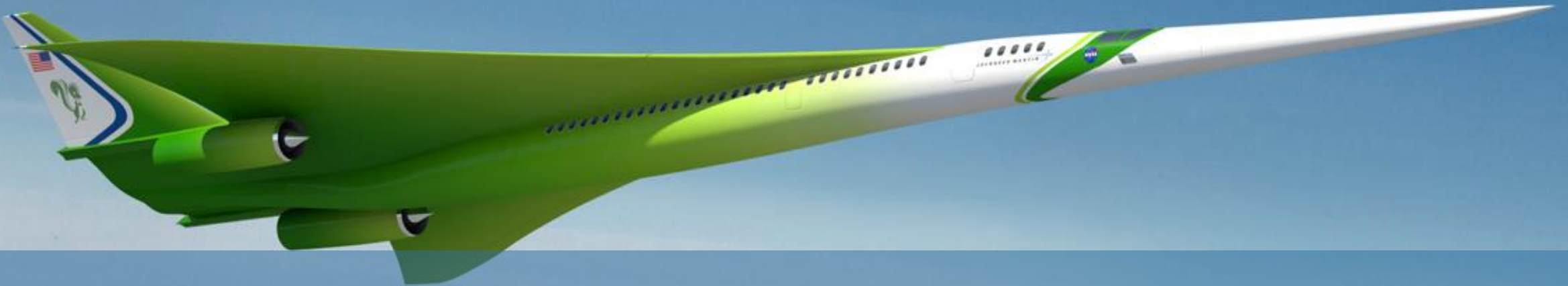
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Housman, Jared Duensing

NASA Ames Research Center

November 2024

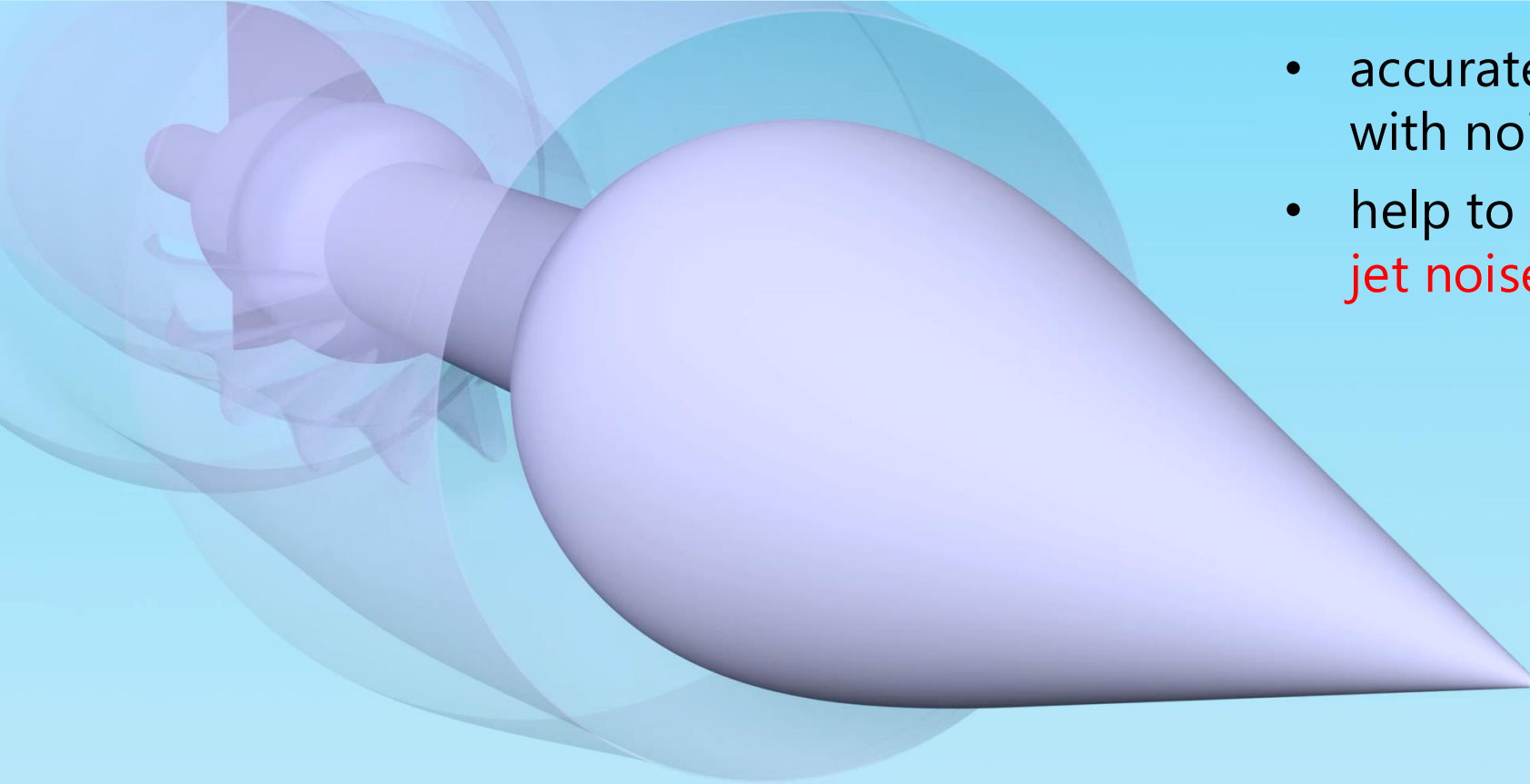
An emerging potential market has generated renewed interest in civil supersonic aircraft

- ✓ appearance of several commercial programs
- ✗ lack of standards for en route noise or landing and takeoff noise



National Research and Policy agencies play a central role in developing the data needed for the regulation change that is essential to enabling this new market

High-fidelity scale resolving simulations conducted at NASA's Ames Research Center with the Launch Ascent and Vehicle Aerodynamics (LAVA) Solver



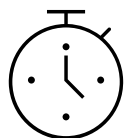
- accurately captures physics associated with noise generation
- help to **shape FAA regulations** + develop **jet noise reduction technologies**

NASA Advanced Supercomputing Division (NAS)

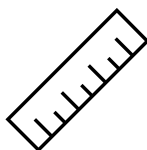
- NASA's supercomputing facility located at NASA's Ames Research Center began operating in 1987
- The NAS Division provides more than 1,500 NASA associated users of the facility with advanced computing technologies, mass storage systems, networking and innovative tools and technologies
- Our in-house solver the **Launch Ascent and Vehicle Aerodynamics (LAVA)**
 - state-of-the-art computer science features
 - enable rapid simulation turnaround times of complex scale-resolving aeroacoustics simulations
- Broadband jet noise can be predicted in **less than two hours** utilizing 100 AMD Rome nodes (12800 CPUs) on the Aitken supercomputer at NAS
- Jet noise simulations generate hundreds of terabytes of data
 - development of **new technologies** + **advance knowledge** of jet noise



The Launch, Ascent, and Vehicle Aerodynamics (LAVA) framework objectives for jet noise within NASA's CST project



Predict jet noise **accurately** and in **short enough turnaround time** using scale-resolving simulations methods



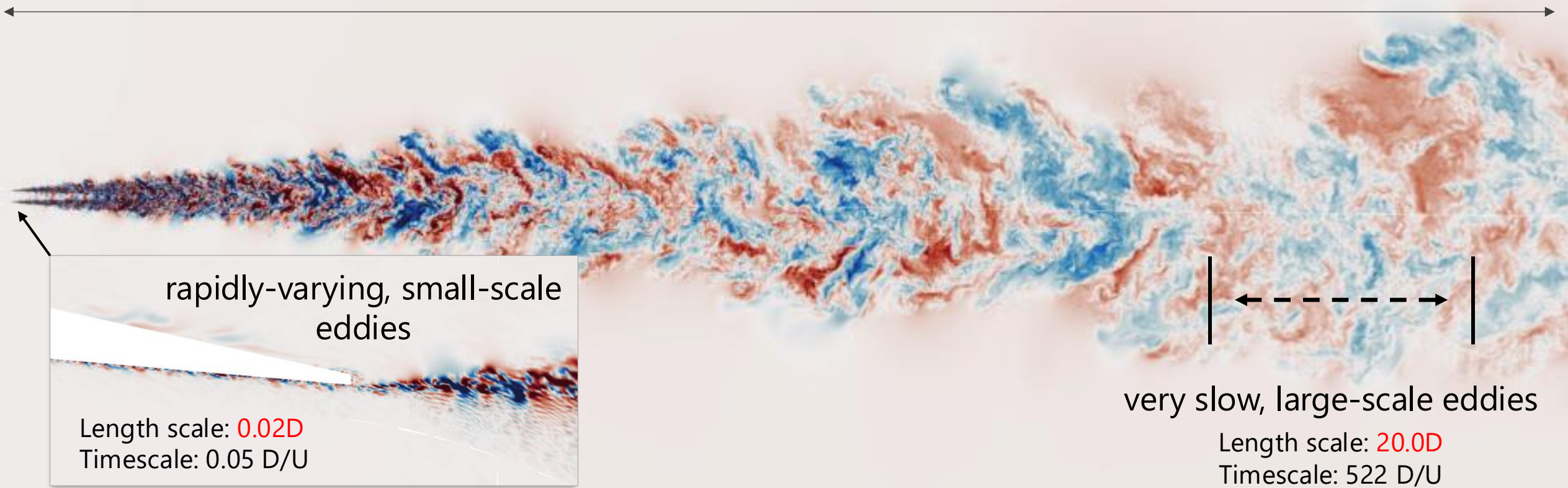
Understand and document **uncertainties** and **shortcomings** of scale-resolving wall-modeled LES for jet noise simulations



Future Impact: complement/replace wind tunnel and flight tests, reduction of associated costs, provides insight into noise reduction technology never-before available

Why are jet noise simulations so difficult?

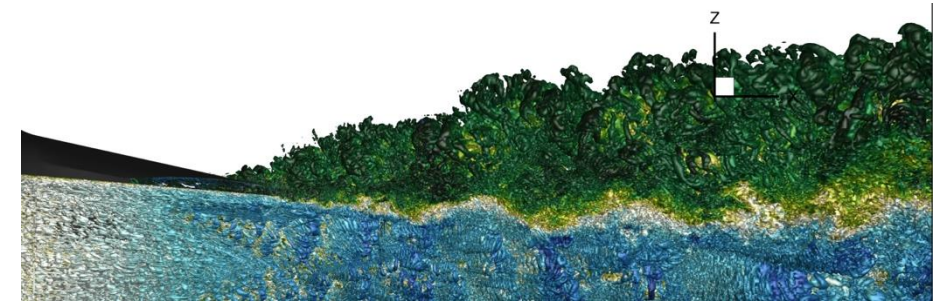
Domain size is ~ 140 nozzle diameters (D)



Several methods of simulating jet noise – we focus on two

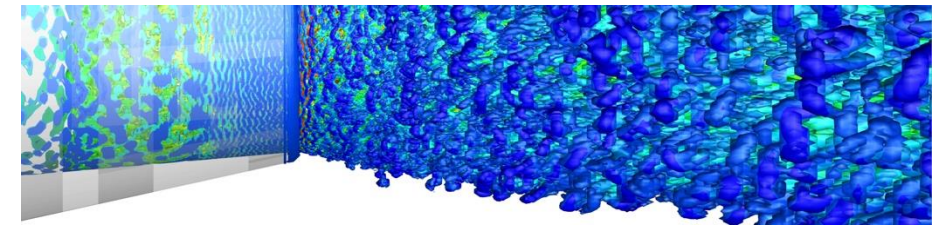
Wall-modeled large-eddy simulation (LES)

- scale resolving, spatially-filtered Navier Stokes equations solved everywhere in the domain
- wall stress model used as boundary condition to the LES



Hybrid RANS/LES

- non-scale-resolving method (Reynolds-Averaged Navier Stokes, RANS) used near the wall and in coarse regions
- LES used in regions with fine mesh resolution

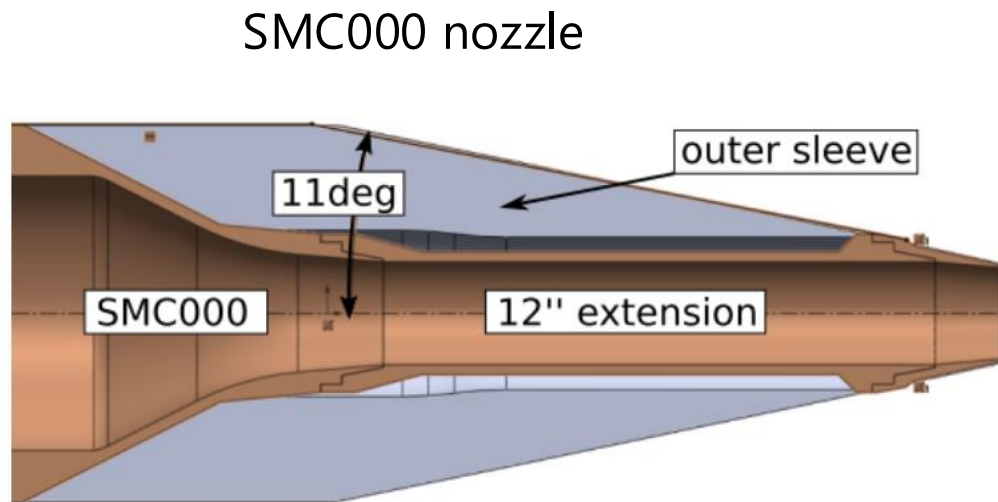


3-step pathway to full aircraft jet noise predictions

- ① round jet validation
- ② shielding concepts
- ③ increasingly complex geometries

3-step pathway to full aircraft jet noise predictions

① round jet validation



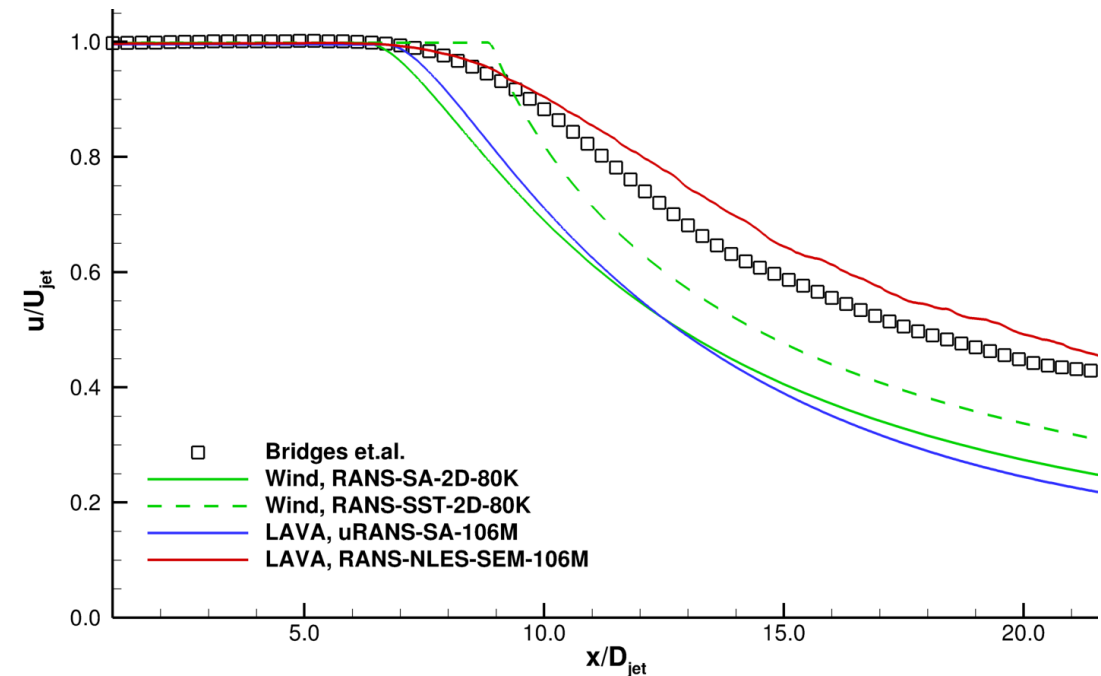
2017: Round jet validation with hybrid RANS/LES

NASA RCA challenge for jet noise

- improve simulation accuracy by 40%
- prediction of length of potential core ($U/U_j = 0.98$)
- improvement of centerline TKE Prediction
- see AIAA-2017-3213 for more information

solver	error [%]
state-of-the-art SA-RANS ¹	-12.3
LAVA Hybrid RANS/LES	1.2

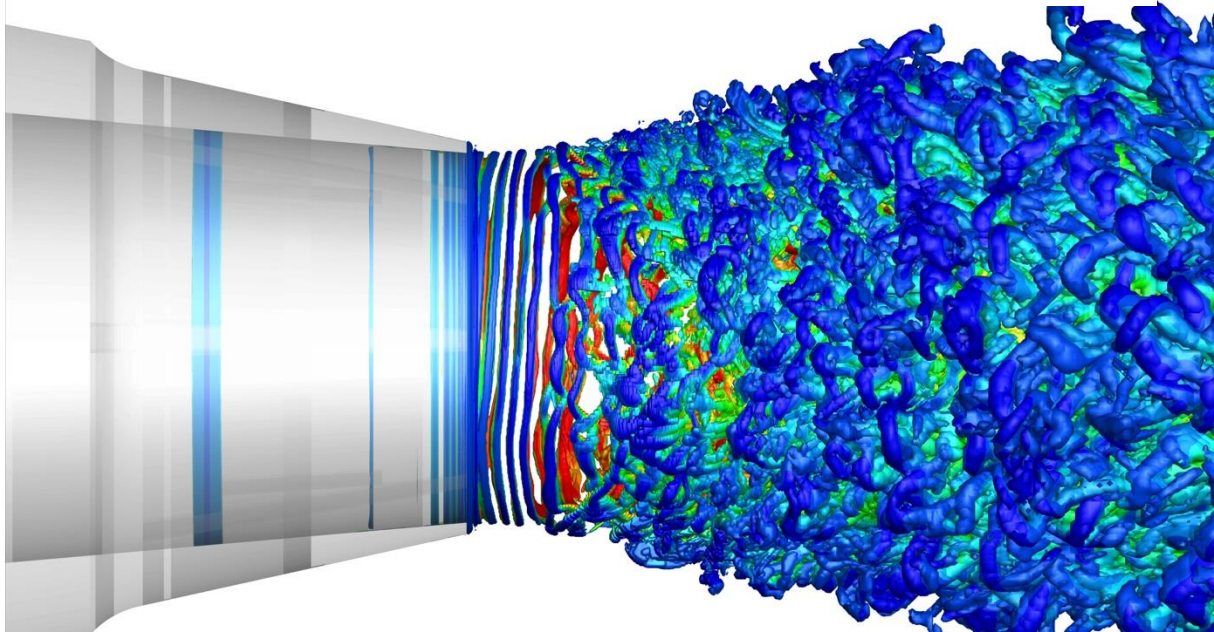
89.6% improvement



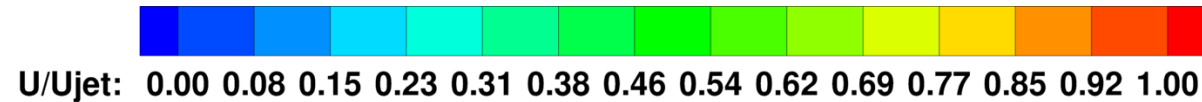
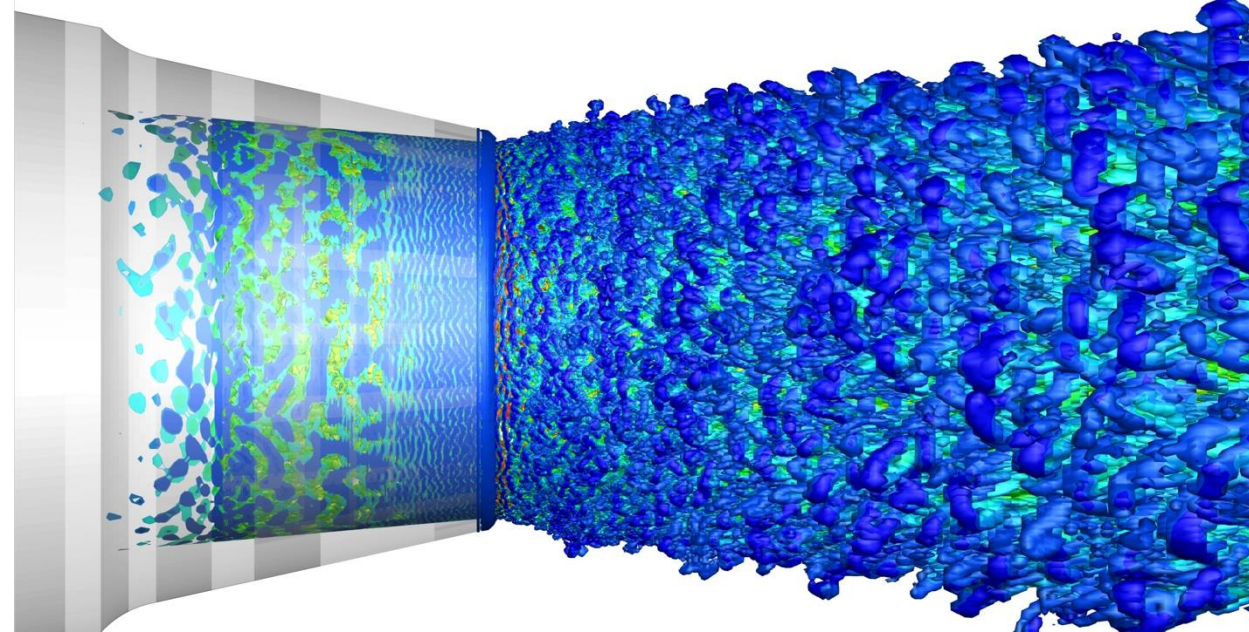
¹ RANS Data, Objectives and Metrics from NASA Turbulence Modeling Resource (TMR) website

2017: Round jet validation with hybrid RANS/LES

Delayed Detached Eddy Simulation
256M grid points



Zonal Detached Eddy Simulation
106M grid points

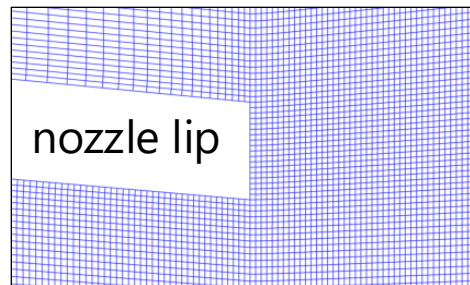


2020: Wall-modeled LES yields large efficiency improvements

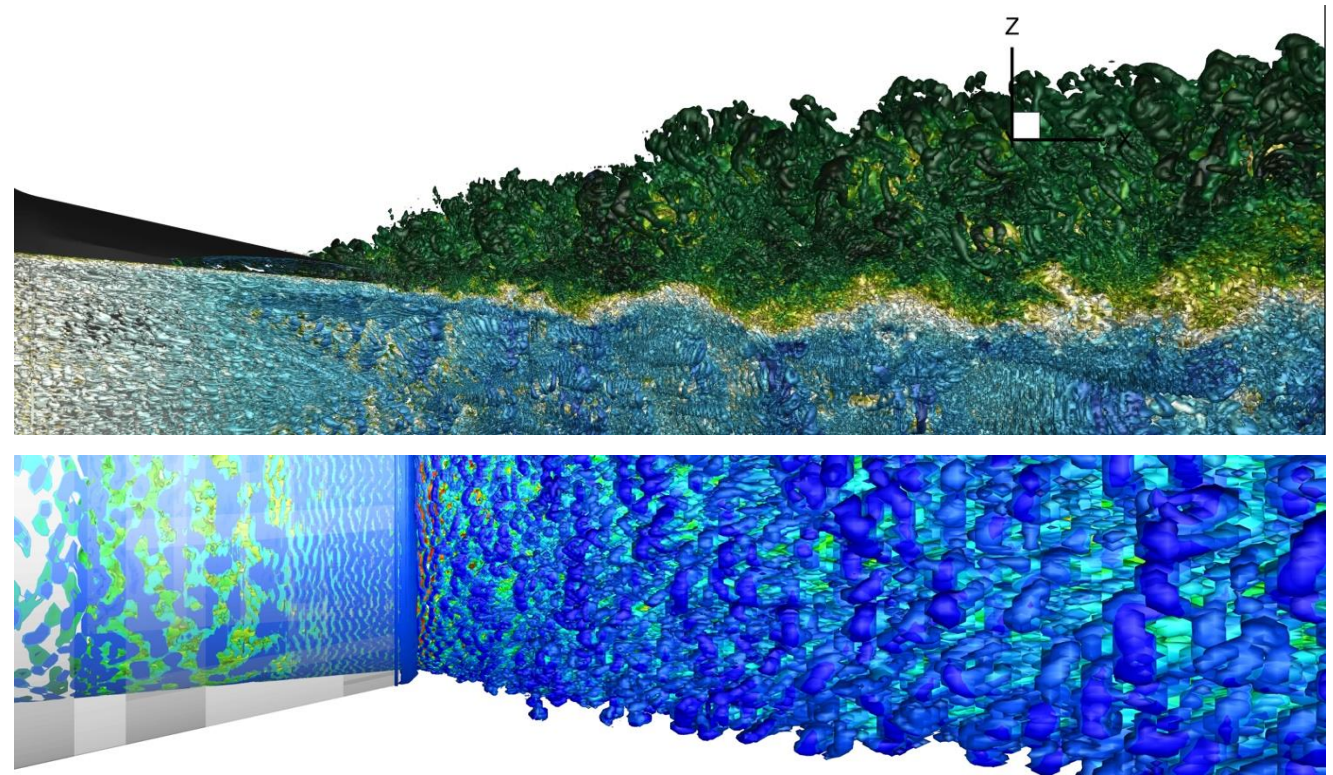
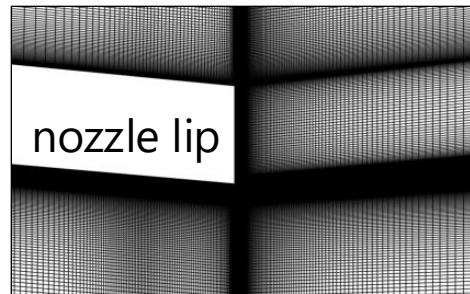
mesh points can get redistributed more evenly

- increases high-frequency resolution
- reduces mesh count

2021: WMLES



2017: hybrid
RANS/LES

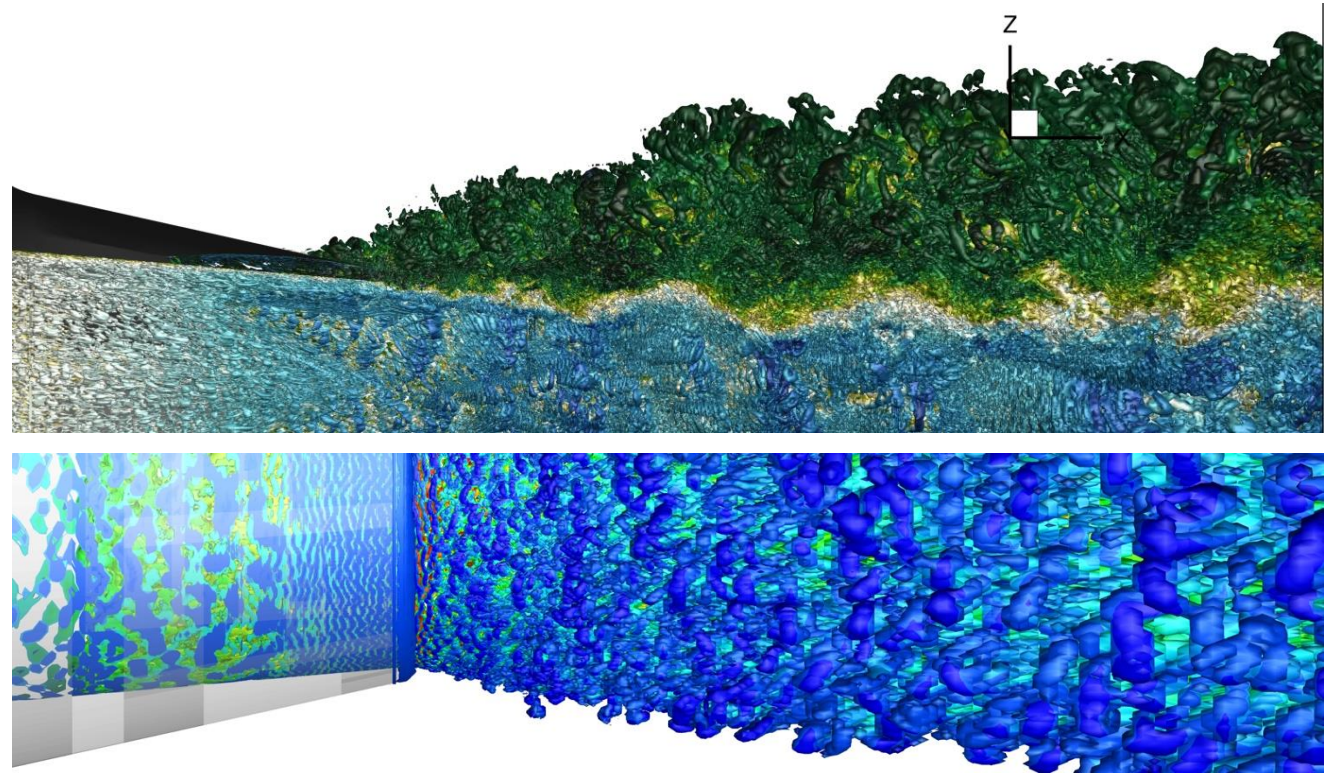
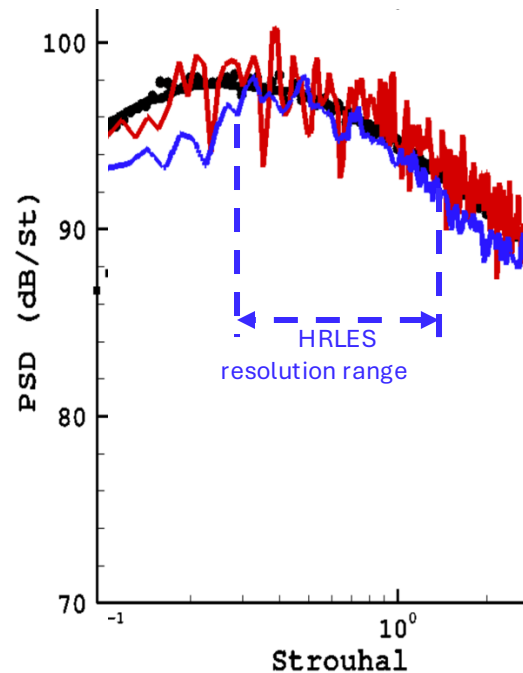


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WMLES | Hybrid RANS/LES

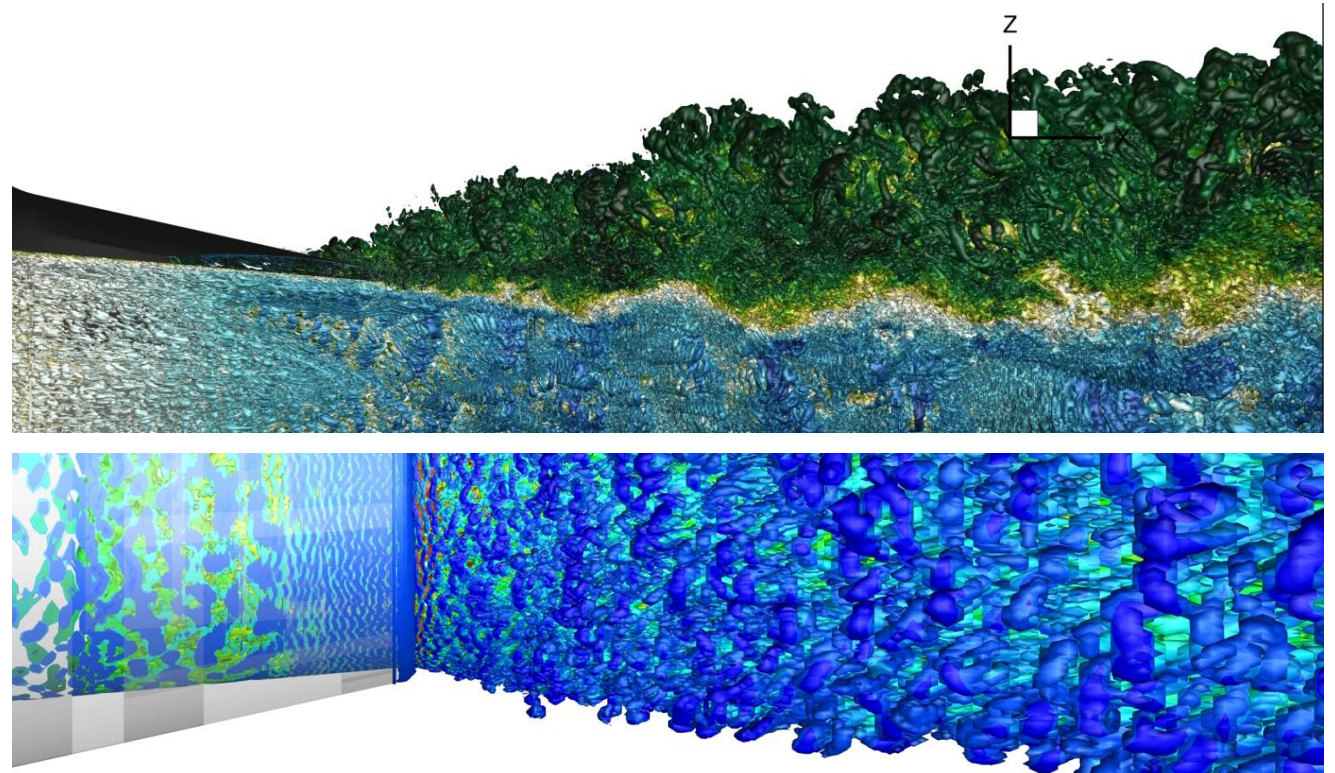
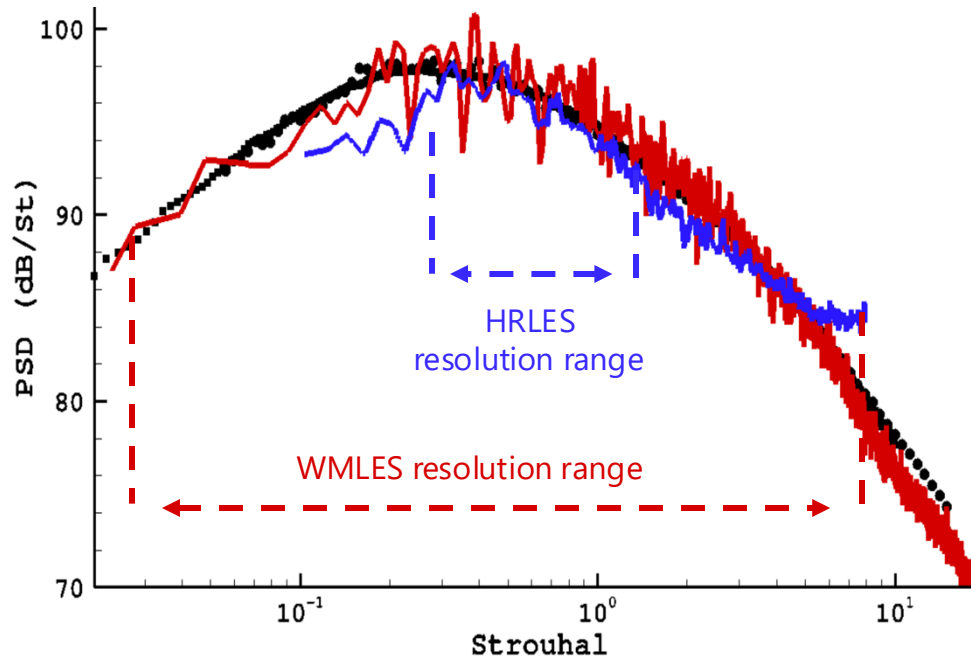


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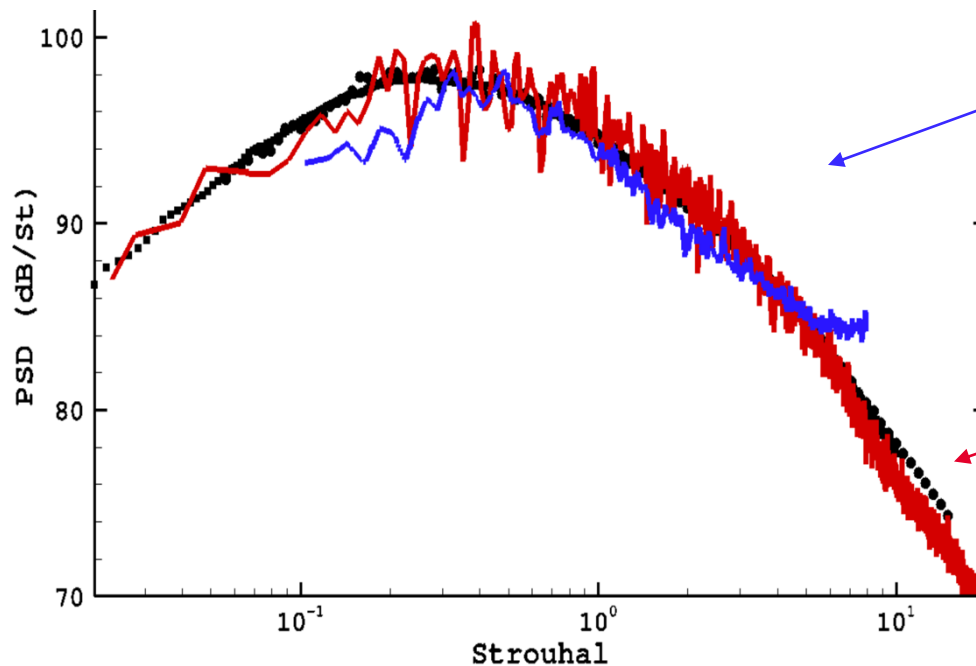


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WMLES | Hybrid RANS/LES



HRLES for round jet (2019)

6.5 days → 300 CTU

60 Skylake Nodes
2,400 cores

WMLES for round jet (2021)

0.6 days → 2000 CTU

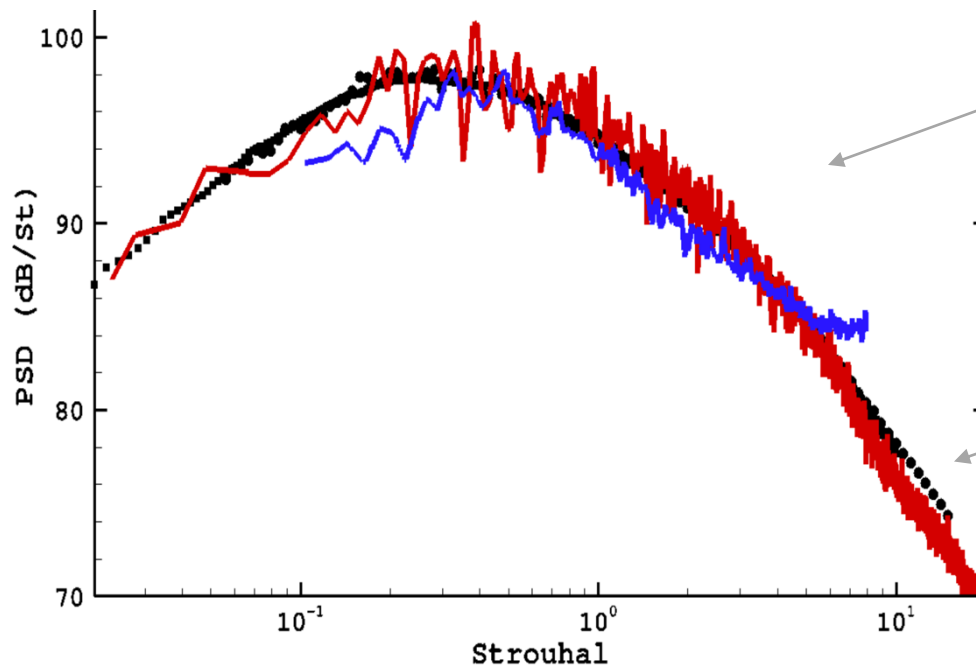
100 AMD Rome Nodes
12,800 cores

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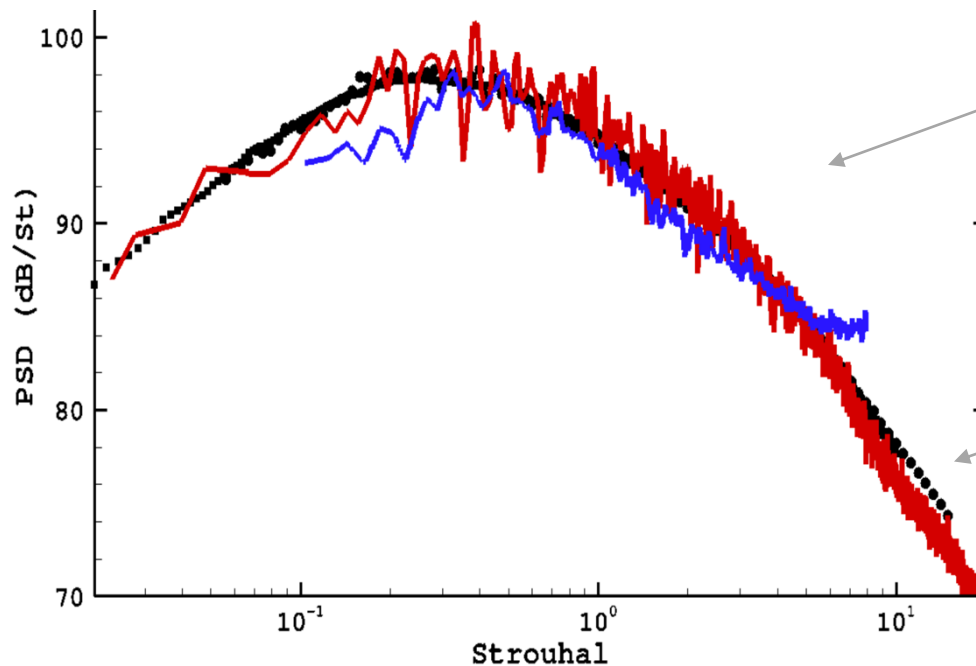
simulation time ↑ 6x
turnaround time ↓ 10x

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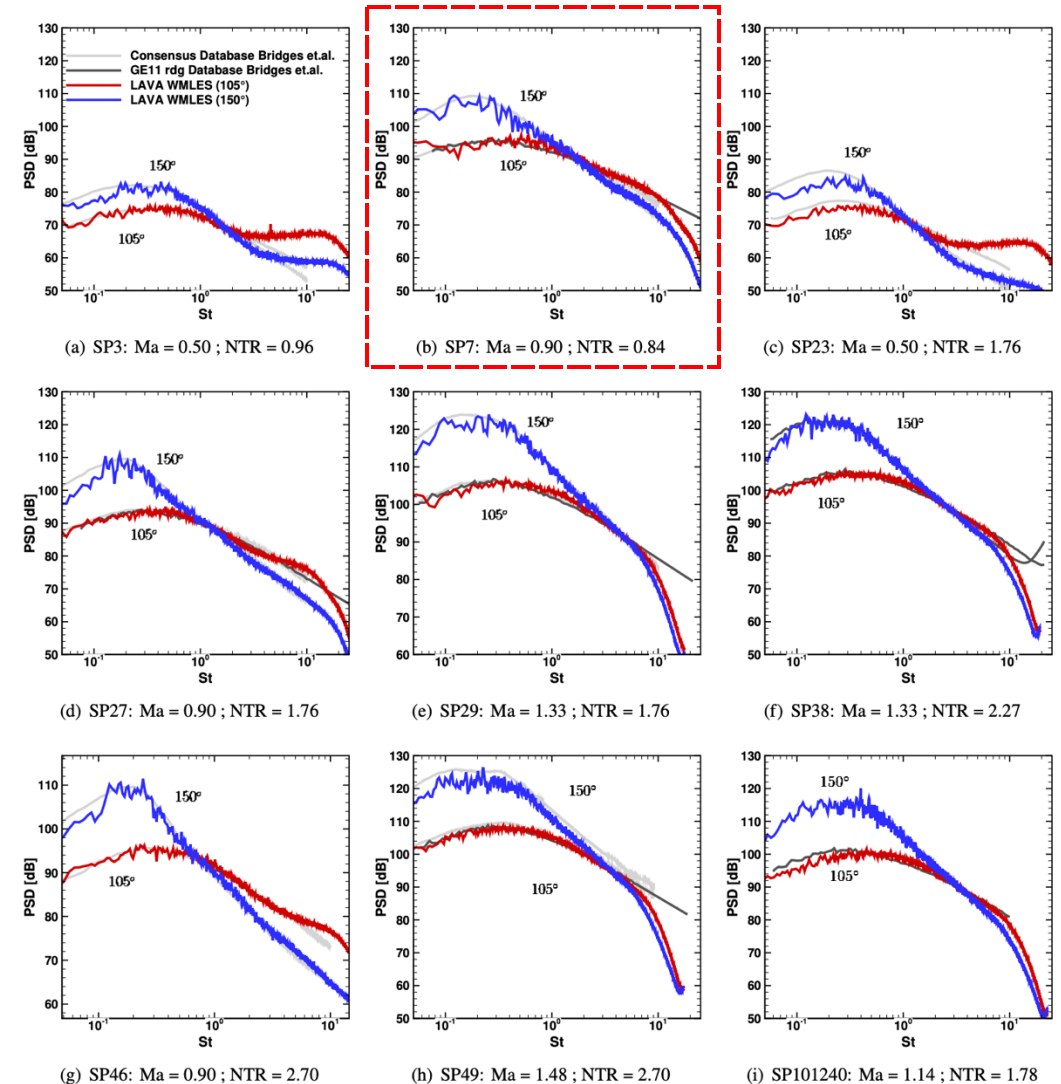
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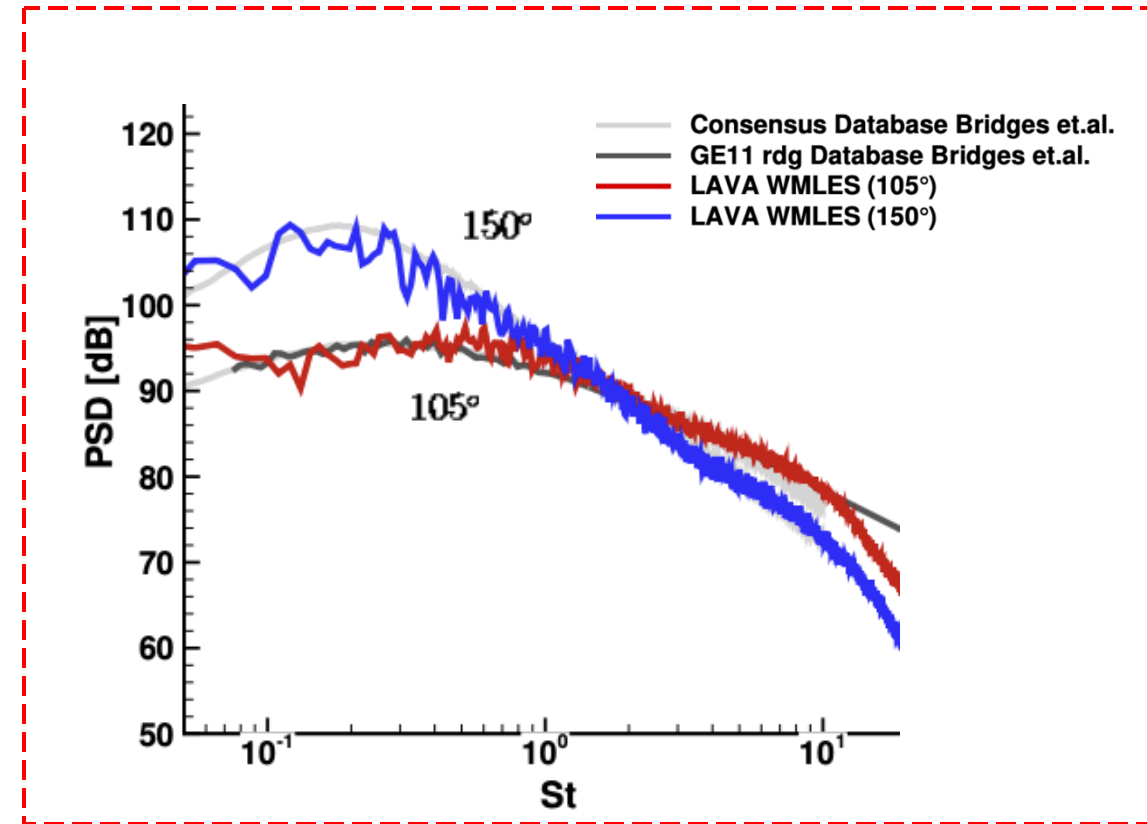
We can now simulate many different operating conditions!

Set Point SP	Ma [-]	M _j [-]	NPR [-]	NTR [-]	P _t [psi]	T _t [R]	U _{jet} [m/s]	X _c /D _j [-]
3	0.50	0.51	1.197	0.96	17.138	535.2	173	5.10
7	0.90	0.98	1.852	0.84	26.516	521.5	306	6.02
23	0.50	0.38	1.102	1.76	15.778	960.5	171	3.85
27	0.90	0.68	1.368	1.76	19.526	1029.5	313	4.32
29	1.33	1.00	1.898	1.76	27.090	1133.6	460	4.94
38	1.33	0.88	1.664	2.27	23.745	1400.7	460	-
46	0.90	0.56	1.219	2.70	17.453	1513.2	305	3.62
49	1.48	0.90	1.697	2.70	24.219	1673.4	512	4.25
101240	1.14	0.85	1.608	1.78	23.080	1086.1	392	-



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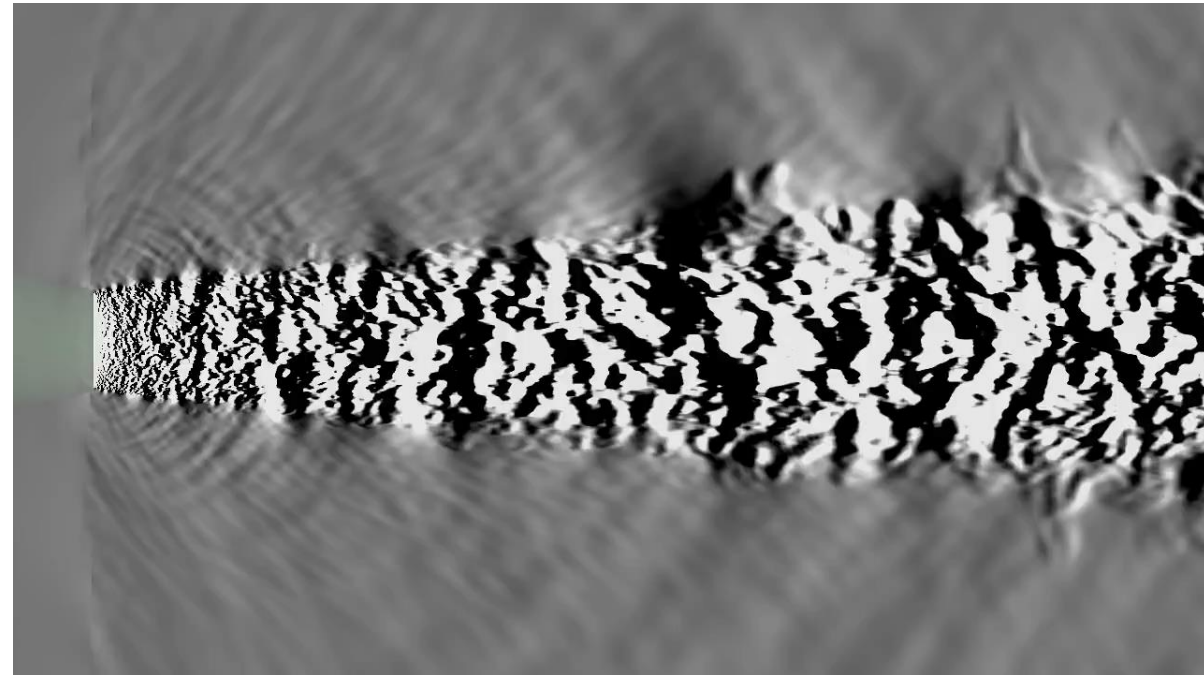
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(b) SP7: Ma = 0.90 ; NTR = 0.84

Jet noise database generated to assess prediction uncertainties

- Successfully generated WMLES database for static and in-flight jet noise simulations within NASA PUR Challenge
- Simulations performed in short turnaround time (**60x improvement** over hybrid RANS/LES - 2019)
- **Excellent agreement with experiments.** Comparable to experimental rig-to-rig data deviations
- Biggest bottleneck is manual mesh generation time



3-step pathway to full aircraft jet noise predictions

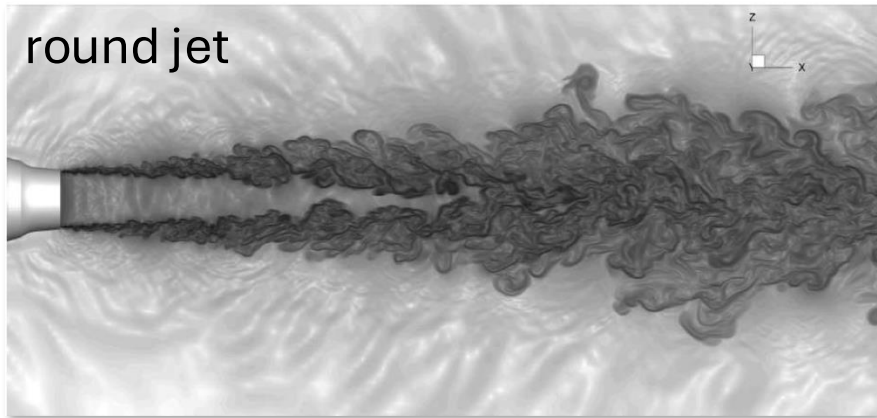
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- ③ increasingly complex geometries

Airframe shielding as a method for noise reduction

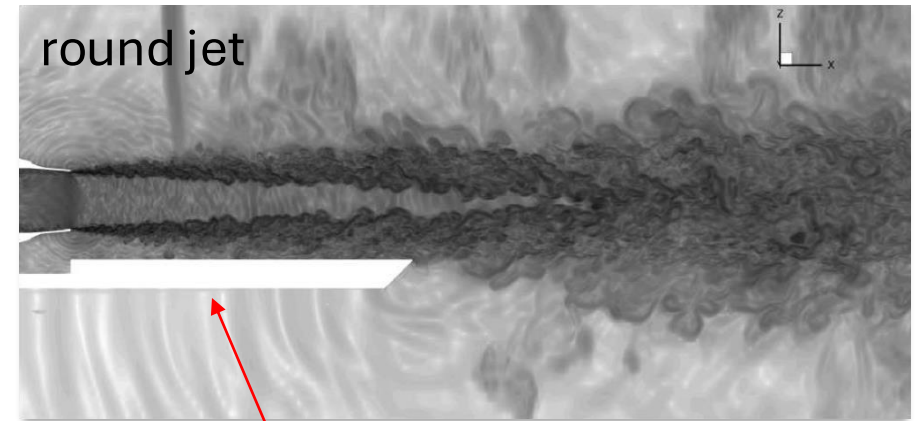
- can we develop novel integrated propulsion concepts that **reduce jet noise through airframe shielding**

Airframe shielding as a method for noise reduction

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what happens if
we try to block
the noise?

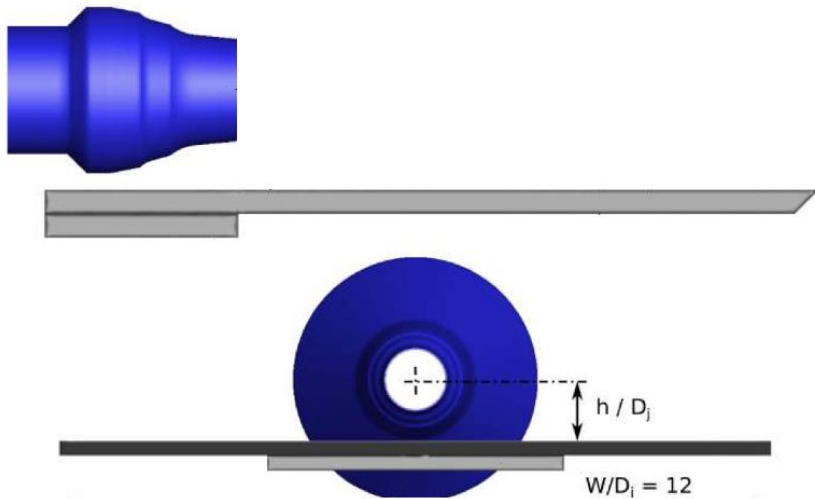


model airframe

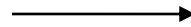
- validating LAVA codes for jet surface interaction problems
- evaluating the performance of shielding concepts

Jet-surface interaction test problem

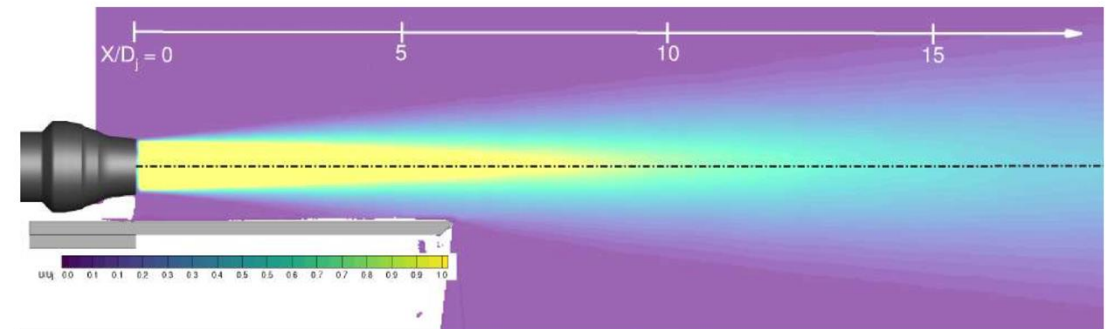
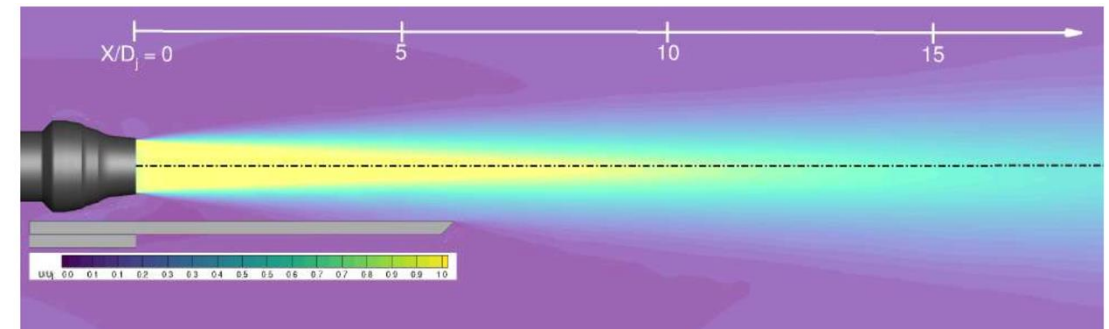
same round jet but now add a shielding surface

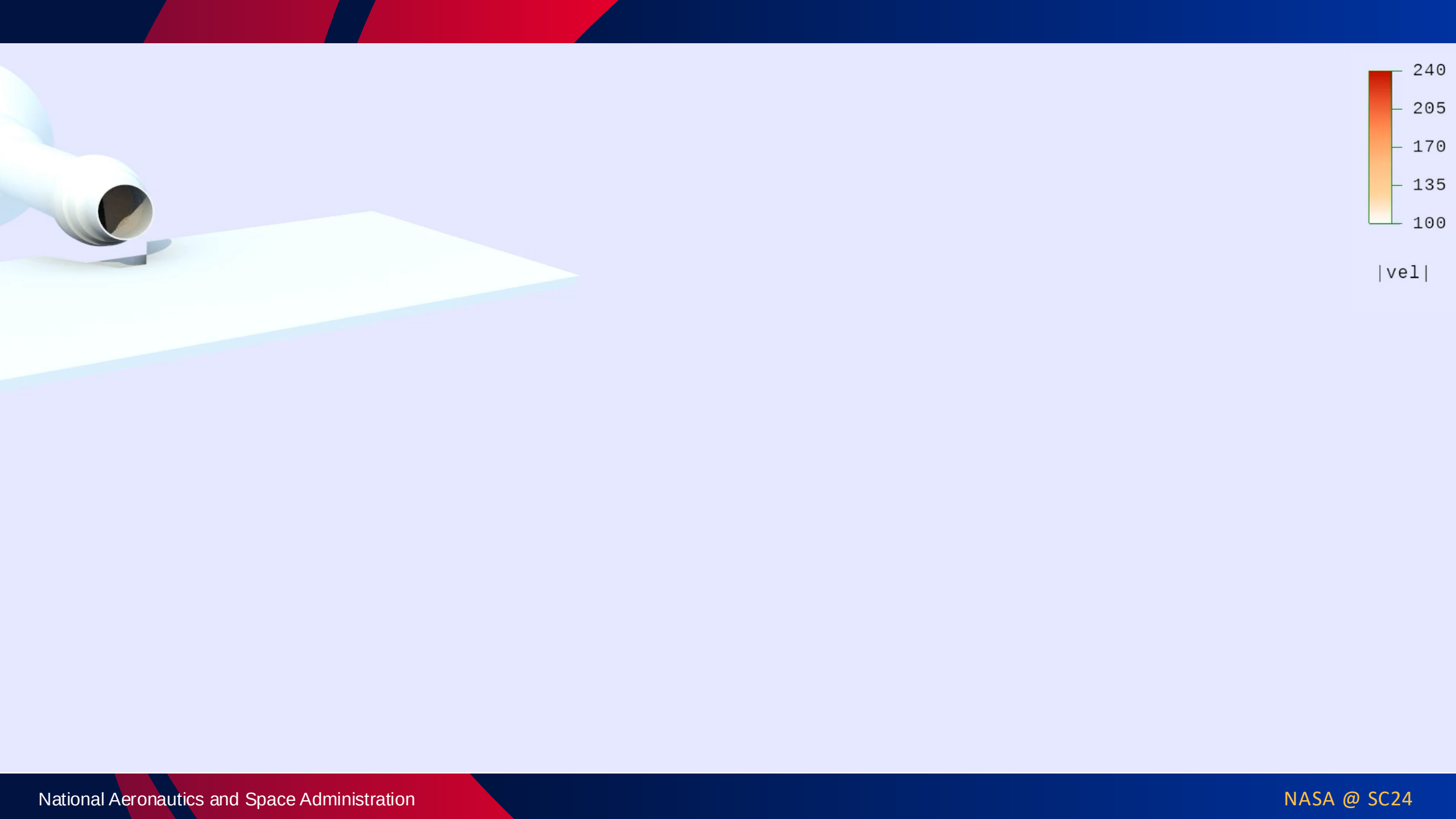


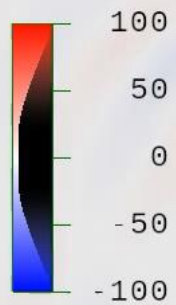
Zonal Detached
Eddy simulation



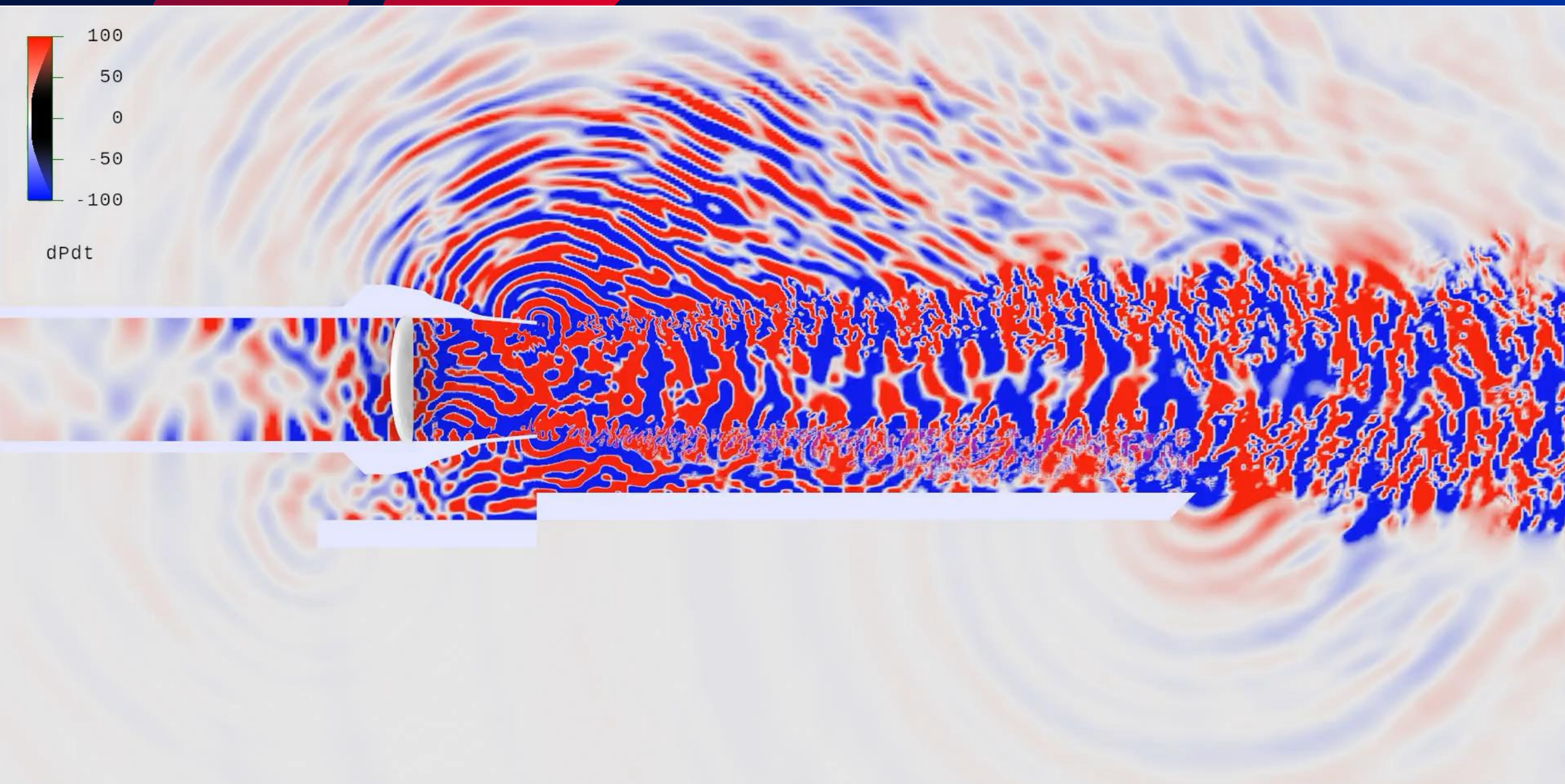
experimental
measurements







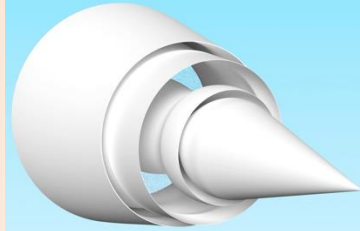
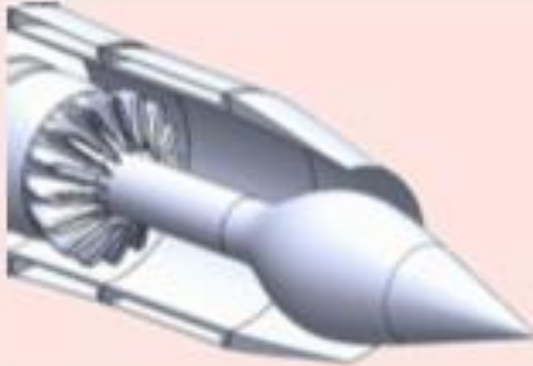
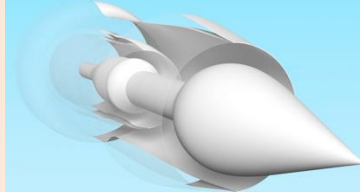
dPdt



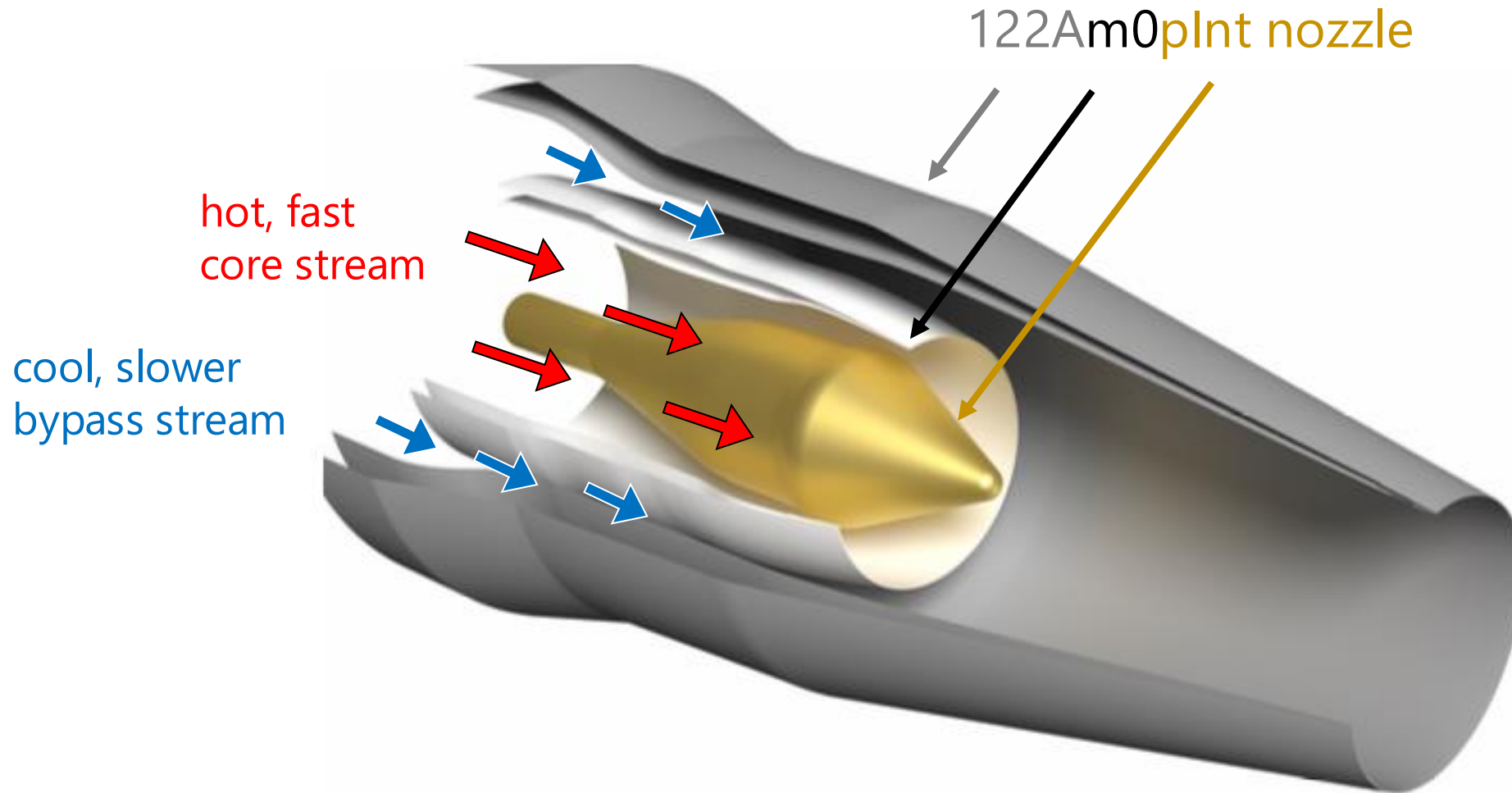
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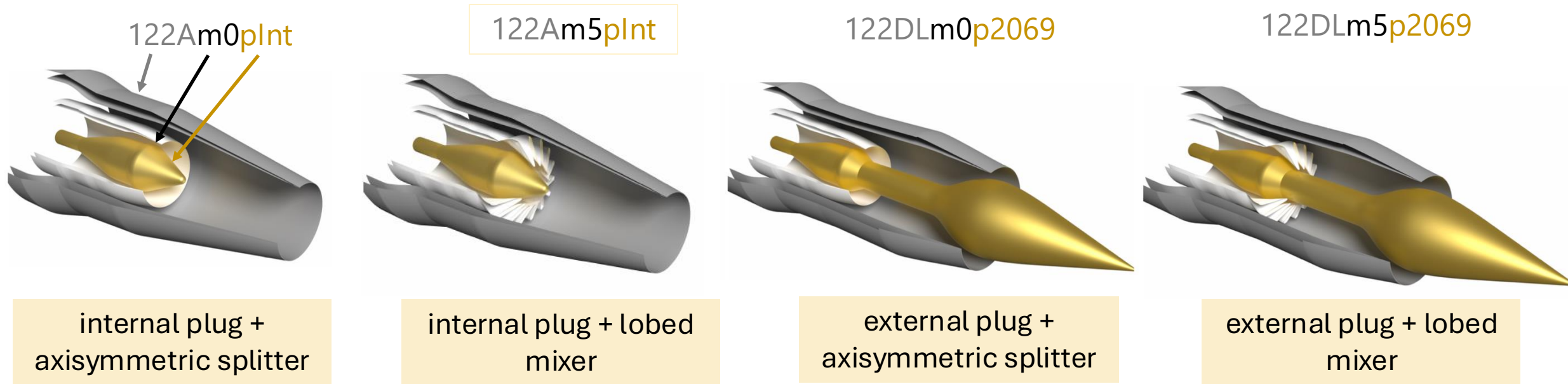
Reduce uncertainty predicting noise for supersonic aircraft

Conventional			
Supersonic			
	Different highlift devices Different installation	Internal mixers Large long plugs	CFD simulations performed with LAVA WMLES

Plug20 nozzle configurations – interchangeable designs

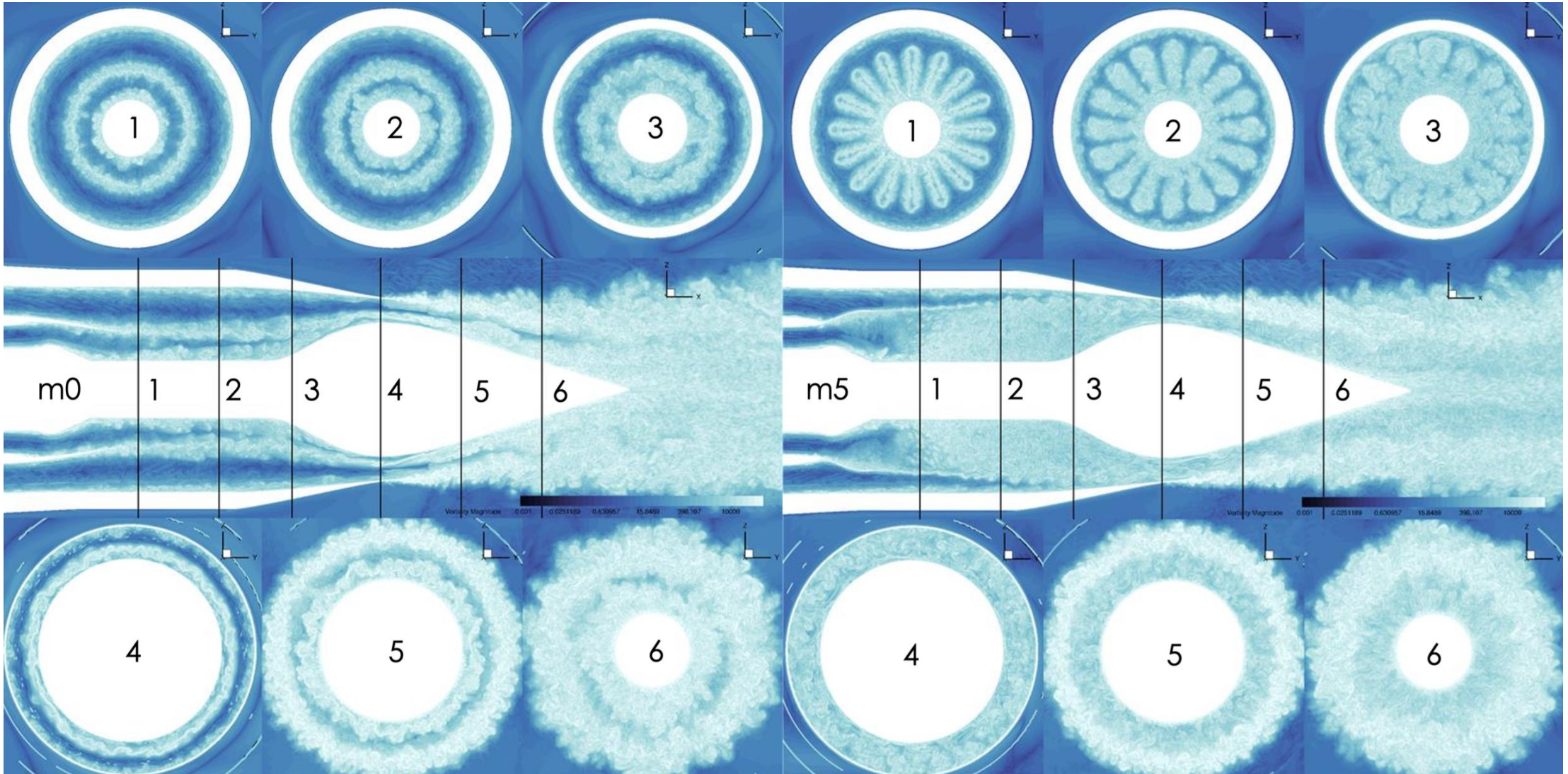


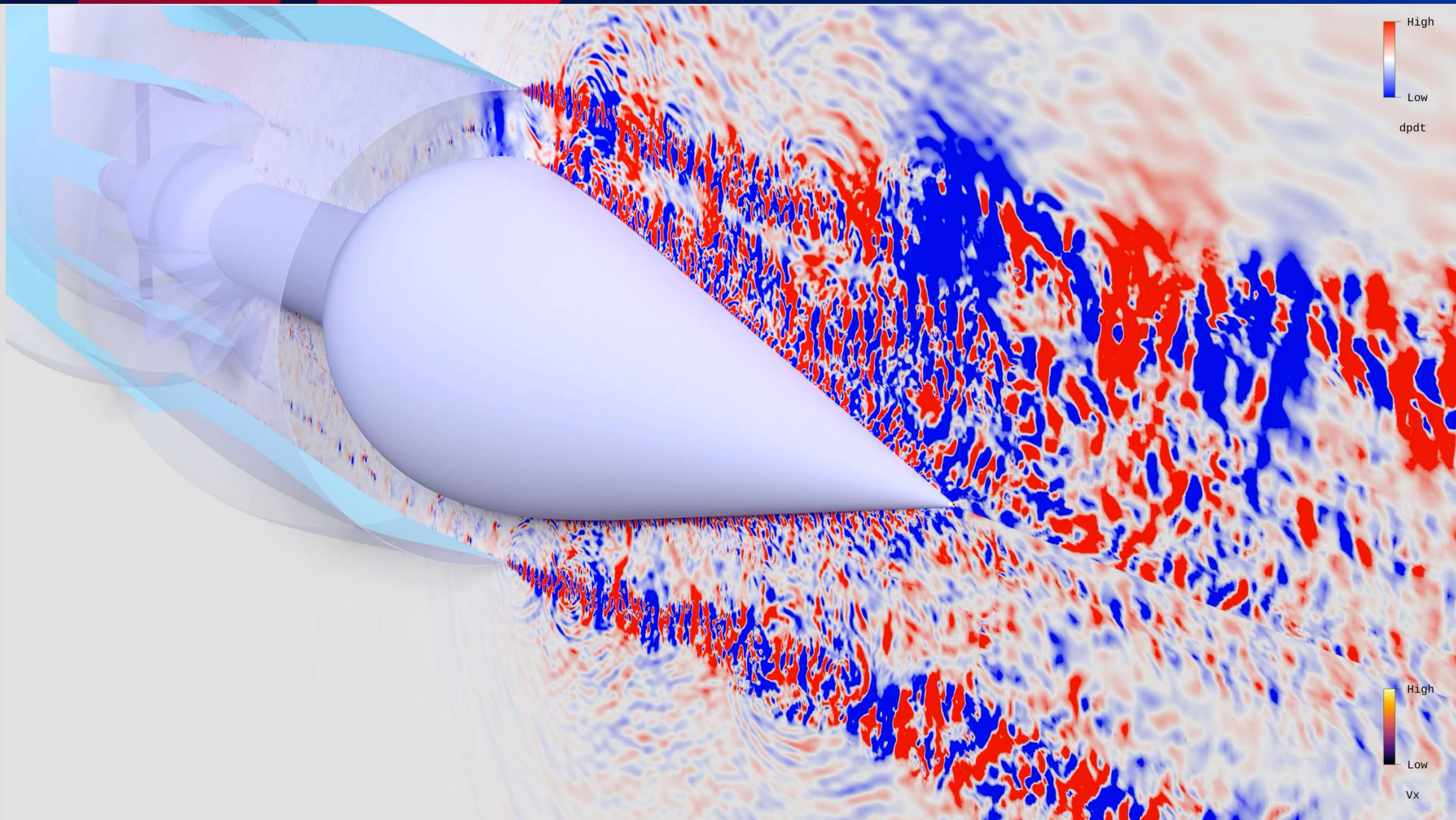
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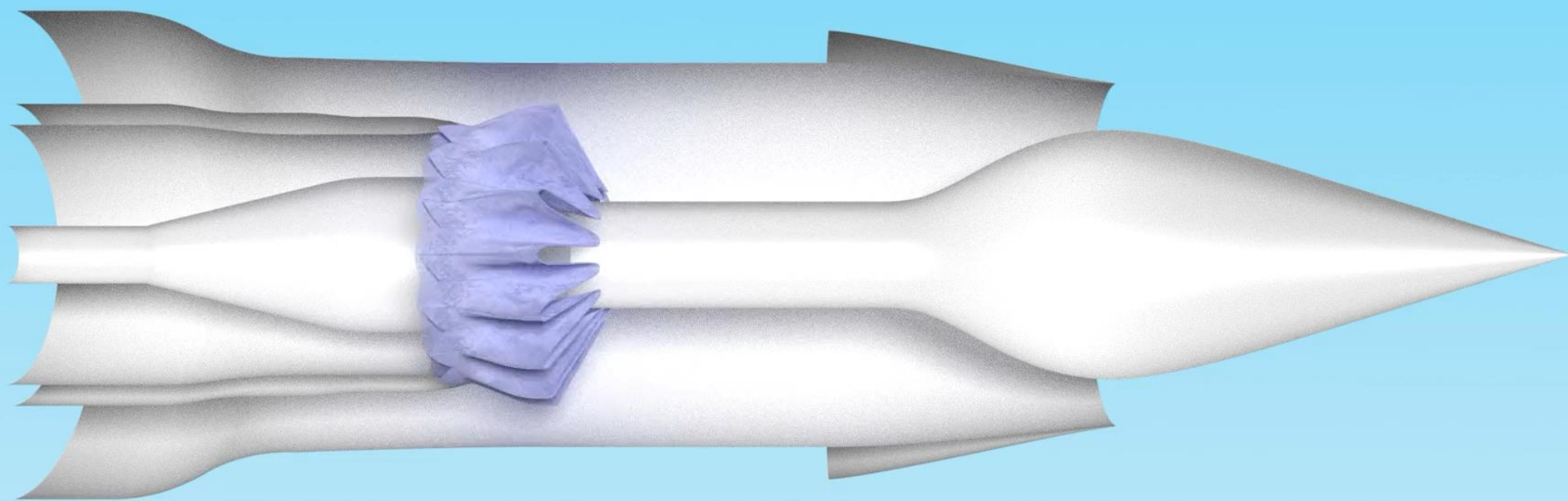


- designed to represent commercial supersonic aircraft configuration
- experimental measurements obtained in NASA's High Flow Jet Exit Rig

Lobed mixer → more uniform profiles → noise reduction









For more information:

NASA LAVA Jet Noise @SC22:
<https://www.nas.nasa.gov/SC22>

NASA LAVA Jet Noise @Advanced Modeling and Simulation Series (AMS):
<https://www.nas.nasa.gov/pubs/ams.html>

NASA LAVA Jet Noise @Publications:
<https://scholar.google.com/gerrit-daniel.stich>

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jared.c.duensing@nasa.gov