National Aeronautics and Space Administration

Scale Resolving Jet Noise Simulations to Reduce Airport Noise

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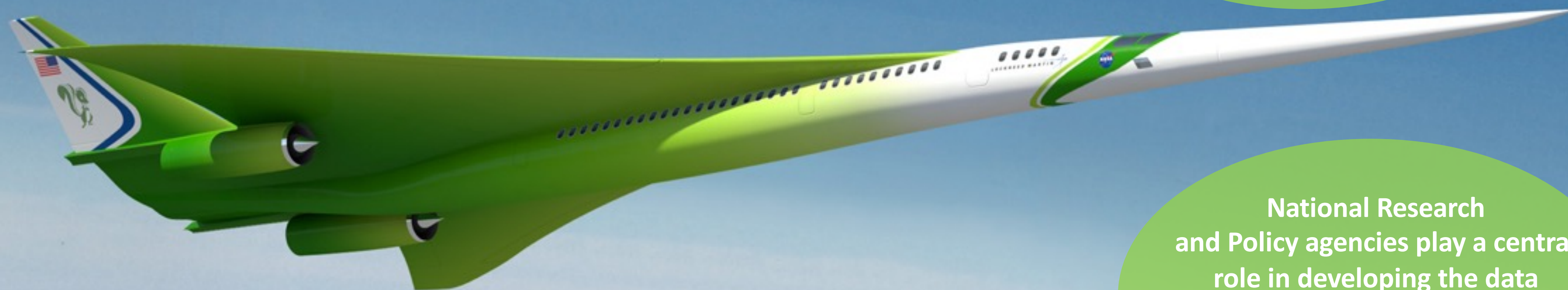
The Vision For Commercial Supersonic Flight

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

- Evidenced by the appearance of several commercial programs despite lack of standards for en route noise or landing and takeoff noise

Overland Flight Restrictions based on unacceptable sonic boom noise are viewed as the main barrier to this vision



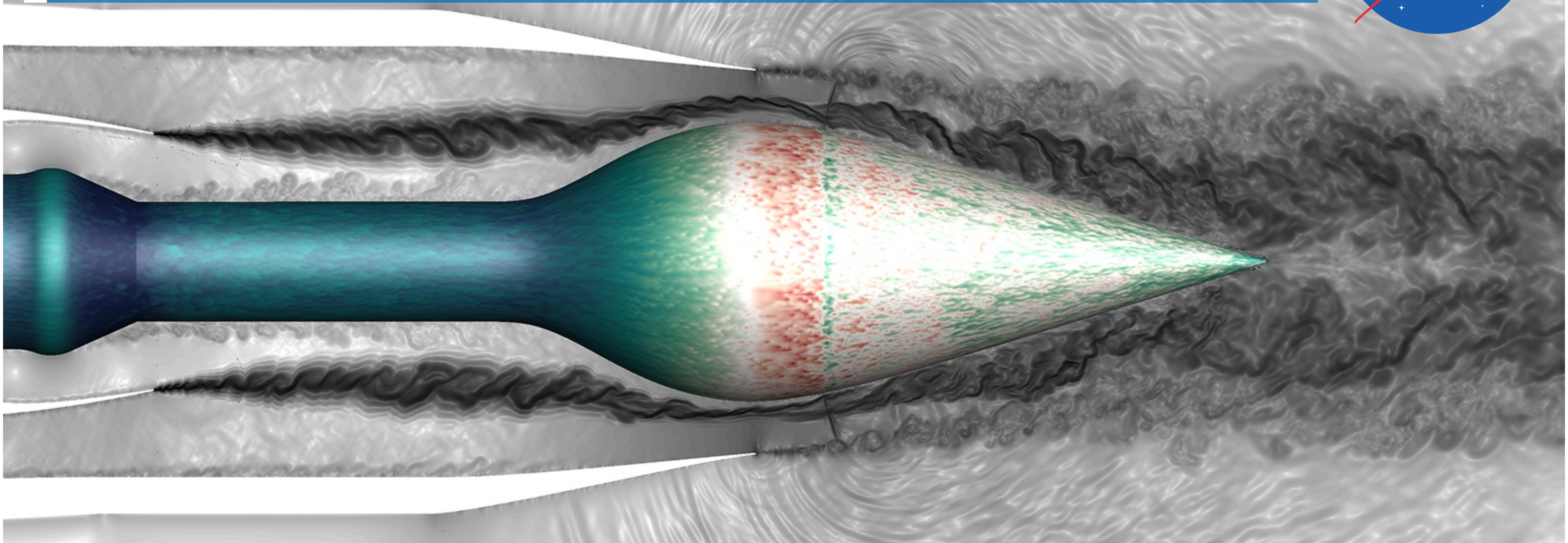
National Research and Policy agencies play a central role in developing the data needed for the regulation change that is essential to enabling this new market

The vision of the Supersonics Community is a future where fast air travel is available for a broad spectrum of the traveling public

- Future supersonic aircraft will not only be able to fly overland without creating an “unacceptable situation” but compared to Concorde and SST will be efficient, affordable, and environmentally responsible

Role of Computational Aeroacoustics (CAA)

High-fidelity scale resolving simulations conducted at NASA's Ames Research Center with the Launch, Ascent and Vehicle Aerodynamics (LAVA) Solver accurately capture physics of turbulence creating noise.



Determining where and how noise is created could help reduce overall jet engine noise. Accurate predictions of jet noise can help shape future FAA guidelines for supersonic vehicle. Before we agree on guidelines we need to agree on our data: Prediction Uncertainty Reduction Challenge (PUR) initiated within NASA's CST Project

The Launch, Ascent and Vehicle Aerodynamics (LAVA) framework

Objectives within NASA's CST project for Jet Noise

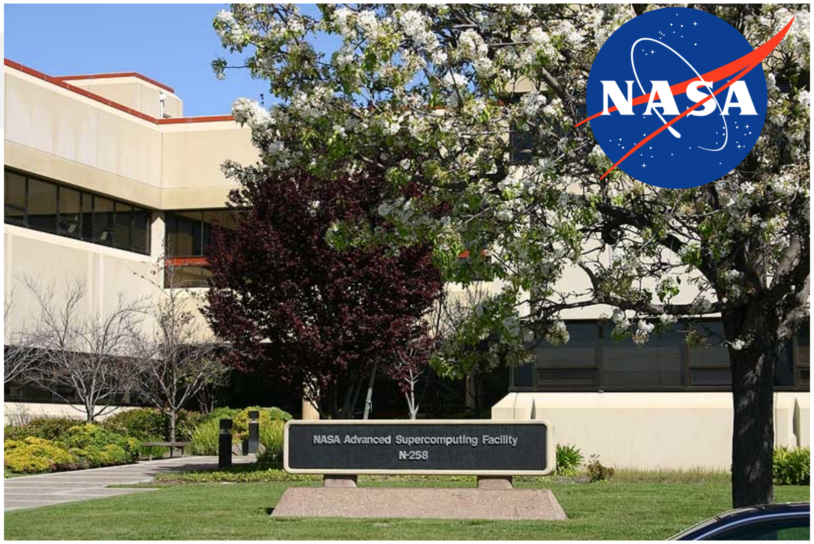
- Predict jet noise **accurately** and in **short enough turnaround time** using **scale-resolving** simulations methods

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

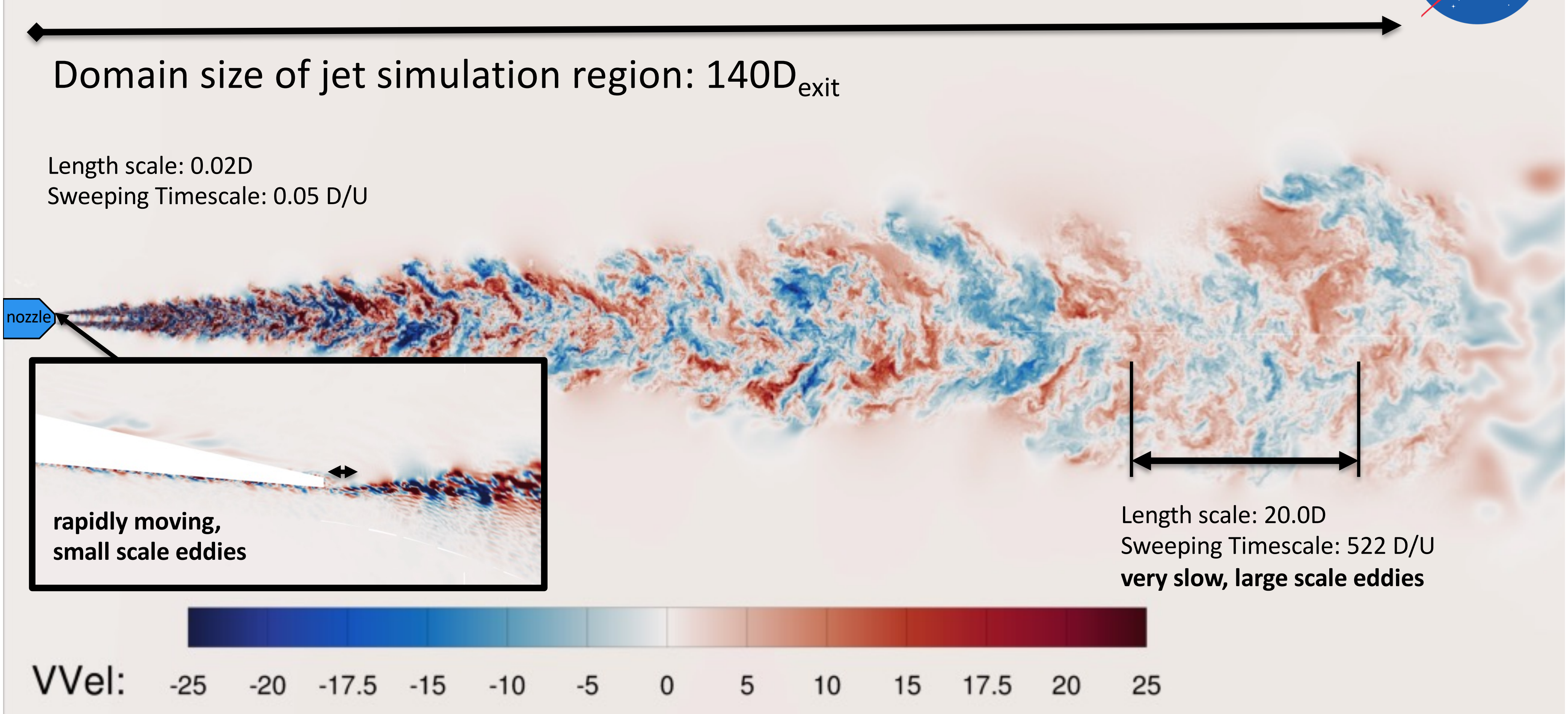
- <u>**Future Impact:**</u> complement/replace wind tunnel and flight tests, reduction of associated costs, provides insight into noise reduction technology never-before available. Aide in the creation of FAA guidelines for supersonic vehicles during landing and takeoff

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)** utilizes state-of-the-art computer science features to enable **rapid simulation turnaround times** of complex scale-resolving aeroacoustics simulations
- Each simulation utilized 100 AMD Rome nodes (12800 CPUs) on the Aitken supercomputer at NAS resulting in **simulation wall-times between 2-12 hours** to predict broadband jet noise
- Each simulation generated **hundreds of terabytes of data** which is utilized **to advance our knowledge** of jet noise and ultimately result in the **development of new noise reduction technologies**



Why are Scale-Resolving Jet Noise Simulations Challenging/Expensive?



2017-2022: Progress Towards Full Aircraft Jet Noise Predictions

Perform systematic validation effort utilizing scale resolving Computational Fluid Dynamics (CFD) to evaluate aerodynamics for increasingly complex jets

1. ROUND JET VALIDATION
2. SHIELDING CONCEPTS
3. INCREASINGLY COMPLEX GEOMETRY (Chevron, Plug, Multi-stream)

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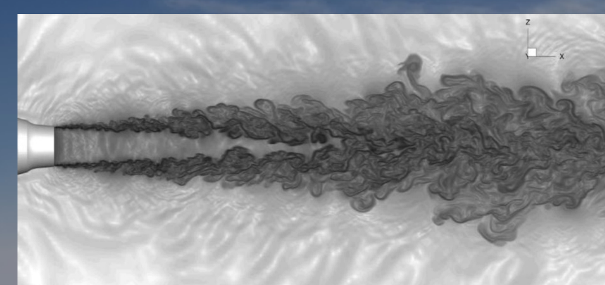
ROUND JET VALIDATION

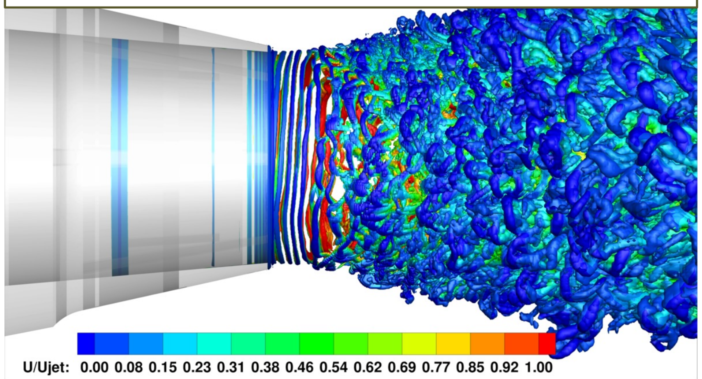
1

- Detached Delayed Eddy Simulation
- Zonal Hybrid RANS LES
- Development of wall-modeled LES within LAVA

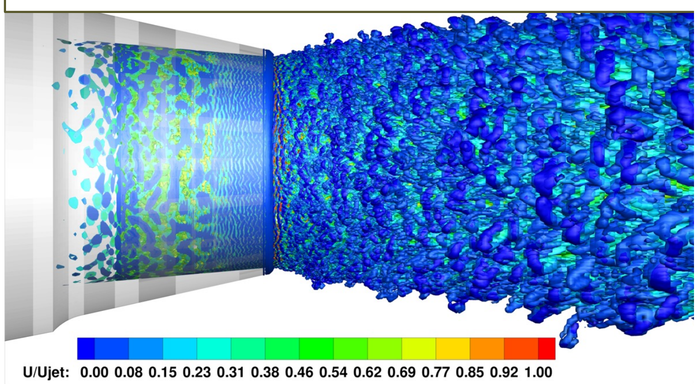


2017: Round Jet Validation - Hybrid RANS/LES

DDES-256M

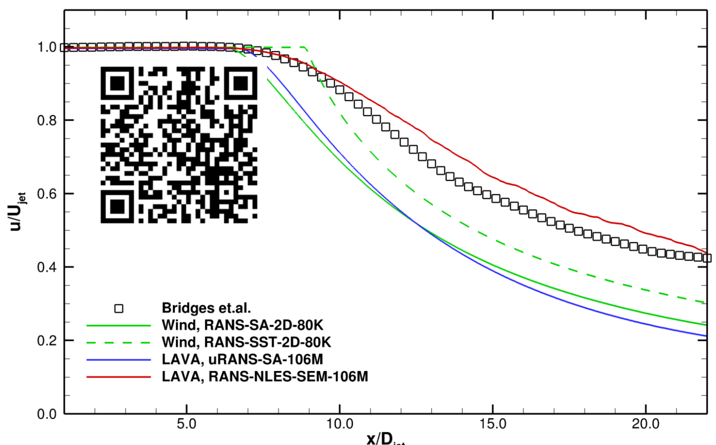


ZDES-106M



NASA Revolutionary Computational Aerosciences (RCA) challenge for jet noise:

- **<u>Goal:</u>** Improve Simulation accuracy by 40%
- Prediction of length of potential core (U/Uj = 0.98)
- Improvement of centerline TKE Prediction
- See AIAA-2017-3213 for more information



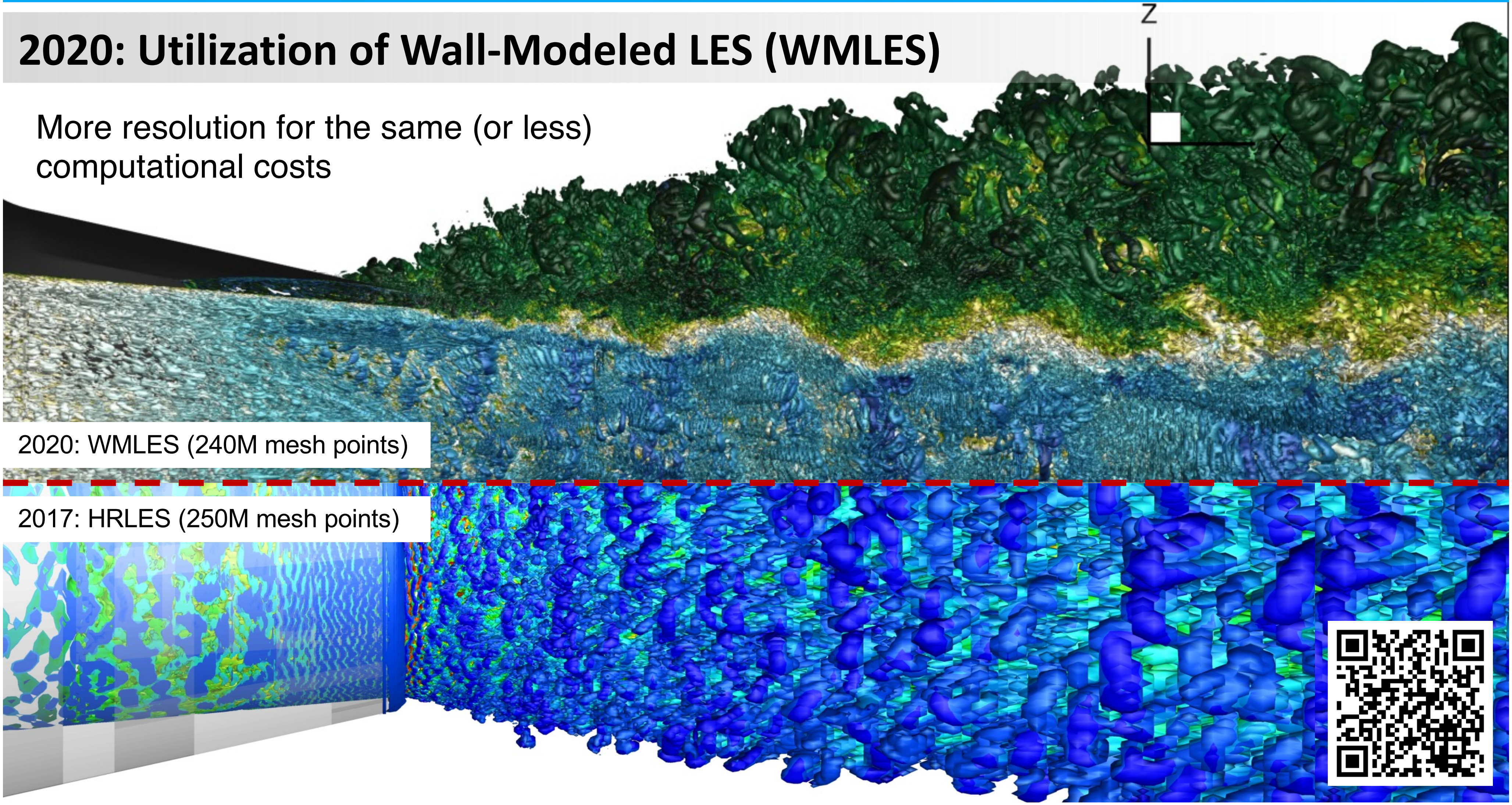
89.6% improvement

solver	Error [%]
Bridges & Wernet Exp.	-
State-of-the-Art SA-RANS[1]	-12.3
LAVA Hybrid RANS/LES	**1.2**

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

2020: Utilization of Wall-Modeled LES (WMLES)

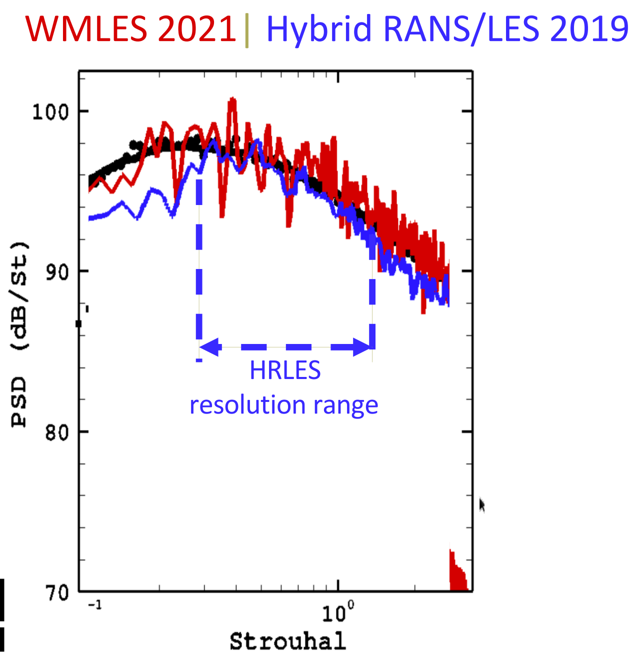
More resolution for the same (or less) computational costs



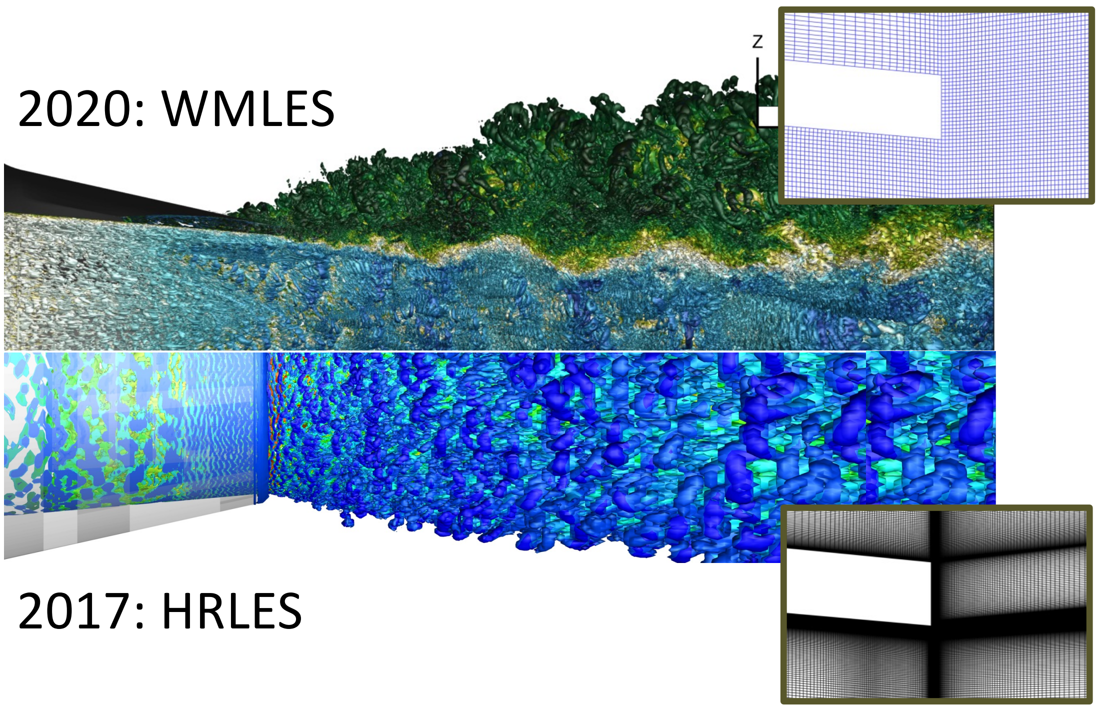
Timings and Improvements – Implications for Science

For the identical number of mesh point we can now:

- Redistribute points over a wider area



Noise at observer location 100D away from the nozzle exit

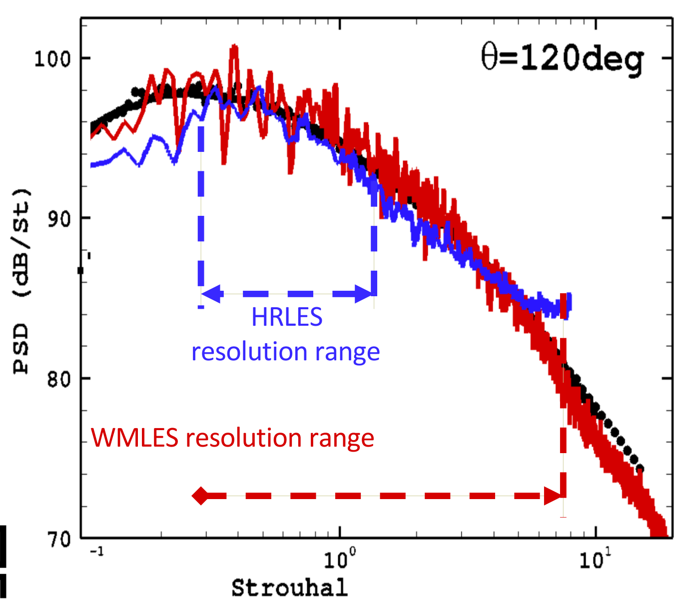


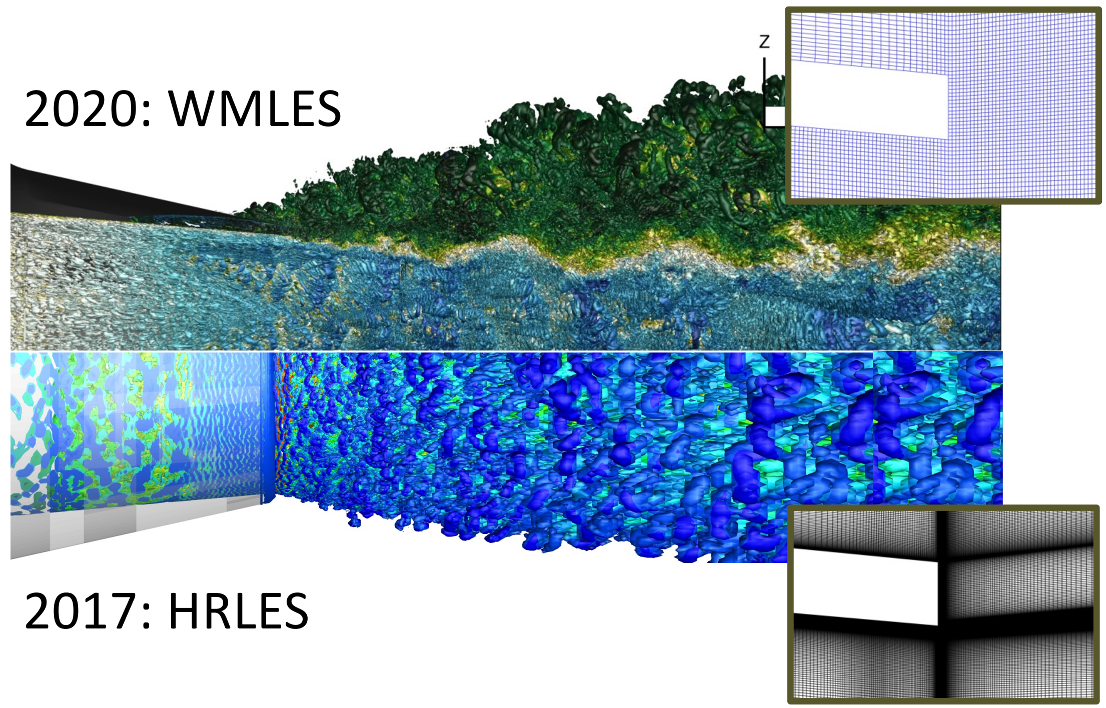
Timings and Improvements – Implications for Science

For the identical number of mesh point we can now:

- Redistribute points over a wider area → increased high frequency resolution

WMLES 2021 | Hybrid RANS/LES 2019



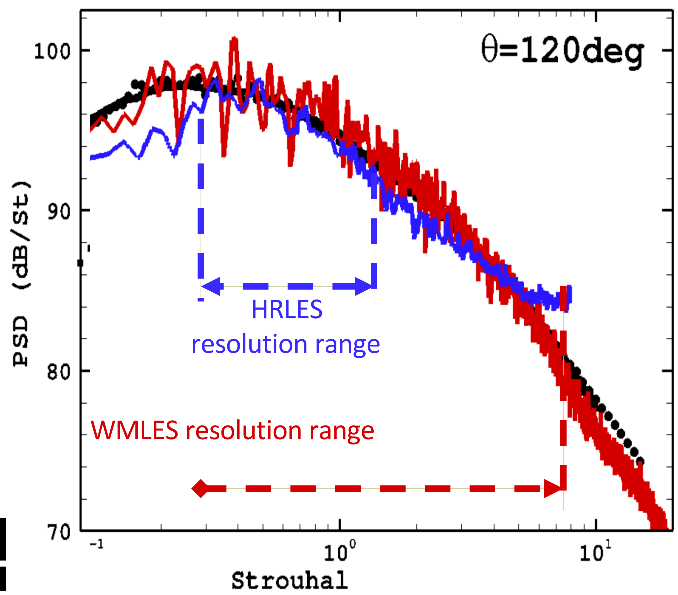


Upper frequency range extended for almost a decade of data

Timings and Improvements – Implications for Science

For identical simulation time cost (CPUh) we can now:

- Increase simulation time interval



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

November 2019	
Hybrid RANS/LES	6.5 days [100 Broadwell]

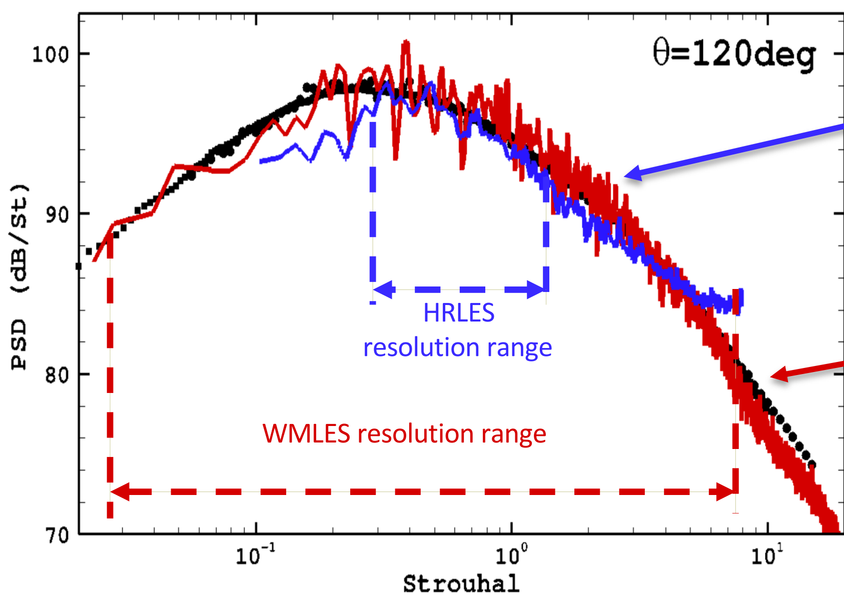
↓

Current	
WMLES + Optimized Code & Best Practices & Scaling	150 minutes [100 Rome]

Timings and Improvements – Implications for Science

For identical simulation time cost (CPUh) we can now:

- Increase simulation time interval → extend lower frequency resolution range



HRLES Simulation for SP7
6.5 days
60 Skylake Nodes
2,400 cores

300 CTU

WMLES Simulation for SP7
0.6 days
100 AMD Rome Nodes
12,800 cores

2000 CTU

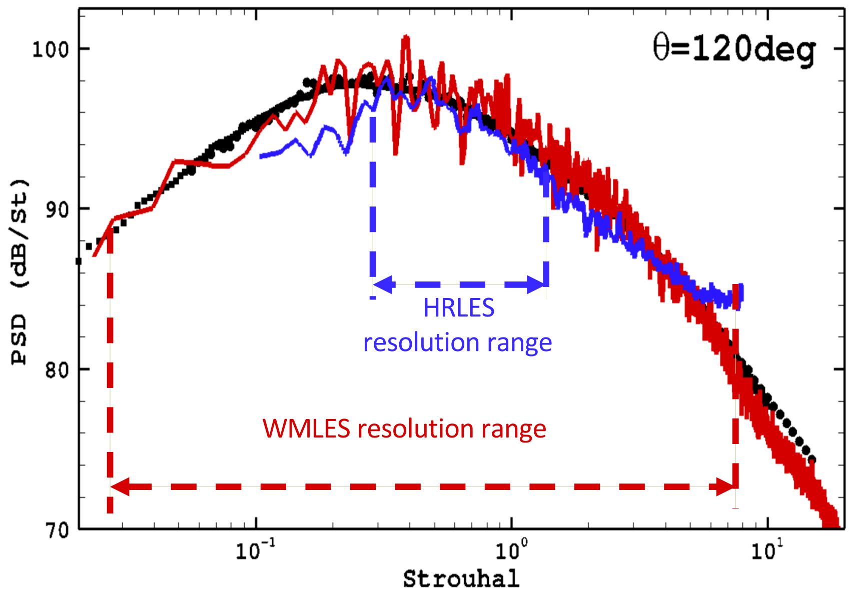
6.6x more simulation time, still factor of 10x faster solution turnaround

Upper and lower frequency range extended for almost a decade each way

Timings and Improvements – Implications for Science

For the identical simulation time cost (CPUh) we can now:

- Increase number of simulations in the same amount of time



	Set Point SP	Ma [-]	M_j [-]	M_∞ [-]	NPR [-]	NTR [-]	Exp. Data PIV	MIC
static	3	0.50	0.51	0.0	1.197	0.96	✓	✓
	7	0.90	0.98	0.0	1.852	0.84	✓	✓
	23	0.50	0.38	0.0	1.102	1.76	✓	✓
	27	0.90	0.68	0.0	1.368	1.76	✓	✓
	29	1.33	1.00	0.0	1.898	1.76	✓	✓
	38	1.33	0.88	0.0	1.664	2.27	✗	✓
	46	0.90	0.56	0.0	1.219	2.70	✓	✓
	49	1.48	0.90	0.0	1.697	2.70	✓	✓
	101240	1.14	0.85	0.0	1.608	1.78	✗	✓
In-flight	100084	1.32	1.09	0.3	2.110	1.48	✗	✓
	100024	1.01	0.85	0.3	1.616	1.40	✗	✓
	100274	1.20	0.99	0.3	1.875	1.47	✗	✓
	101244	1.13	0.85	0.3	1.603	1.78	✗	✓

Code improvements enable new frontiers in WMLES for jet noise

2017-2022: Progress Towards Full Aircraft Jet Noise Predictions

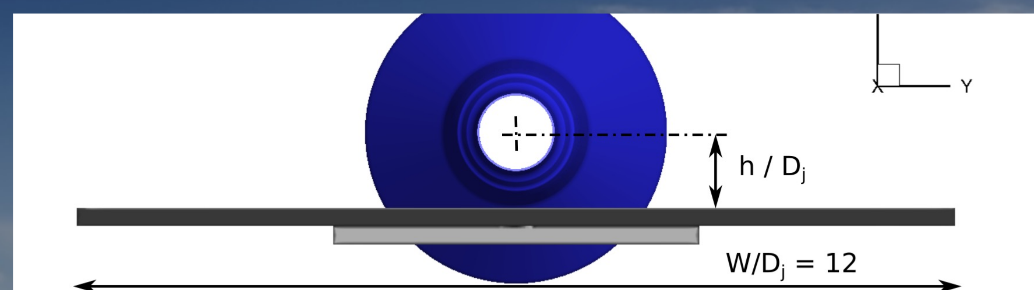
Perform systematic validation effort utilizing scale resolving Computational Fluid Dynamics (CFD) to evaluate aerodynamics for increasingly complex jets

SHIELDING CONCEPTS

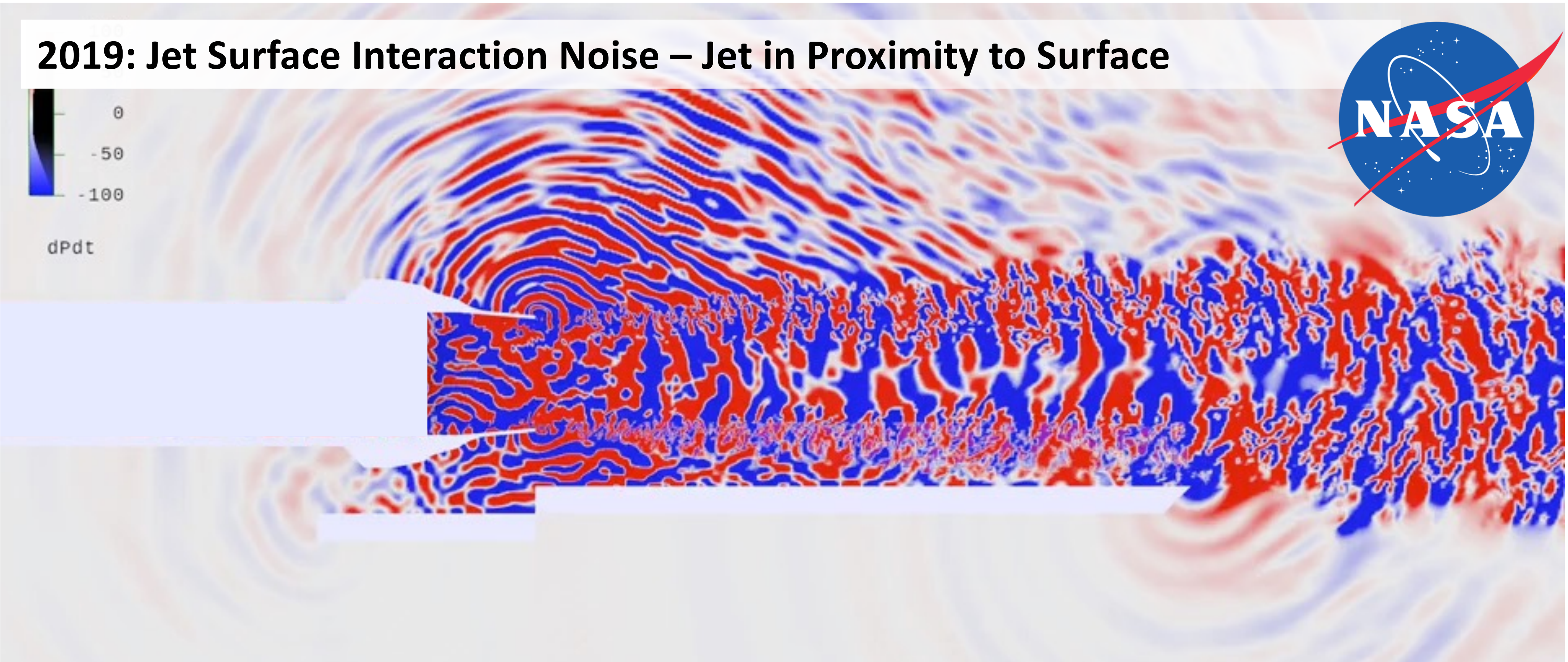
2

jet-surface interaction noise

- **Same round jet configuration utilized with plate mounted underneath**



2019: Jet Surface Interaction Noise – Jet in Proximity to Surface



See AIAA2019-2475: Large-Eddy Simulation of Jet Surface Interaction Noise

Determining where and how noise is created and how noise can be “shielded” from the observer could help reduce overall jet engine noise.

Flow Visualization by Timothy Sandstrom NASA Ames Research Center

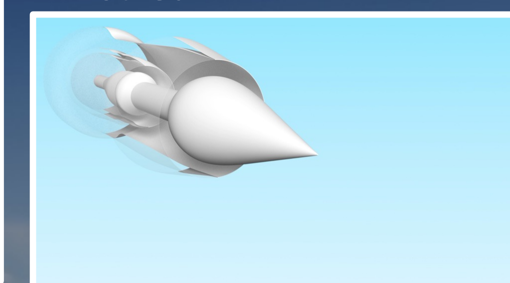
2017-2022: Progress Towards Full Aircraft Jet Noise Predictions

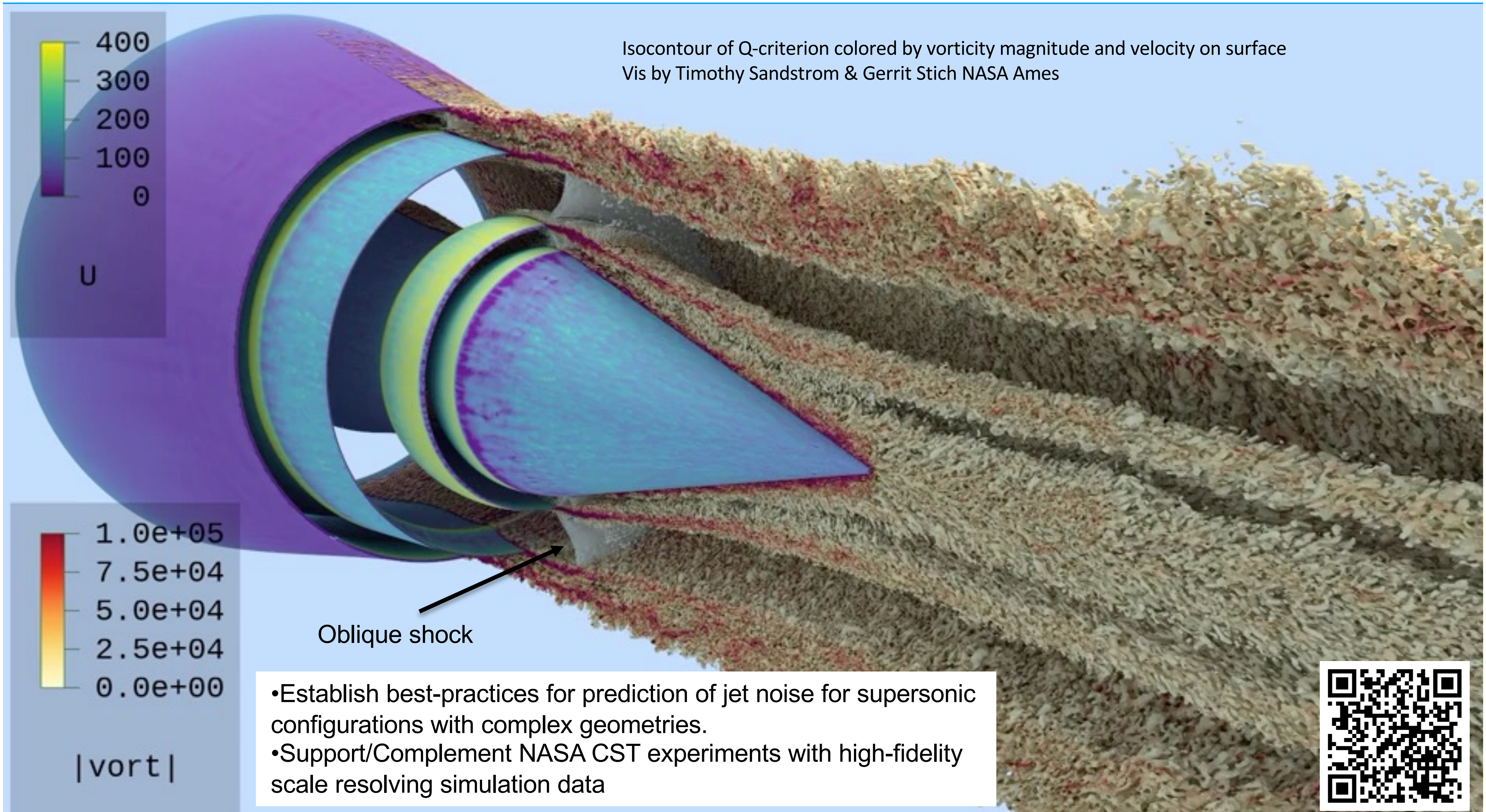
Perform systematic validation effort utilizing scale resolving Computational Fluid Dynamics (CFD) to evaluate aerodynamic for increasingly complex jets

INCREASINGLY COMPLEX GEOMETRY
(Chevron, Plug, Multi-stream)

3

- **Increase geometric and numerical complexity**
- **Three-stream plug nozzle with heated primary stream**





- Establish best-practices for prediction of jet noise for supersonic configurations with complex geometries.
- Support/Complement NASA CST experiments with high-fidelity scale resolving simulation data

Timings and Code Improvements

Time savings due to algorithm, code improvements and development

Date	Method	Mesh size [10^6]	$\Delta t/c_\infty$	CPU	Time/CTU [CPUh]	Time to solution 150 / 300 convective units	Speedup (November baseline)
November 2019	Hybrid RANS/LES (ZDES III)	225	0.007	60 Skylake (2400 cores)	995	3.2 day / 6.5 day	--
March 2020	Wall-stress WMLES	254	0.0005	60 Skylake (2400 cores)	430	26.8 hr / 2.3 day	**2.8x**
November 2020	Wall-stress WMLES	110	0.001	60 Skylake (2400 core)	69	**4.3 hr / 8.6 hr**	**18x**
March 2022	Wall-stress WMLES	250	0.0007	100 Rome (12800 core)	106	**75min / 150 min**	**62X**

CTU: Convective Flow Through Unit

** Timings include high frequency (sampling rate 200kHz) i/o output for solution*

*** Substantially better temporal resolution and spatial resolution (azimuth, stream) achieved compared to baseline November 2019*

**** Improvements possible due to improved scalability of code (scales well up to 10-20k pnts/core)*

Generation of Jet Noise Database to Assess Prediction Uncertainties

Set Point SP	Ma [-]	M_j [-]	M_∞ [-]	NPR [-]	NTR [-]	Exp. Data PIV	Exp. Data MIC
3	0.50	0.51	0.0	1.197	0.96	✓	✓
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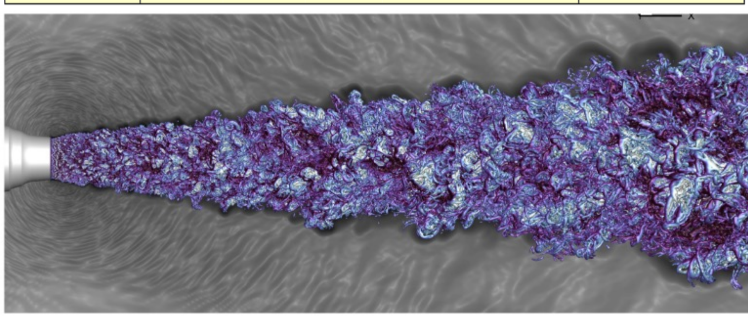
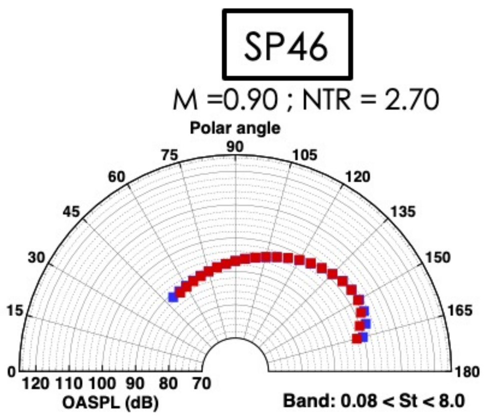
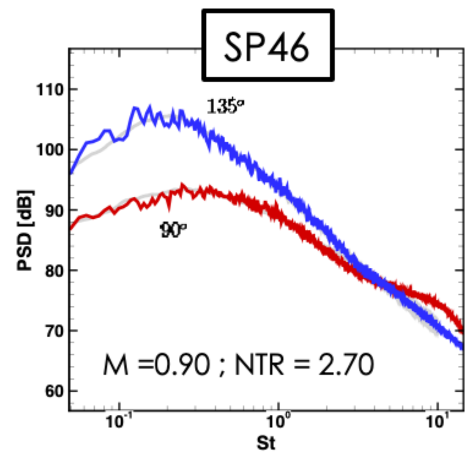


- **Successfully** generated WMLES database for **static and in-flight** jet noise simulations within NASA PUR Challenge
- Simulations can be performed in **short turnaround time**
- **Excellent agreement** with experiments:
  Comparable to experimental rig-to-rig data deviations
- Data delivered to project to **reduce prediction uncertainties of LES for jet noise simulations**





For More Information

This work was partially funded by the Commercial Supersonics Technology (CST) Project and the Transformational Tools and Technology (TTT) project under the Aeronautics Research Mission Directorate (ARMD)

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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

SC22 Presentation @ NASA Booth Theater B:

Tuesday 15th 11:00 – 11:40 AM
Wednesday 16th 4:20 – 5:00 PM
Thursday 17th 2:30 – 3:00 PM

For More Information

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