NASA's Large-Eddy Simulation Research for Jet Noise Applications

Research into large-eddy simulation (LES) for application to jet noise is described. The LES efforts include in-house code development and application at NASA Glenn along with NASA Research Announcement sponsored work at Stanford University and Florida State University. Details of the computational methods used and sample results for jet flows are provided.

National Aeronautics and Space Administration

NASA's Large-Eddy Simulation Research for Jet Noise Applications

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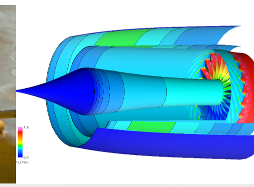
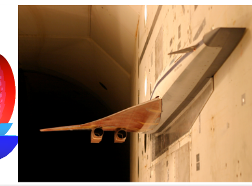
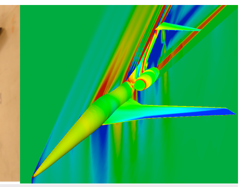
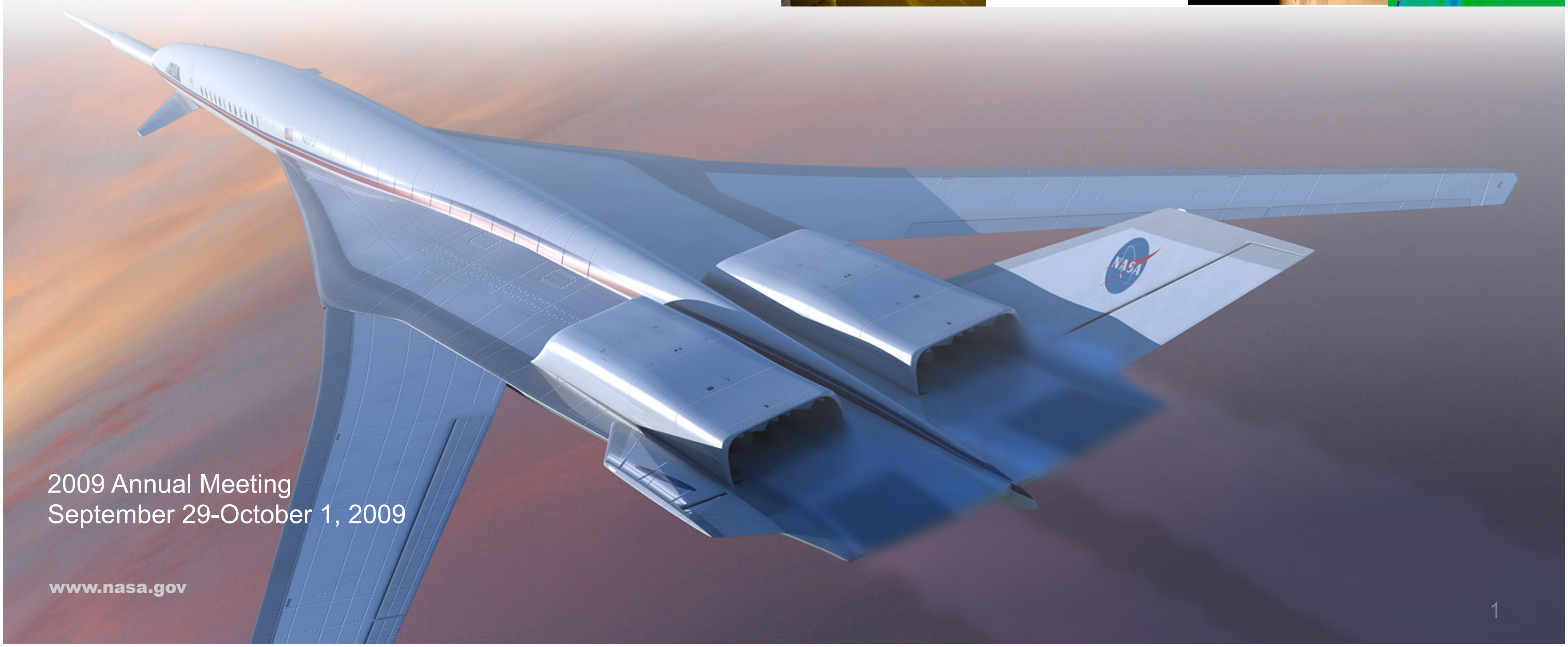






2009 Annual Meeting
September 29-October 1, 2009

www.nasa.gov

NASA's LES Research for Jet Noise

- In-house
  - WRLES code development
  - Jet noise applications
- NRA sponsored research
  - Prediction and Modeling of Jet Noise Using Large-Eddy Simulation
    - Stanford University
    - Sanjiva Lele & Parviz Moin, PIs
    - Supersonics Project
  - High-Fidelity Jet Noise Simulations
    - Florida State University
    - M. Youssuf Hussaini, PI
    - Subsonics Fixed Wing Project

WaveResolvingLES

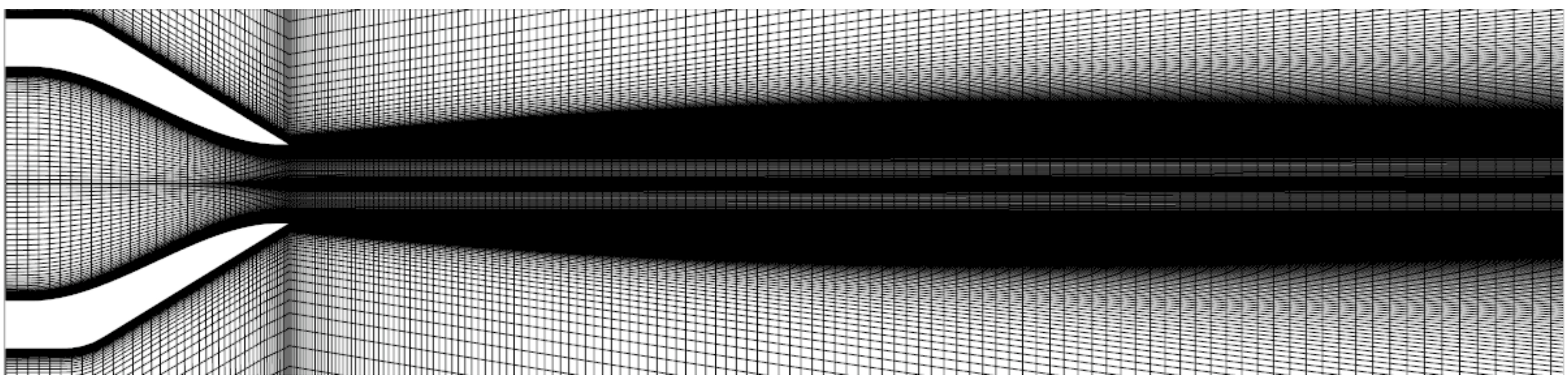
- Time advancement
  - Low dispersion Runge-Kutta time stepping
  - 1st - 4th order
- Spatial discretization
  - Explicit central differencing
  - Standard schemes 2^{nd} – 12^{th} order
  - DRP schemes
    - Tam
    - Bogey & Bailly 9, 11 and 13 point schemes
- Filtering
  - Carpenter & Kennedy 2^{nd} – 12^{th} order
  - Bogey and Bailly 9, 11 and 13 point filters
  - Shock capturing filters
- Hybrid MPI/OpenMP parallel
- Generalized curvilinear coordinates

Turbulent Jet Flow

- 2-inch Acoustic Reference Nozzle
- Tested at the NASA Glenn Small Hot Acoustic Rig (SHAR)
- Particle Image Velocimetry (PIV) measurements (Bridges & Wernet)
- Flow Conditions
  - Exit Mach number 0.9
  - Cold flow
  - Quiescent freestream
  - Jet Reynolds number ~ 2 million

Computational Grid

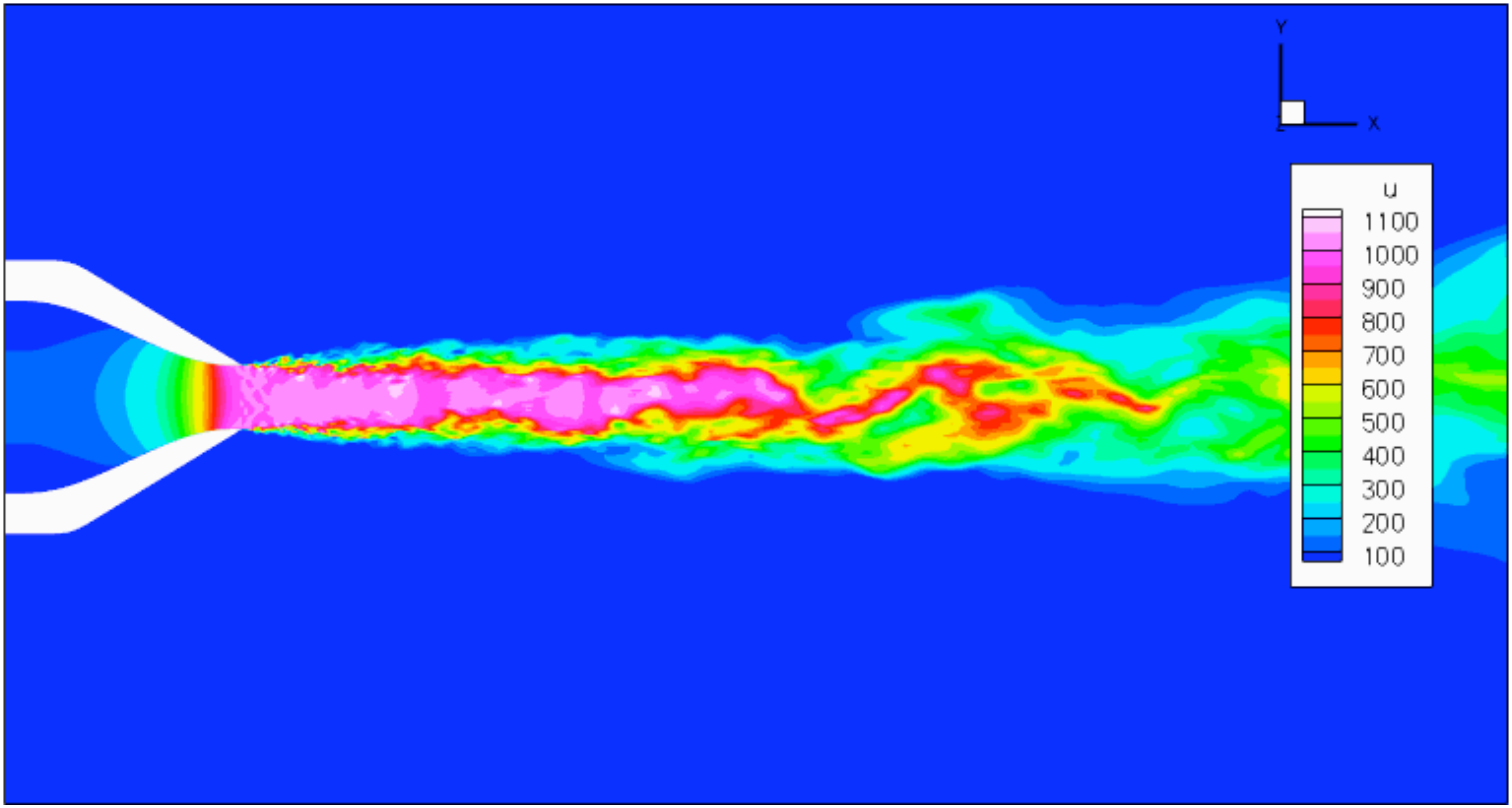
Grid	Interior of Nozzle	Exterior of Nozzle	Nozzle Plume	Total
Baseline	45 x 55 x 102	45 x 65 x 102	196 x 148 x 102	3,509,616
Refined	45 x 55 x 132	45 x 65 x 132	294 x 148 x 132	6,456,384



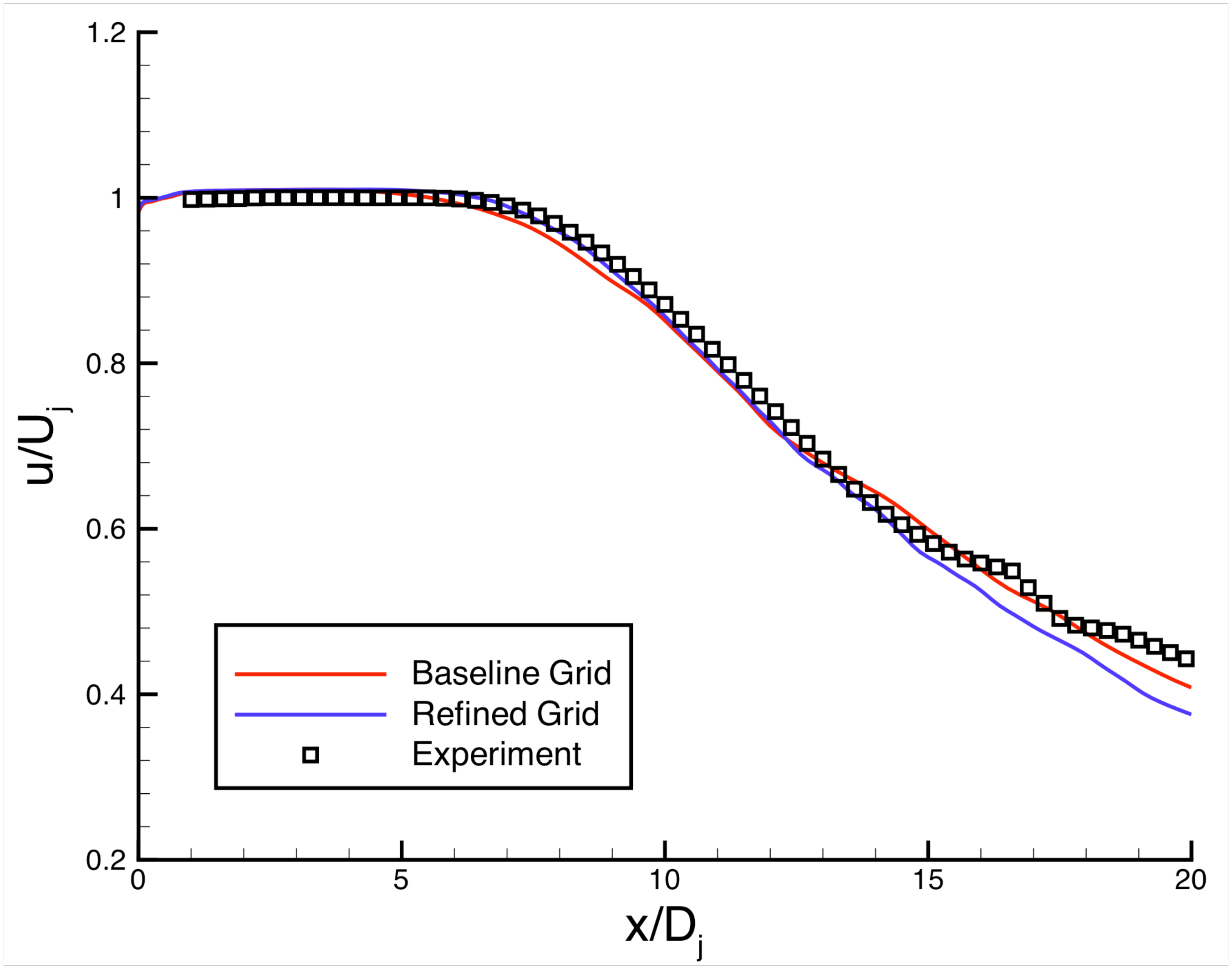
Computational Approach

- Implicit LES
  - No sub-grid model
  - Dissipation from filter used to dissipate large-scales
- Laminar nozzle boundary layers
  - Accelerating flow reduces turbulence at nozzle exit
  - Transition occurs quickly in the jet mixing layer
- Simulation Reynolds number, 50,000
- Solution processing
  - Entire solution saved every $2 \cdot 10^{-5}$ seconds
  - 50kHz sampling rate
  - 2,048 solutions used in post processing

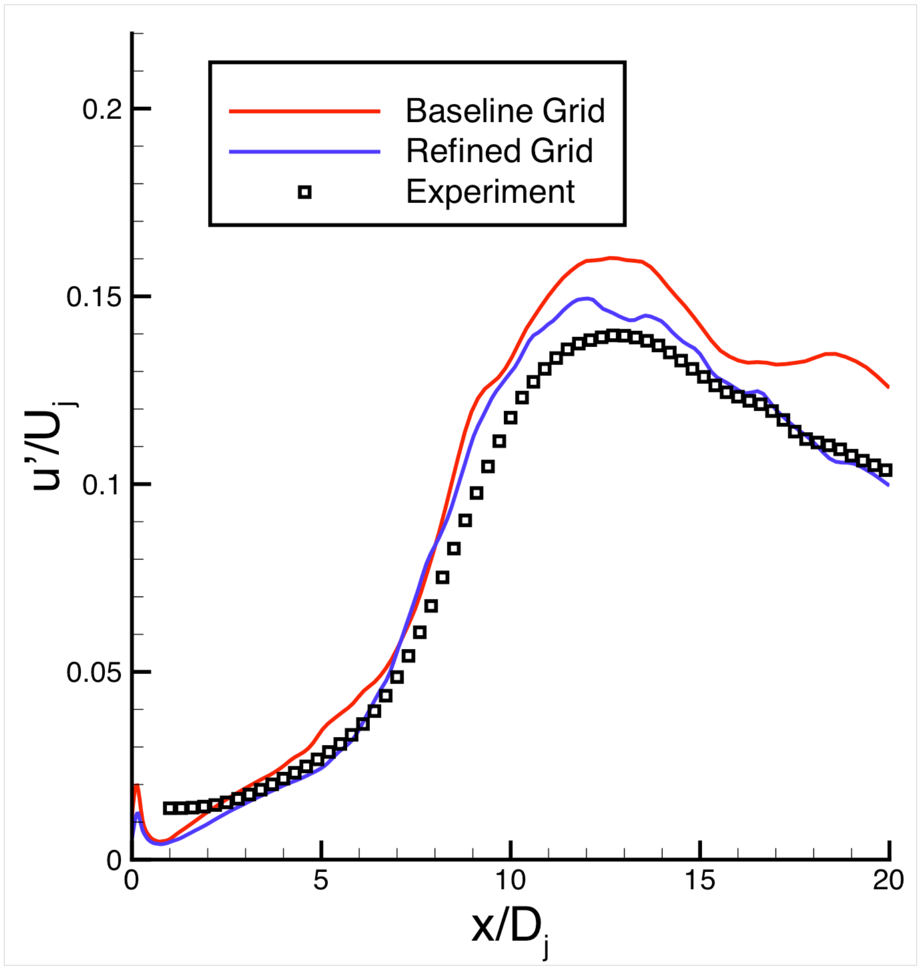
Axial Velocity Animation



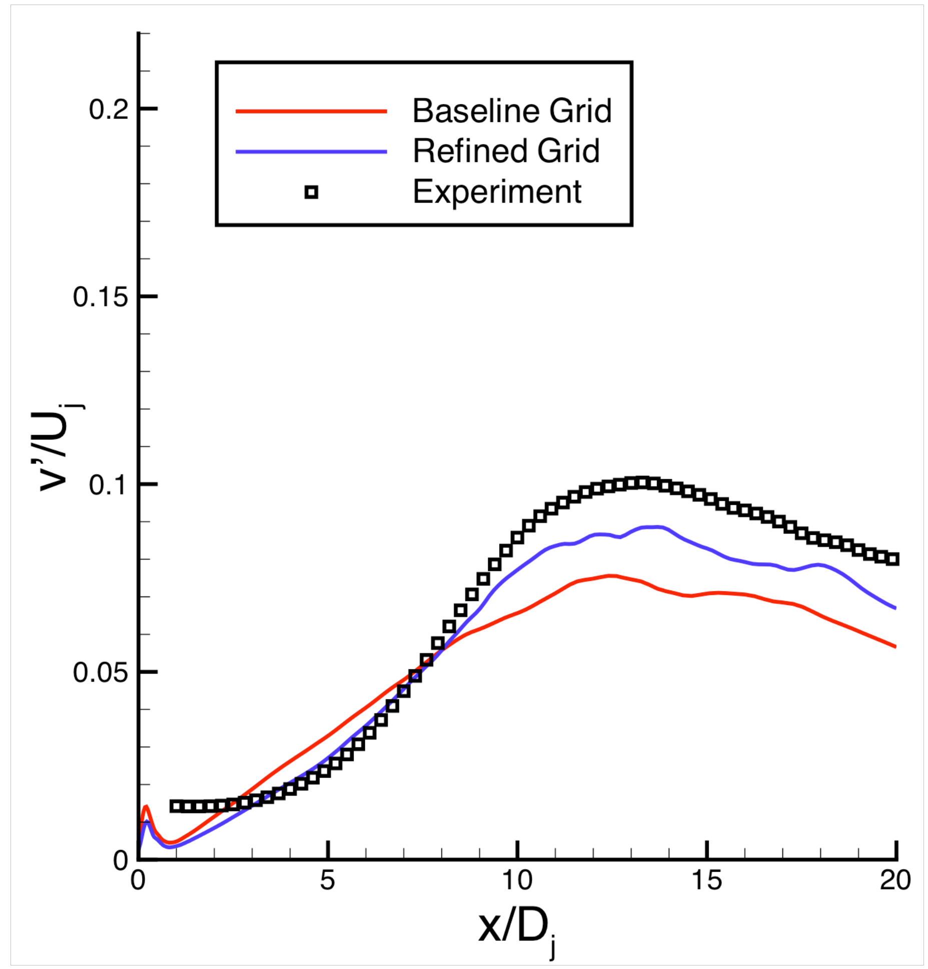
Centerline Velocity



Centerline Turbulent Intensities

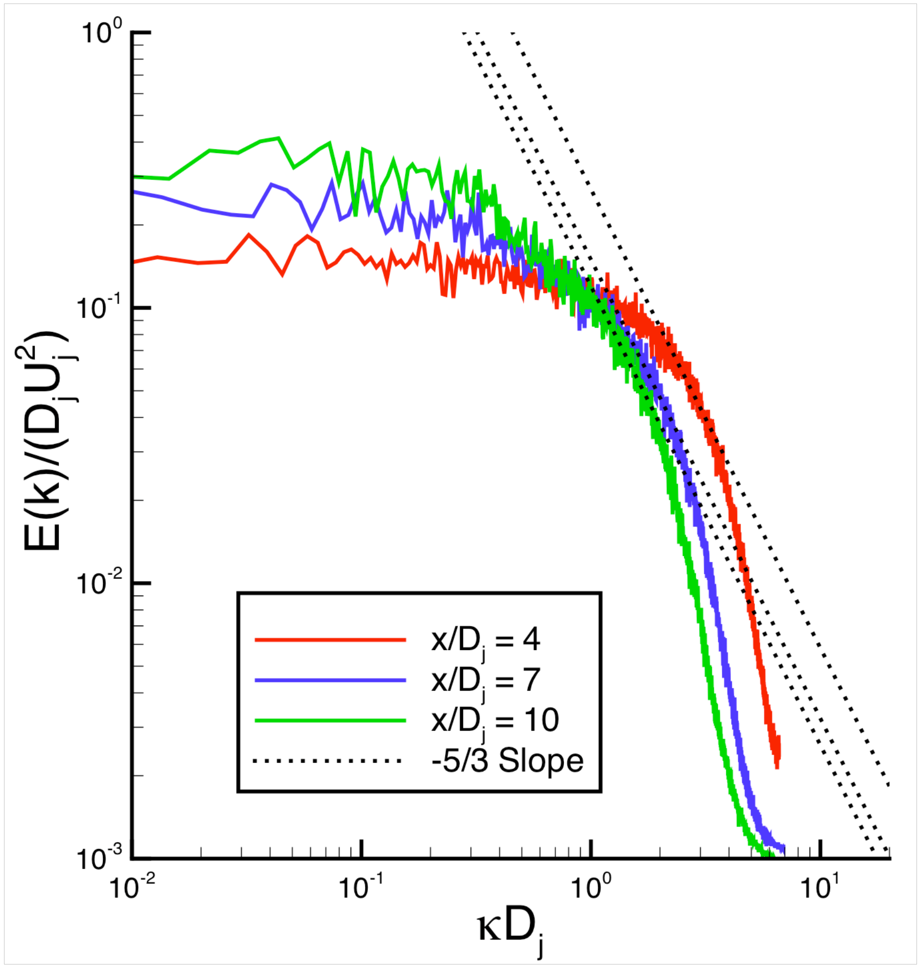


Axial turbulent intensity

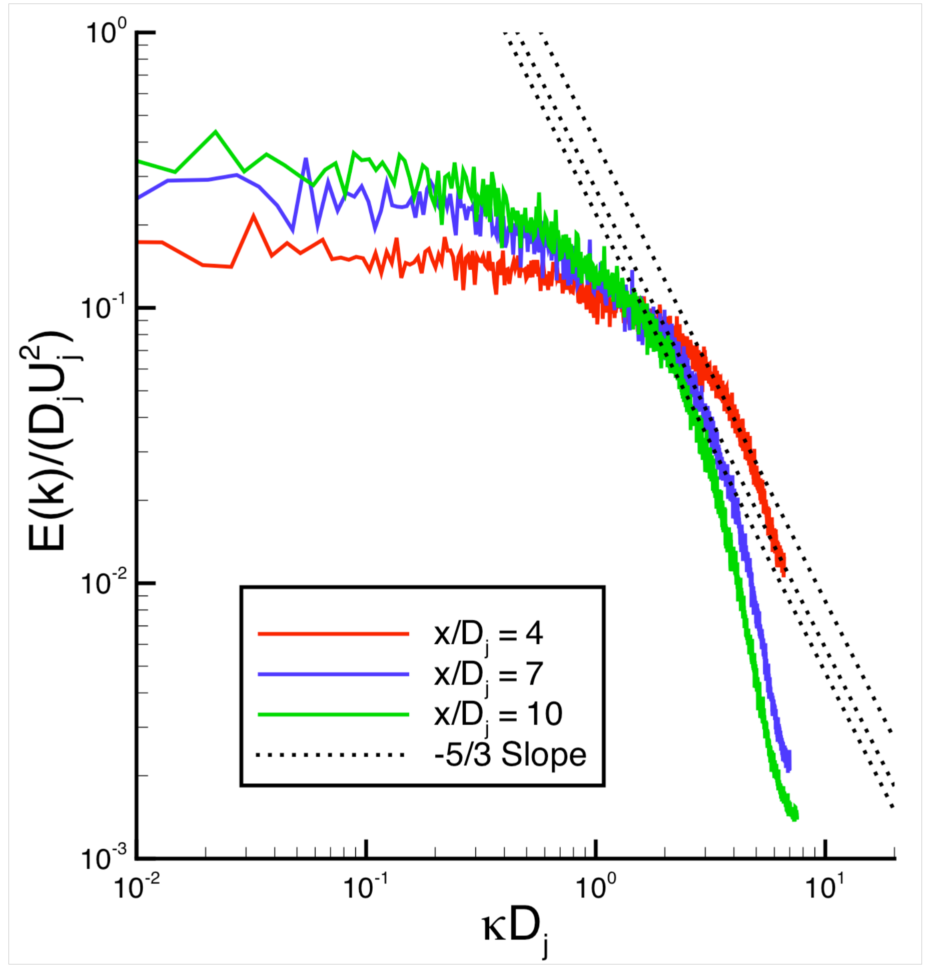


Radial turbulent intensity

Turbulent Spectra - κD_j

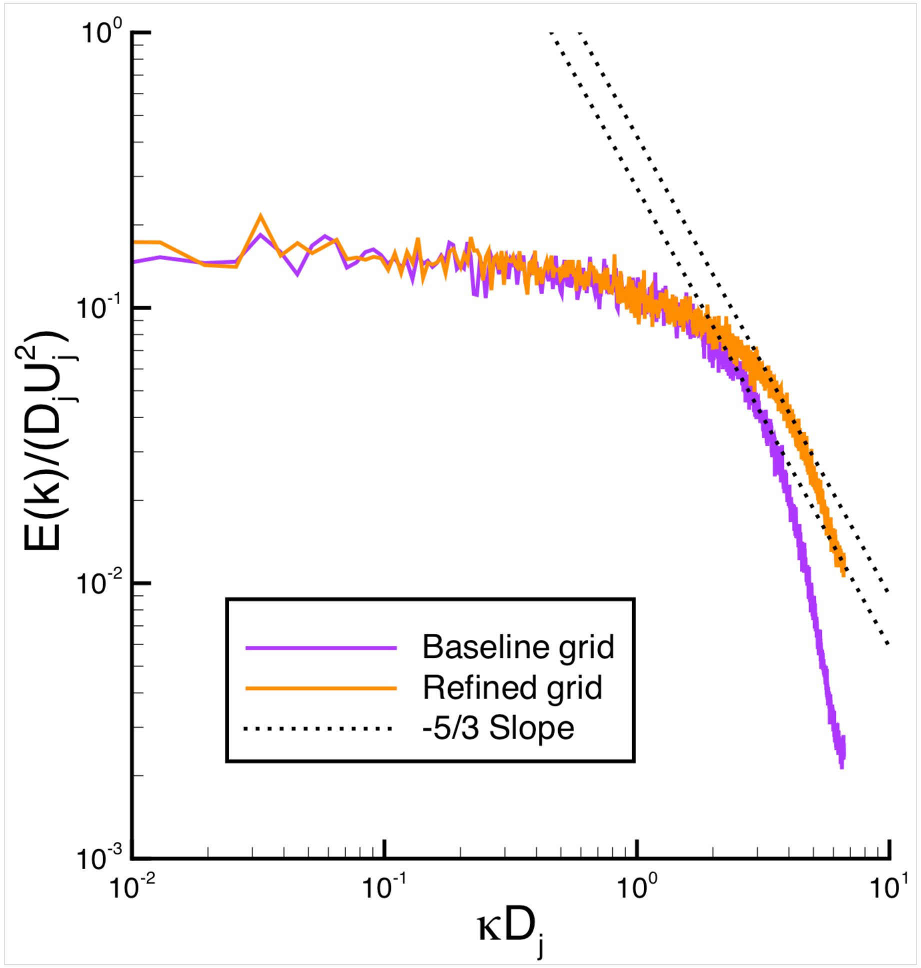


Baseline grid

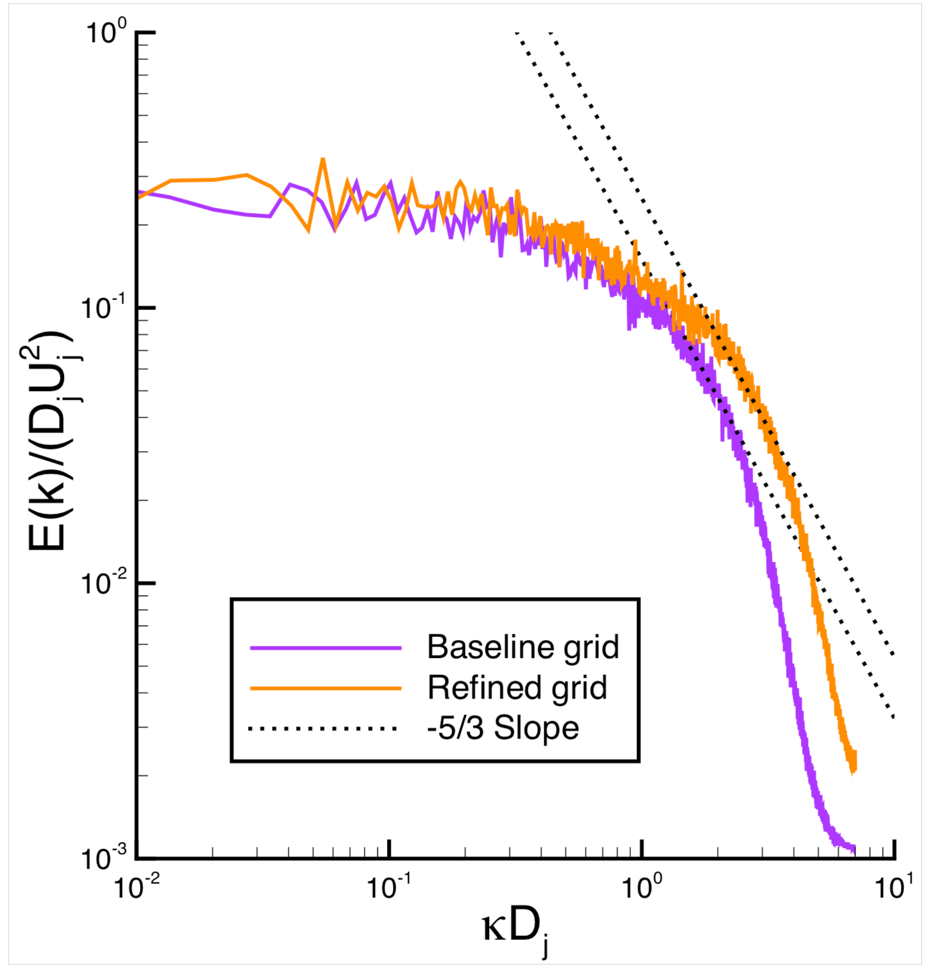


Refined grid

Spectra - Grid Comparison



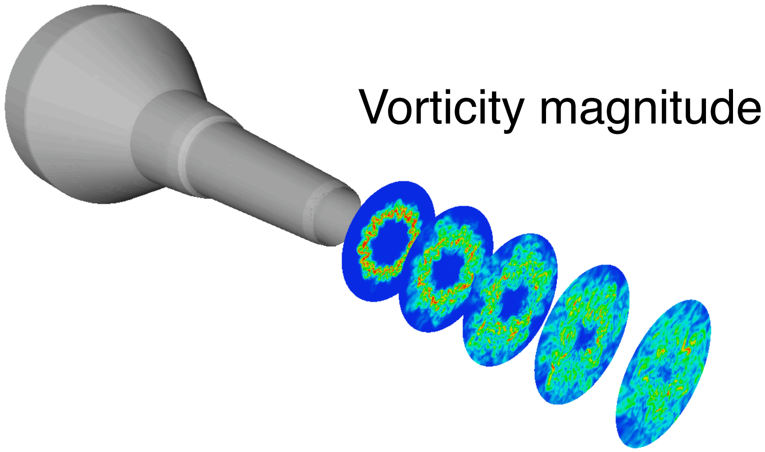
$x/D_j = 4$

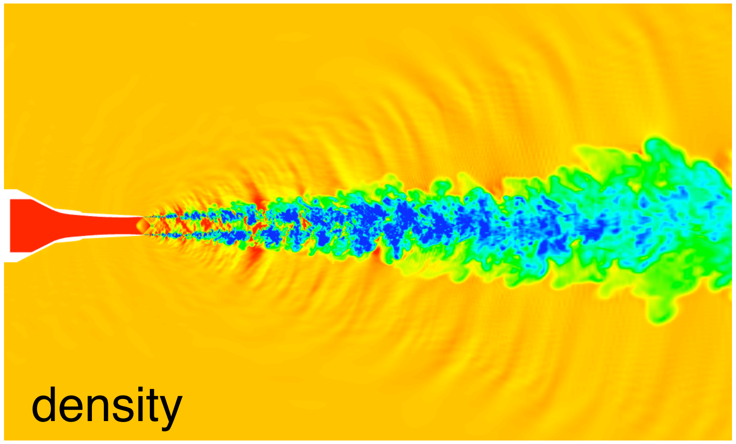


$x/D_j = 7$

Prediction and Modeling of Jet Noise Using Large-Eddy Simulation

- Stanford University
  - Simon Mendez, Post Doctoral Researcher
  - Sanjiva Lele & Parviz Moin, Principal Investigators
- Unstructured LES
  - Non-dissipative schemes
  - Shock capturing
- Potential benefits
  - Complex Geometry
  - Gain knowledge of unstructured methods



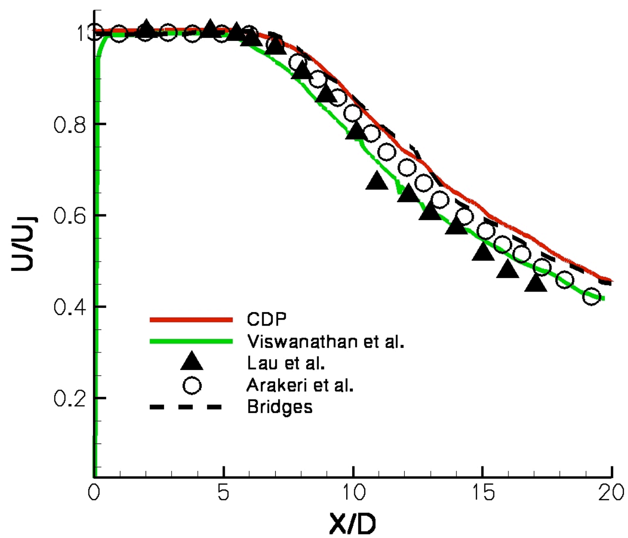


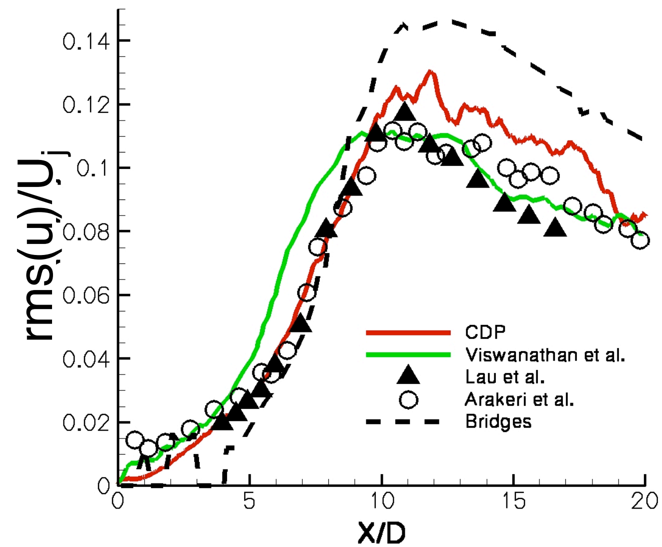
Approach

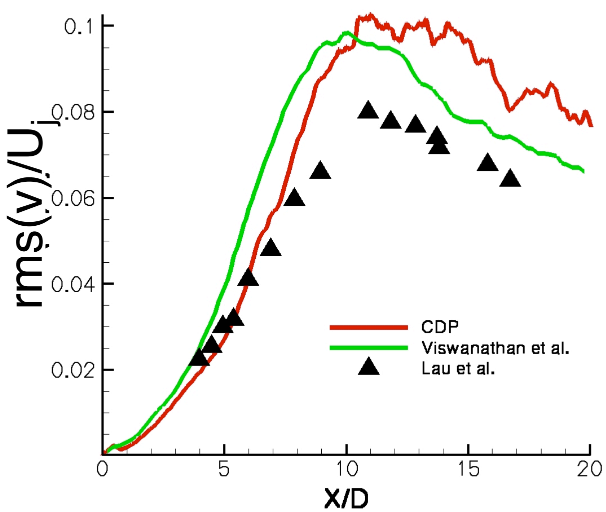
- CDP code
  - 2^{nd} order energy conserving finite volume
  - Hybrid explicit/implicit time stepping
- Unstructured grids
- Dynamic Smagorinsky sub-grid model
- Cases
  - Subsonic, M = 0.95
  - Supersonic, M = 1.4
    - Cold
    - Hot
- Farfield noise
  - Ffwocs-Williams Hawkings solver

Comparison to Experiment

Subsonic Jet



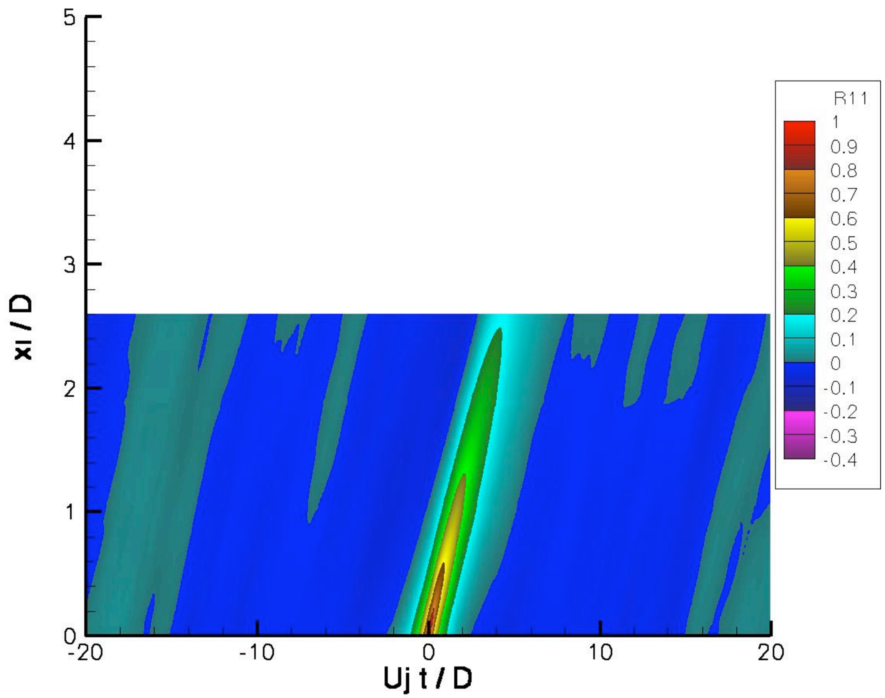




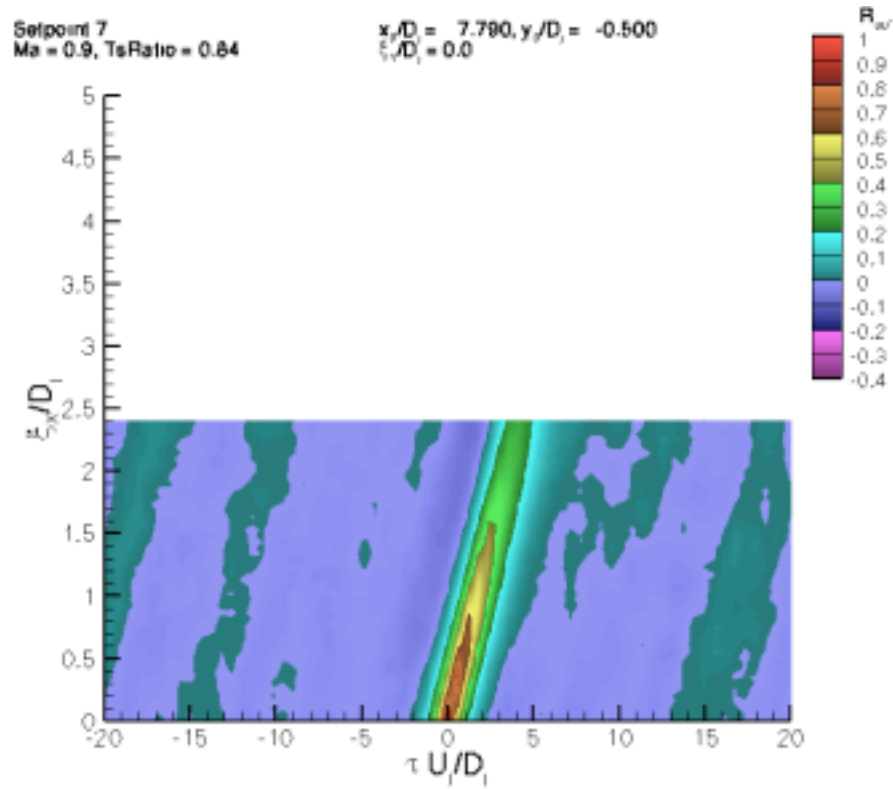
Viswanathan et al. – LES calculation
AIAA J. 45(8) 2007

Space-Time Correlations, x/D = 7.8

Subsonic Jet



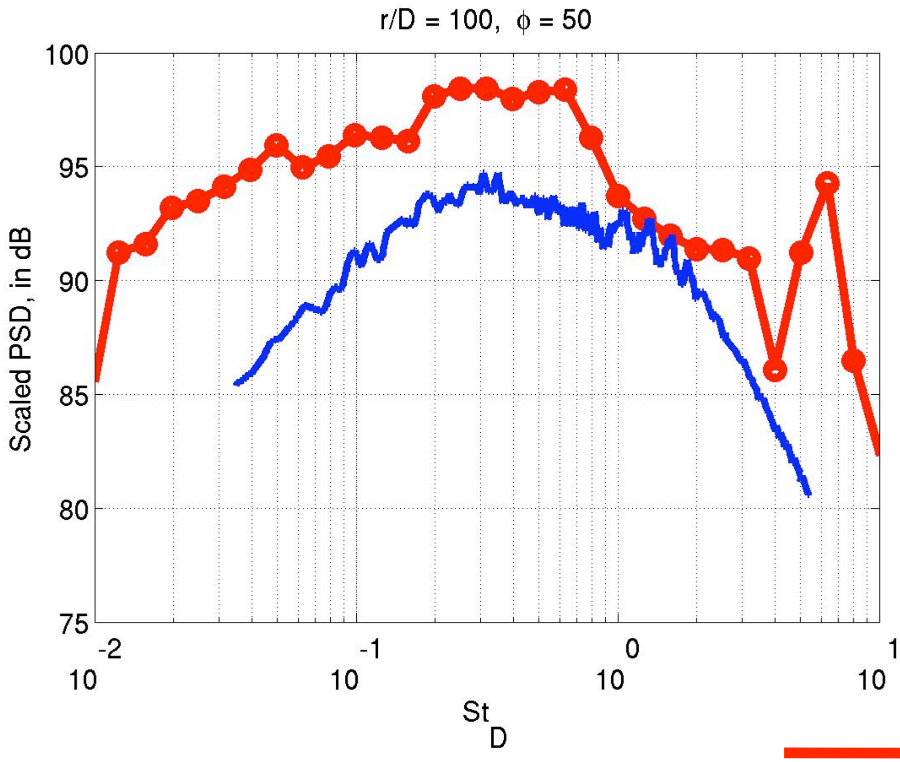
CDP

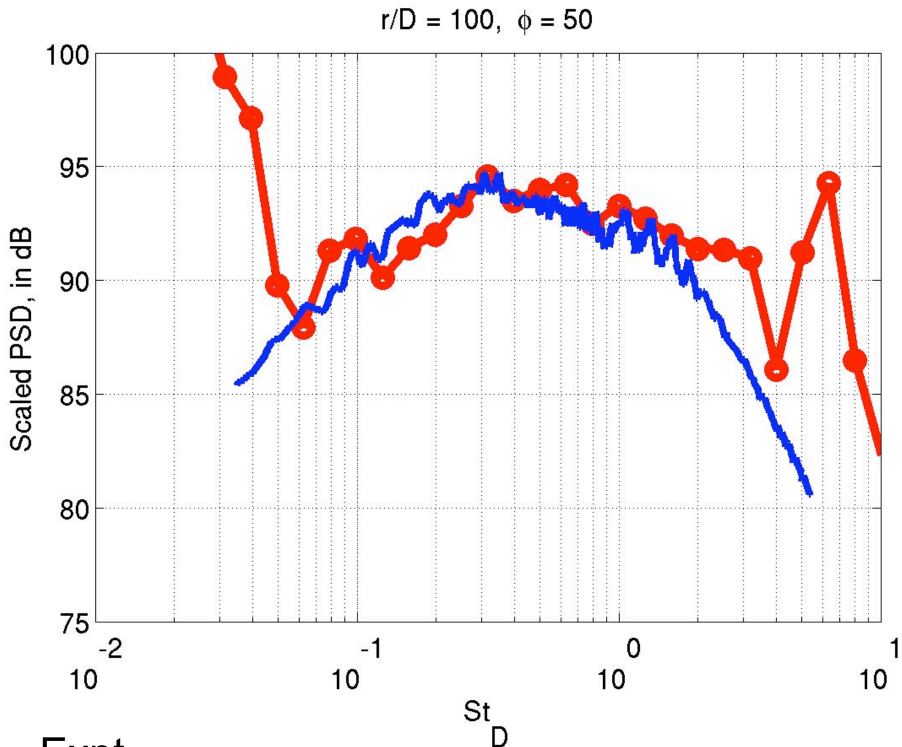


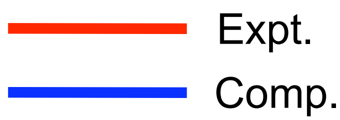
Bridges and Wernet 2007

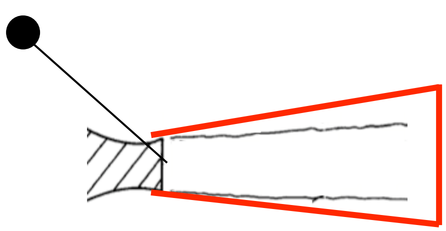
Farfield Noise, FWH Solver

Subsonic Jet

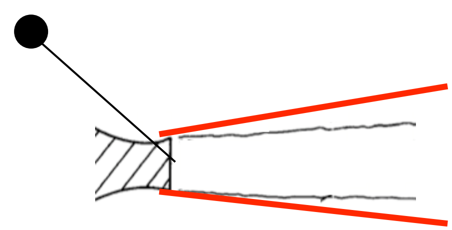








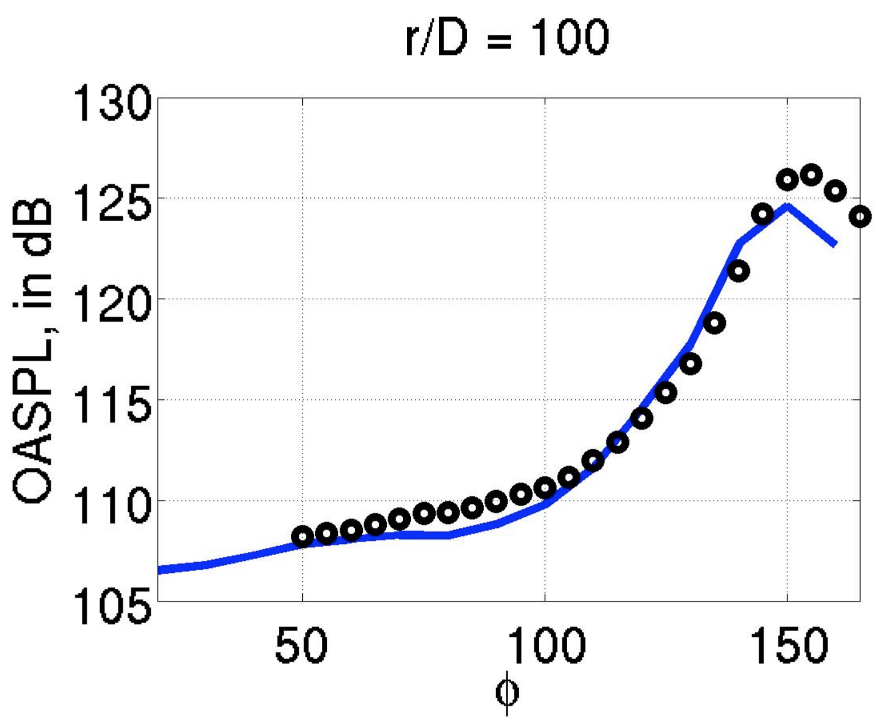
Closed



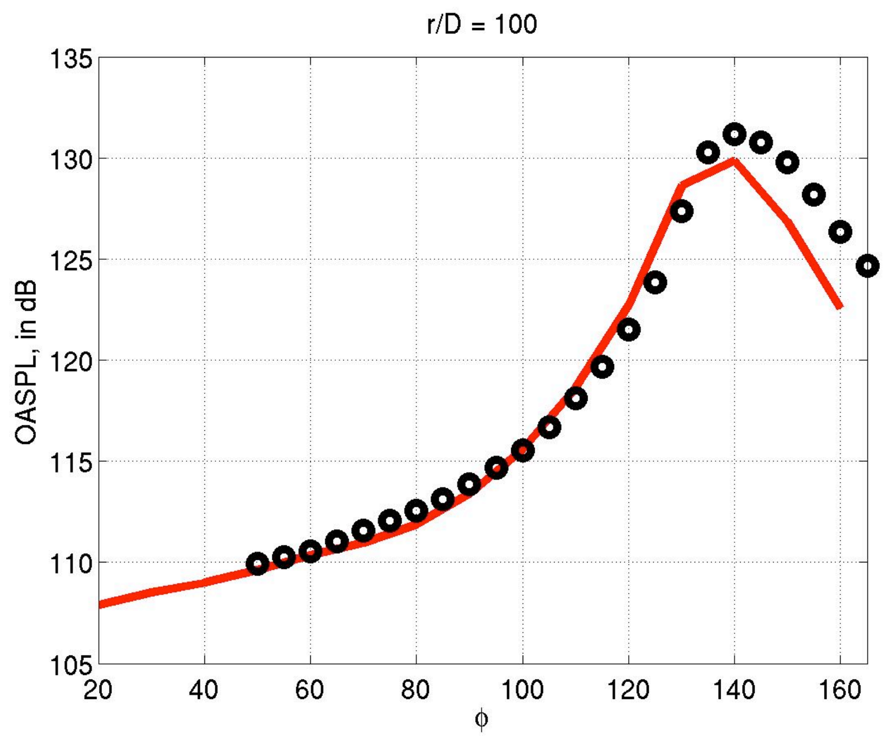
Open

Farfield Sound (100D), OASPL

Supersonic Jets



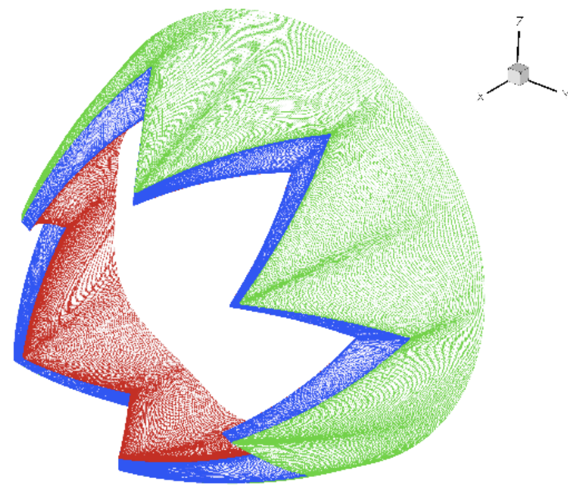
Unheated

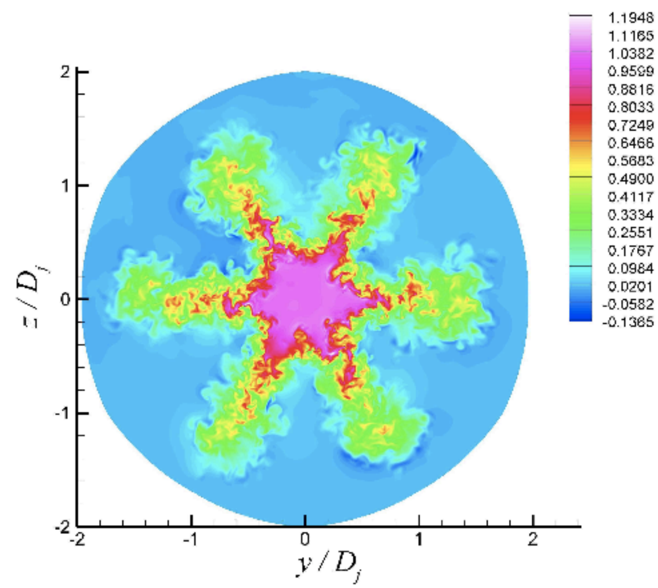


Heated

High-Fidelity Jet Noise Simulations

- Florida State University
  - Ali Uzun, Post Doctoral Researcher
  - M. Yousuff Hussaini, Principal Investigator
- Very high resolution LES
  - 300 – 400 million grid points
  - High resolution numerical schemes
- Potential benefits
  - Very high accuracy
  - Excellent database for jet noise modeling

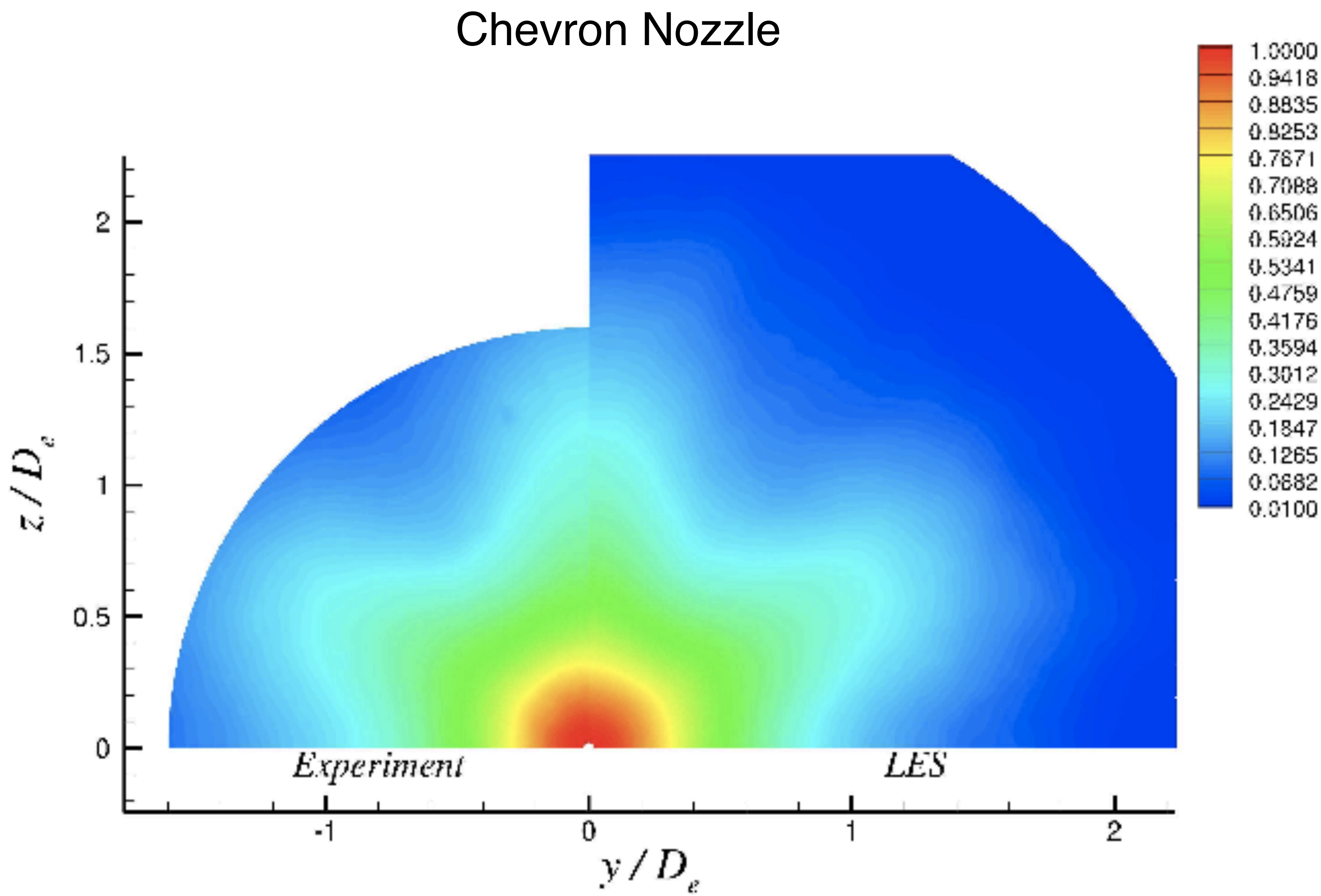




Approach

- Numerical Scheme
  - Implicit time advancement
  - Fourth-order compact spatial differencing
- Overset grids
- Implicit LES – no sub-grid model
- Turbulent nozzle boundary layers using a recycling technique
- Cases
  - Chevron Nozzle
  - Round Jet
- Farfield noise
  - Ffwocs-Williams Hawkings solver

Axial Velocity

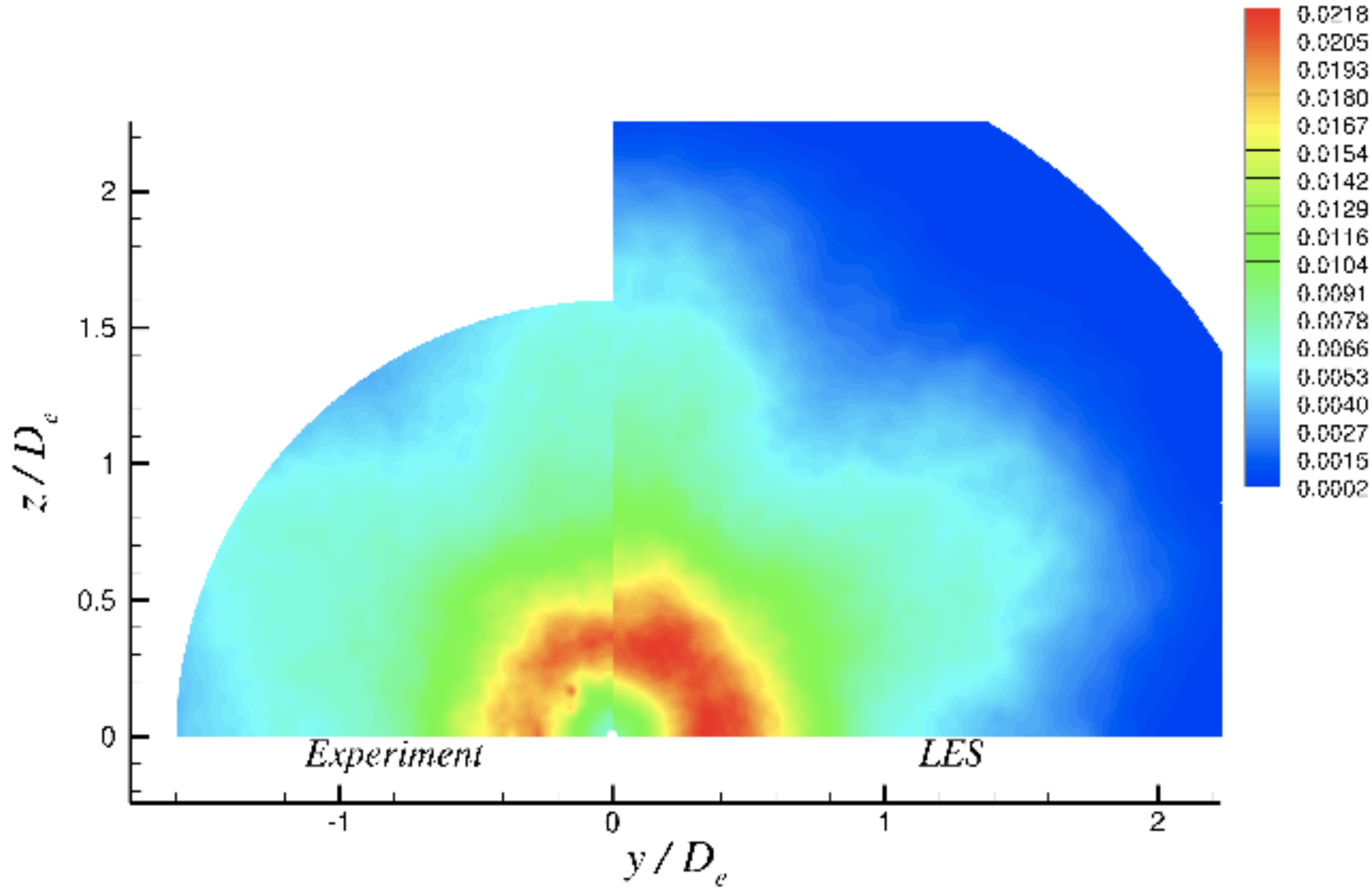


$x/L_{core} = 1.03$

Note: L_{core} scaling corrects for disparity between CFD and expt.

Turbulent Kinetic Energy

Chevron Nozzle

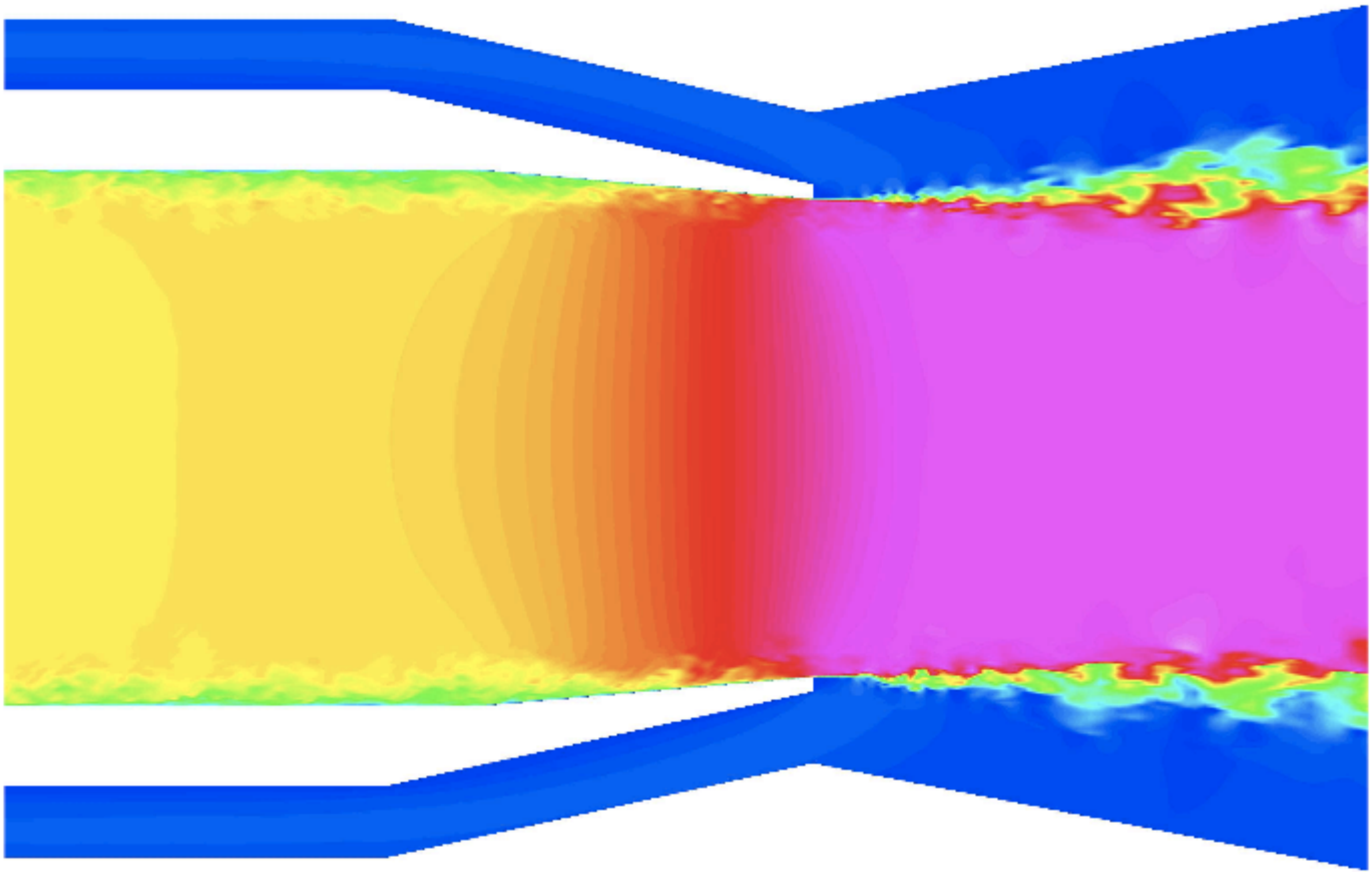


$x/L_{core} = 1.03$

Note: L_{core} scaling corrects for disparity between CFD and expt.

Nozzle Boundary Layers

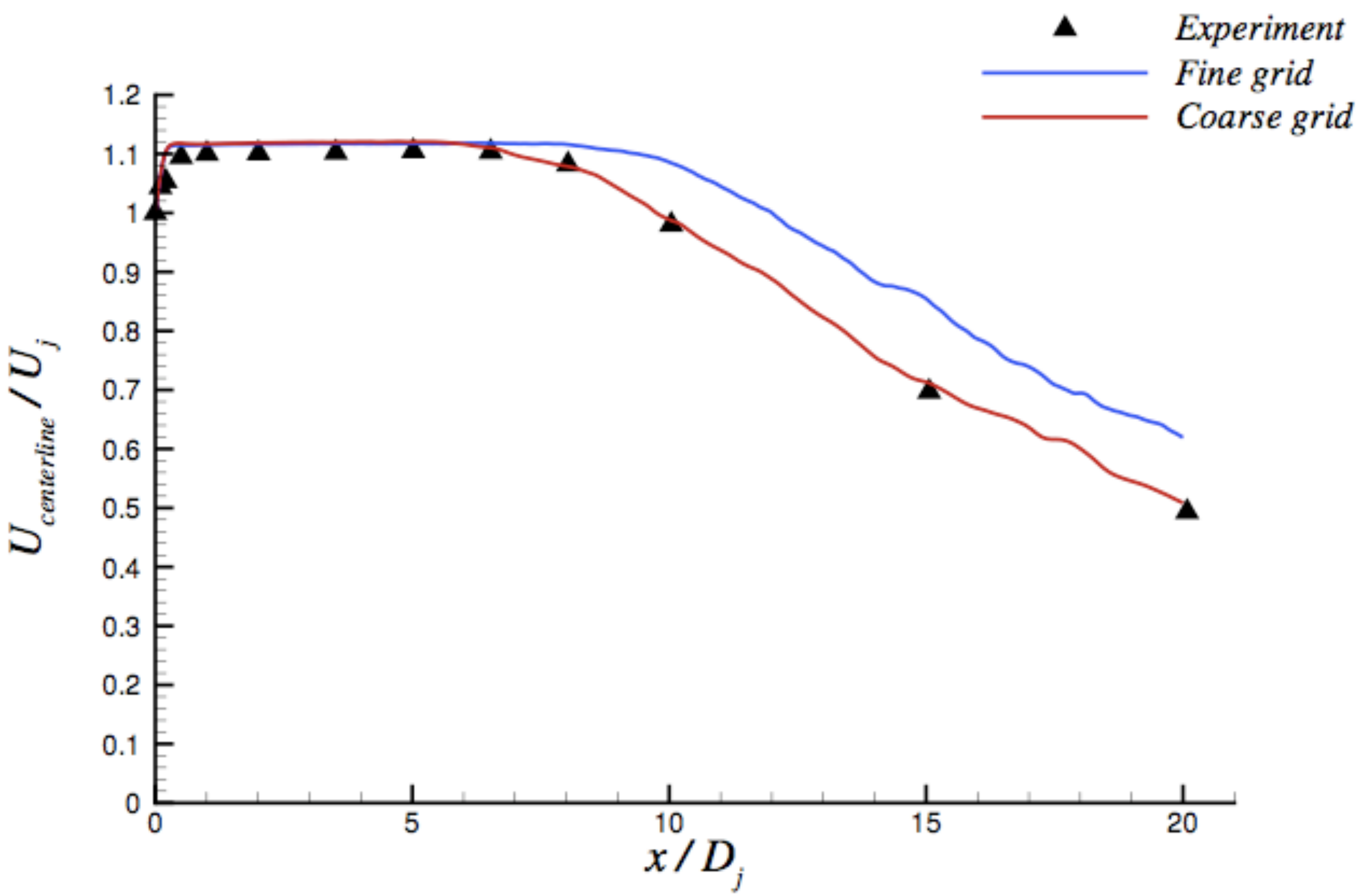
Round Jet



Axial Velocity Contours

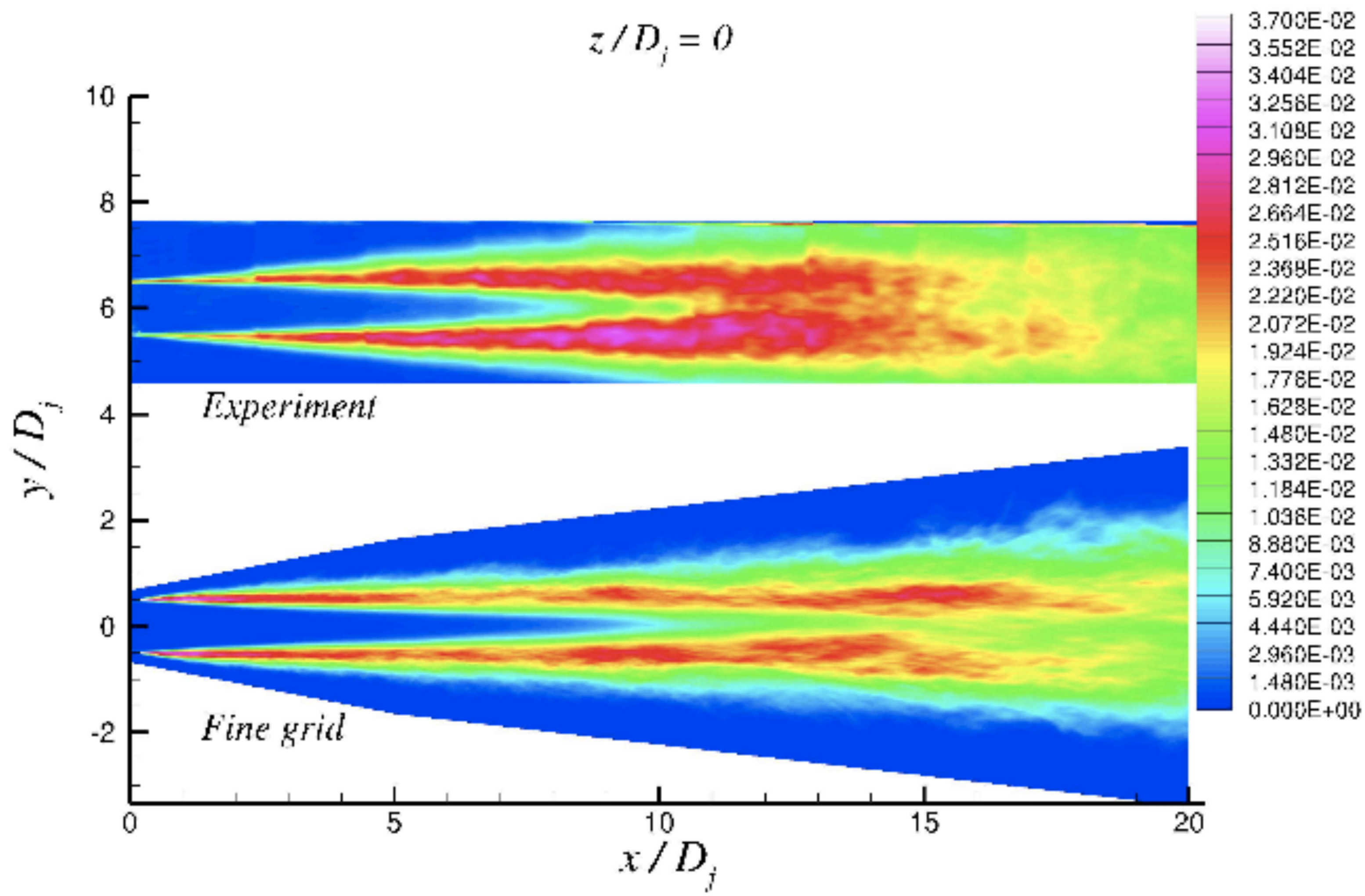
Centerline Velocity Profiles

Round Jet



Axial Turbulent Intensity

Round Jet



Conclusions

- LES methods are now doing a good job of reproducing simple jet flowfields
- Further research needed for…
  - Complex flows
    - Complex geometries: chevrons, mixer/ejectors, etc.
    - Flows with shocks
  - Computing farfield noise
    - FWH closure methods
    - Exploring alternate propagation techniques

NASA