Supersonics Project
Airport Noise Technical Challenge

Presented by: James Bridges

Abstract:
This presentation gives an overview of the work being done under the Airport Noise Technical Challenge portion of the Supersonics Project in the Fundamental Aeronautics Program. The objective of the Challenge is to provide technology (e.g. low noise nozzle concepts) and engineering tools required for a viable supersonic aircraft. To accomplish this we have activities divided into Prediction, Diagnostics, and Engineering elements. Each of the tasks reviewed here have potential applications to work being done at other flight regimes and other aircraft and are of interest to the Acoustics Technical Working Group.

Supersonics Project
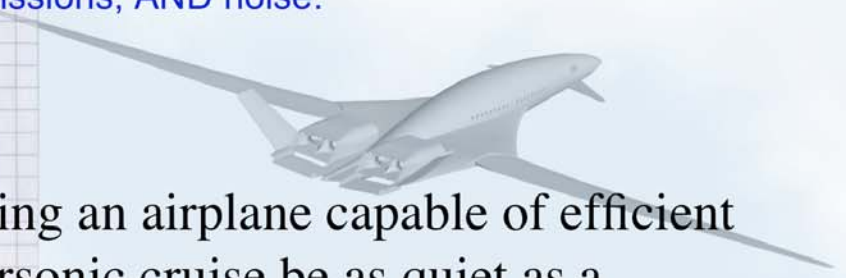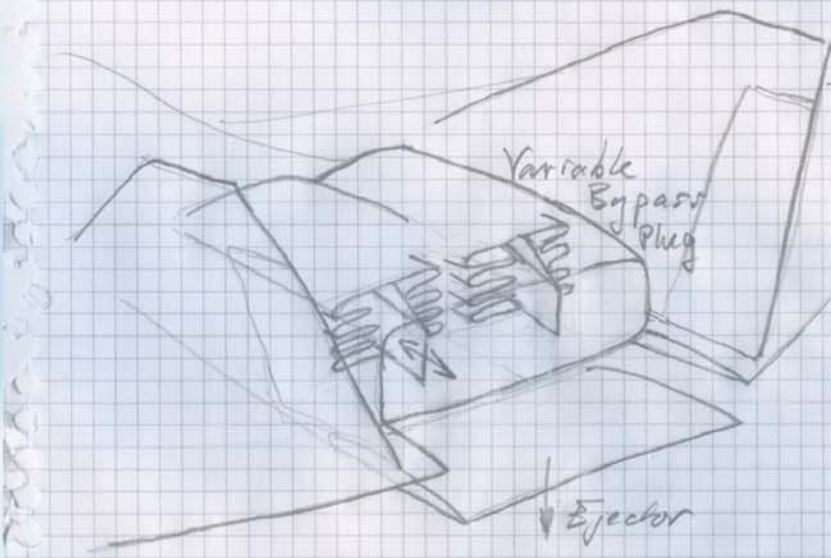# Airport Noise Technical Challenge

James Bridges

Assoc Principal Investigator, Airport Noise Discipline

Acoustics Technical Working Group

Williamsburg, VA

Sept 23, 2008

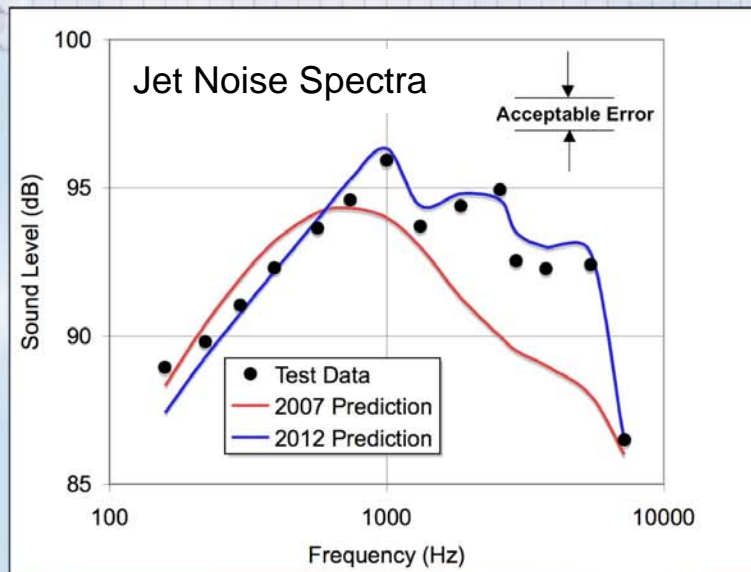# Airport Noise Technical Challenge

Making an airplane capable of efficient supersonic cruise be as quiet as a standard airplane requires **innovative propulsion concepts**.

Lack of jet noise **prediction capability** requires assessment of noise *after* optimization of performance. Too late.

Advanced empirical modeling will allow noise assessment of innovative concept *while design still on drawing board*. **Physics-based modeling** will show sources of noise so they can be addressed in subsequent design iterations.

Jet Noise Spectra

Acceptable Error

- • Test Data
- — 2007 Prediction
- — 2012 Prediction

Sound Level (dB)

Frequency (Hz)

Airport Noise Elements

- Prediction
  - Time-resolved CFD/CAA for Jet Aeroacoustics
  - Statistical Modeling of Supersonic Jet Noise
  - MDOE-based Empirical Prediction Tool for ANOPP
  - Assessment of Supersonic Noise Prediction Tools

- Diagnostics
  - Turbulence Statistics for Statistical Noise Prediction
  - Supersonic Aeroacoustic DB for Dual Flow Jets
  - Phased Array Survey of Broadband Shock Noise Source

- Engineering
  - Shock Modifications for Noise Reduction (N+1)
  - Offset Stream Concepts (N+1)
  - Highly Variable Cycle (HVC) Concept (N+1)
  - SERDP Hi-Perf Noise Reduction (N+1)
  - Iconic Supersonic Vehicle (N+2)
  - Unsteady Actuator Validation (N+3)

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# Prediction and Modeling of Supersonic Jet Noise Using LES

NRA PI: Sanjiva Lele, Stanford University

- Code development for time-dependent turbulent simulations of flowfields from noise suppressing nozzles with complex geometry.
- Developing computational tools to coupled Reynolds Averaged Navier-Stokes (RANS) and Large-Eddy Simulation (LES) methods for jet noise analyses.

ω: 0.0 2.0 4.0 6.0 8.0 10.0

Vorticity magnitude contours for a Mach 0.9 jet
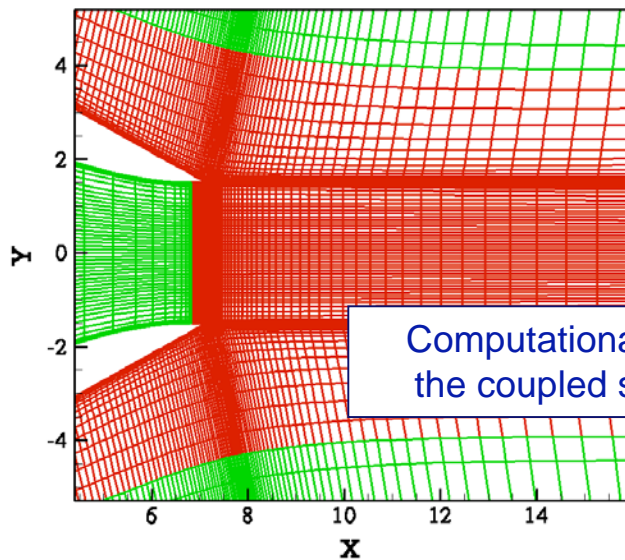
Computational grid illustrating the coupled solution strategy

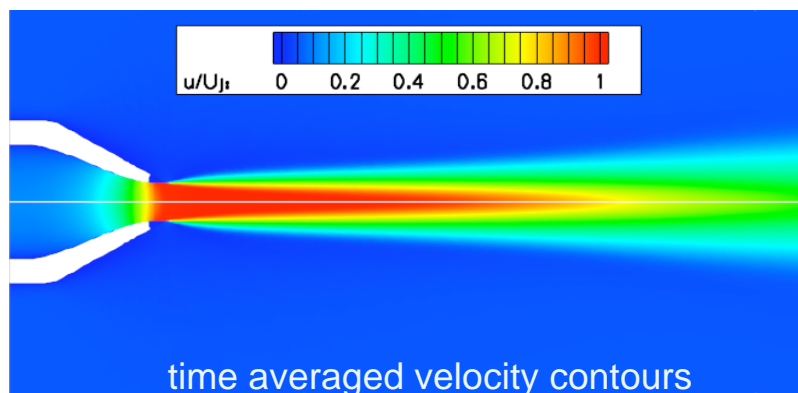Green: URANS, NSSUS code
Red: LES, CDP-C code
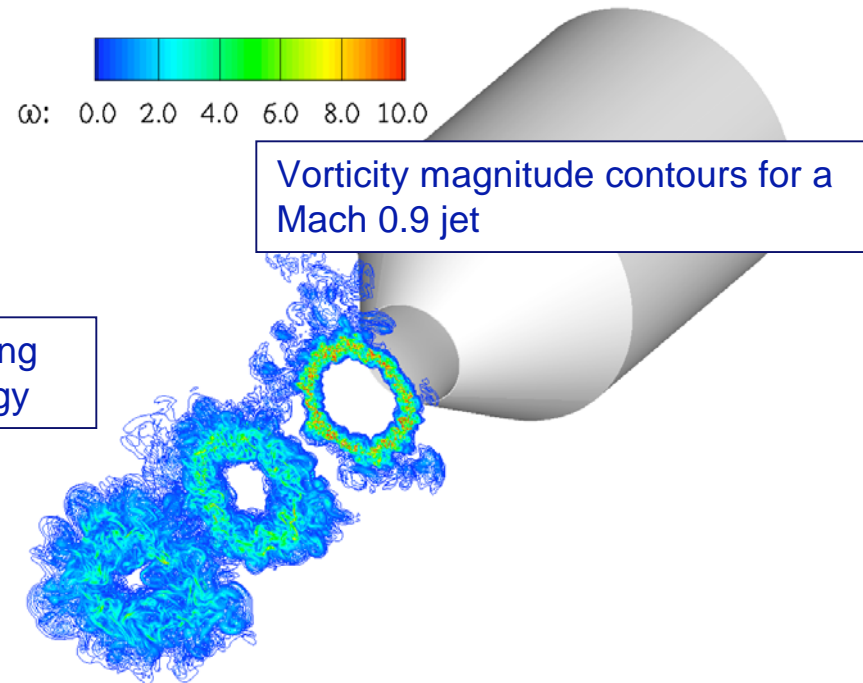
NASA Large-Eddy Simulation Research

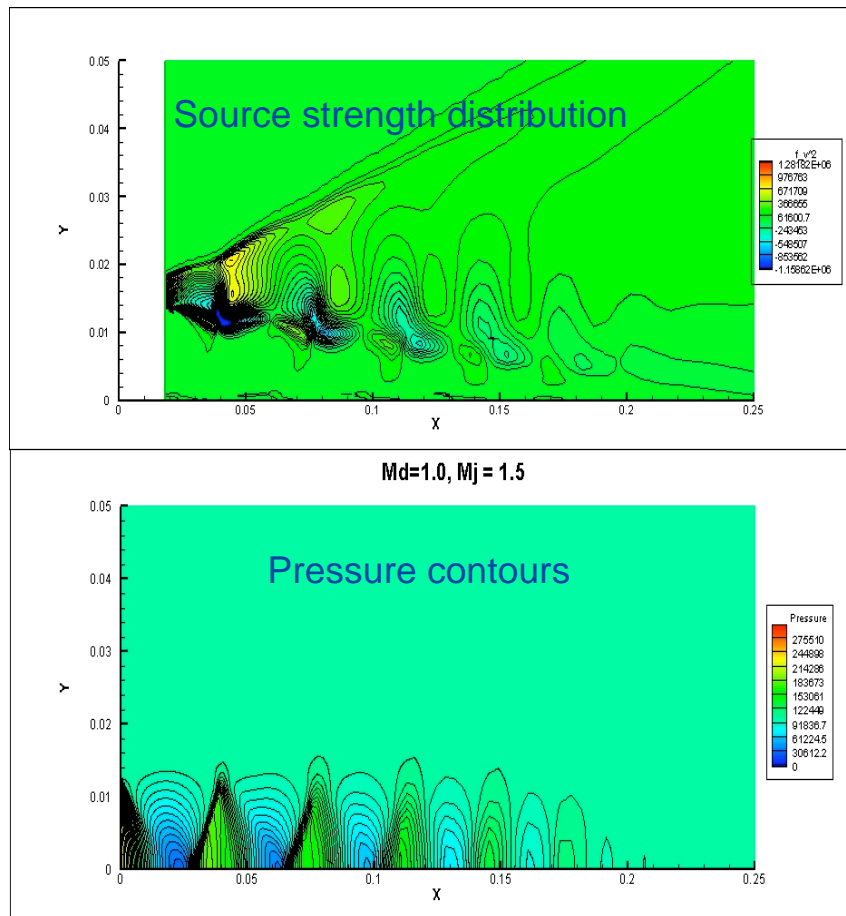NASA POC: Jim DeBonis <James.R.Debonis@nasa.gov>

- In-house research code for technique evaluation
  - Low dispersion 4th order Runge-Kutta in time
  - High-order (2nd - 12th) central and DRP based spatial schemes
  - Shock capturing filters for shocked jets
  - Hybrid MPI/OpenMP parallel
  - Generalized curvilinear coordinates
- Status:
  - Assessing promising results for Mach 0.9 round jet using Bogey & Bailley 13 pt. DRP scheme
 - Have tried and discarded many reported good ideas

time averaged centerline velocity

time averaged velocity contours

turbulent energy spectra
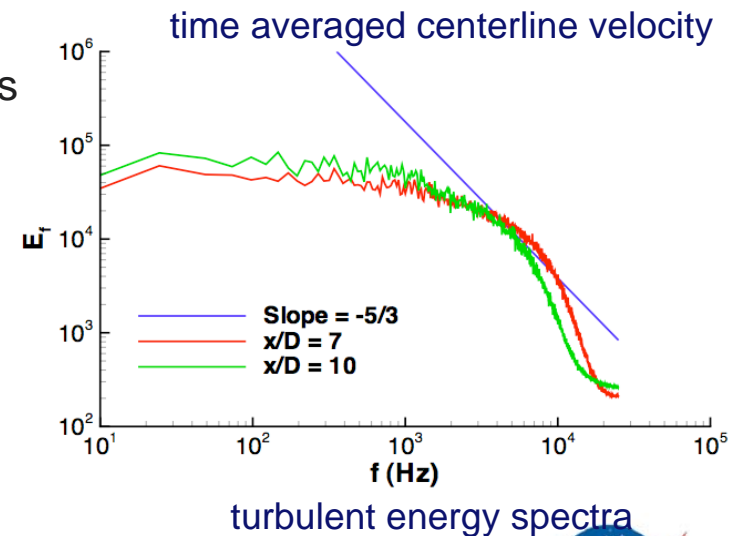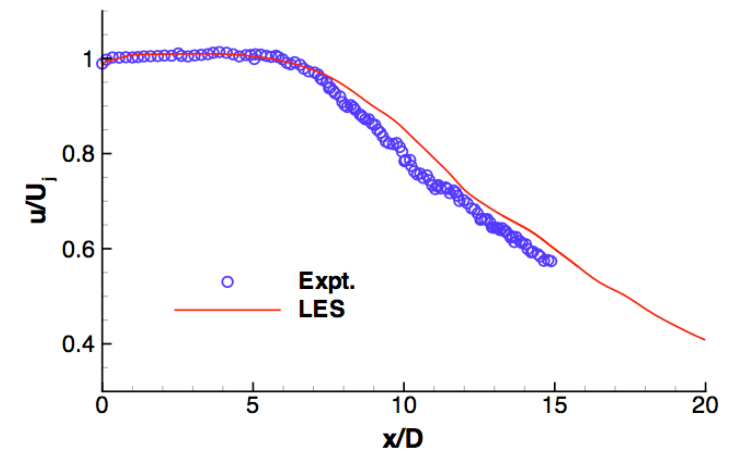
Broadband Shock Associated Noise Prediction

NRA PI: Philip Morris, Penn State University

Jet Mean Flow Calculations And Source Modeling

Far Field Radiated Noise Spectrum

Source strength distribution

Md=1.0, Mj = 1.5

Pressure contours

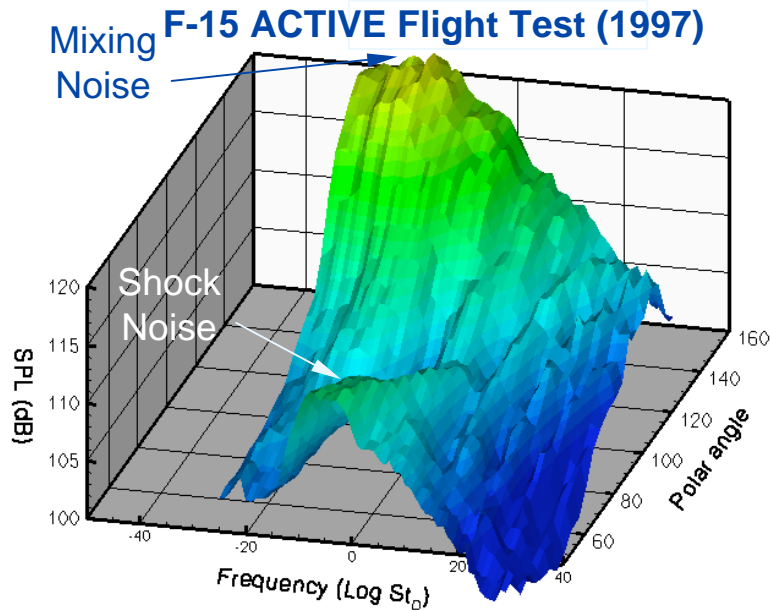Preliminary BBSAN prediction
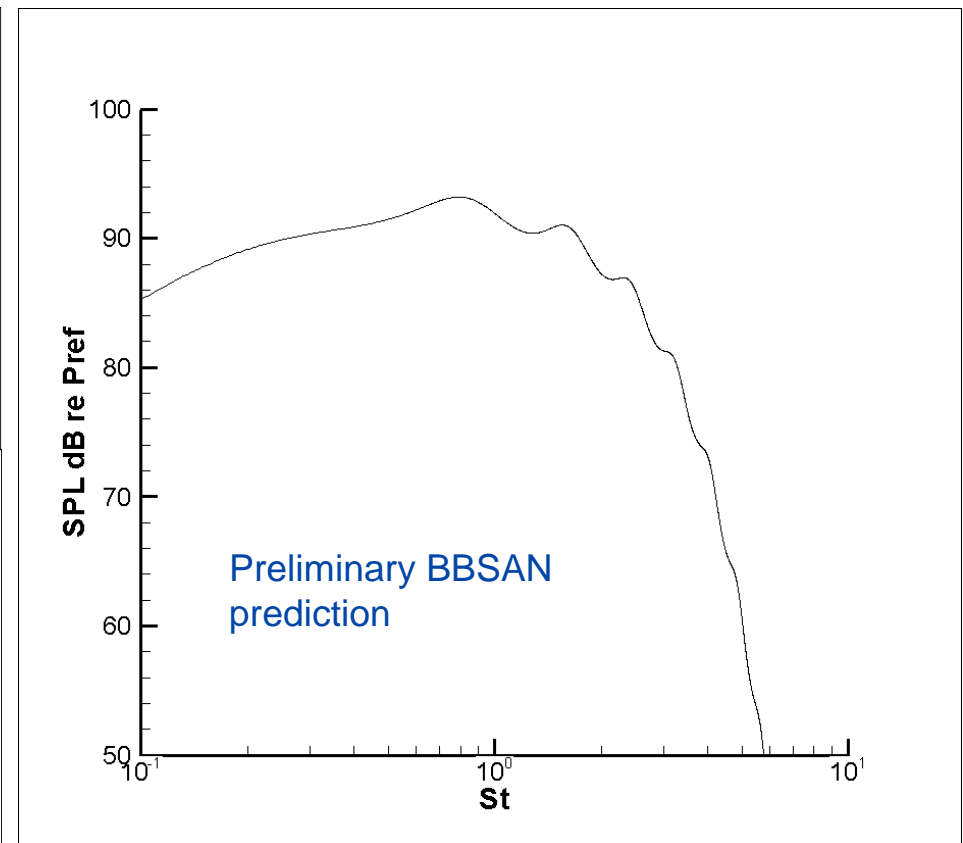
Improving Scale Model Noise Prediction

NASA POC: Tom Norum <Thomas.D.Norum@nasa.gov>

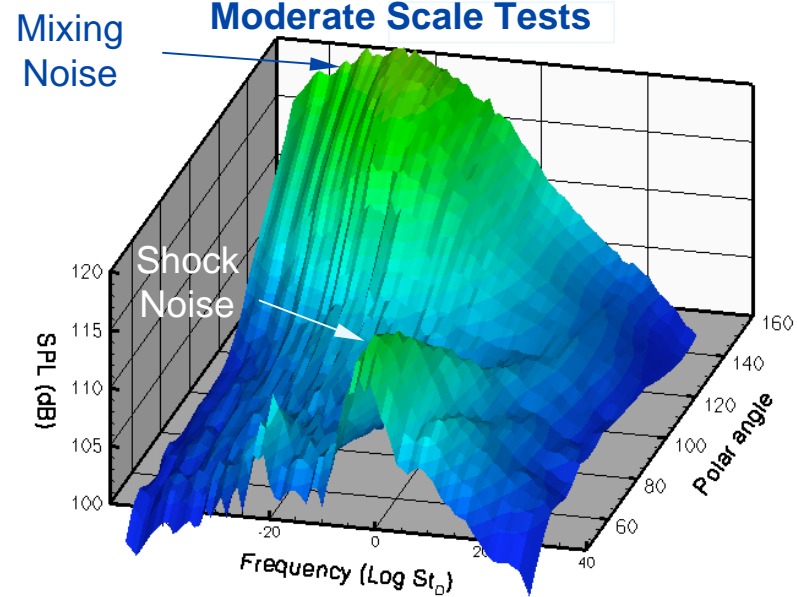Partnered with Strategic Environmental R & D Program (SERDP)

F-15 ACTIVE Flight Test (1997)
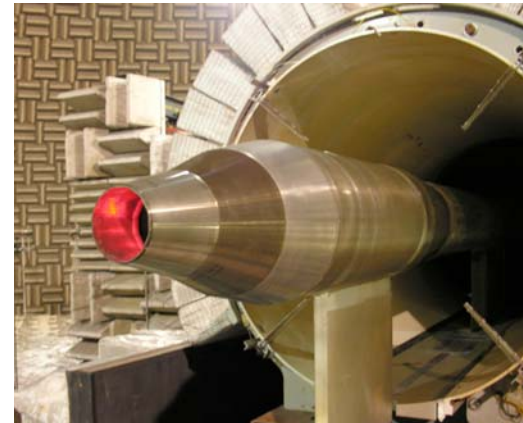
Moderate Scale Tests

MDOE-Based Tool for Jet Noise Modeling

NASA POC: Brenda Henderson <Brenda.S.Henderson@nasa.gov>

- Objective:

  - Bridge physics-based prediction codes and empirical codes
  - 'Fast' method of creating noise prediction module for ANOPP to capture parametric variations in jet noise from exotic designs.
  - Based on Modern Design Of Experiments tools,
    - Use MDOE tools and intuition to design parametric matrix for designs of interest
    - Obtain spectral directivity noise data from limited runs of physics-based codes
    - Use MDOE tools to create multi-dimensional empirical model
    - Attach to ANOPP for system analysis use.

- Status:

  - New task for 2009.
  - Attempting first versions using experimental databases from existing tests.

Assessment of Statistical Noise Prediction Methods

NASA POC: James Bridges <James.E.Bridges@nasa.gov>

- Validation of RANS CFD for hot supersonic jets (38 cases) against PIV database
  - Turbulent Kinetic Energy
  - Lengthscales
  - Timescales
- JeNo acoustic analogy applied and <u>deficiencies in spectral directivity catalogued</u>
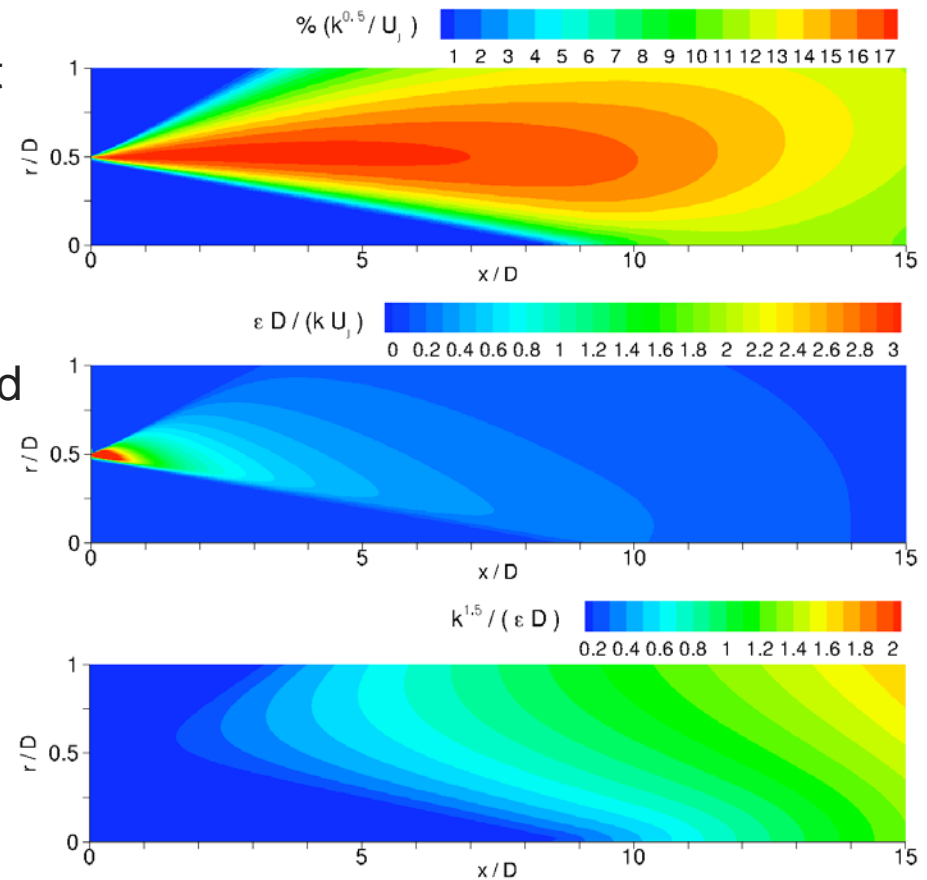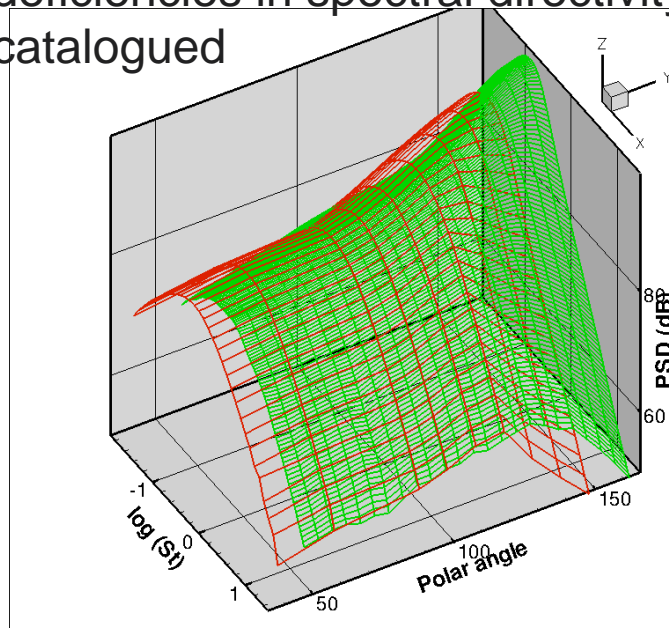
Airport Noise Elements

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  - Statistical Modeling of Supersonic Jet Noise
  - MDOE-based Empirical Prediction Tool for ANOPP
  - Assessment of Supersonic Noise Prediction Tools

- **Diagnostics**
  - **Turbulence Statistics for Statistical Noise Prediction**
  - **Supersonic Aeroacoustic DB for Dual Flow Jets**
  - **Phased Array Survey of Broadband Shock Noise Source**

- Engineering
  - Shock Modifications for Noise Reduction (N+1)
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  - Iconic Supersonic Vehicle (N+2)
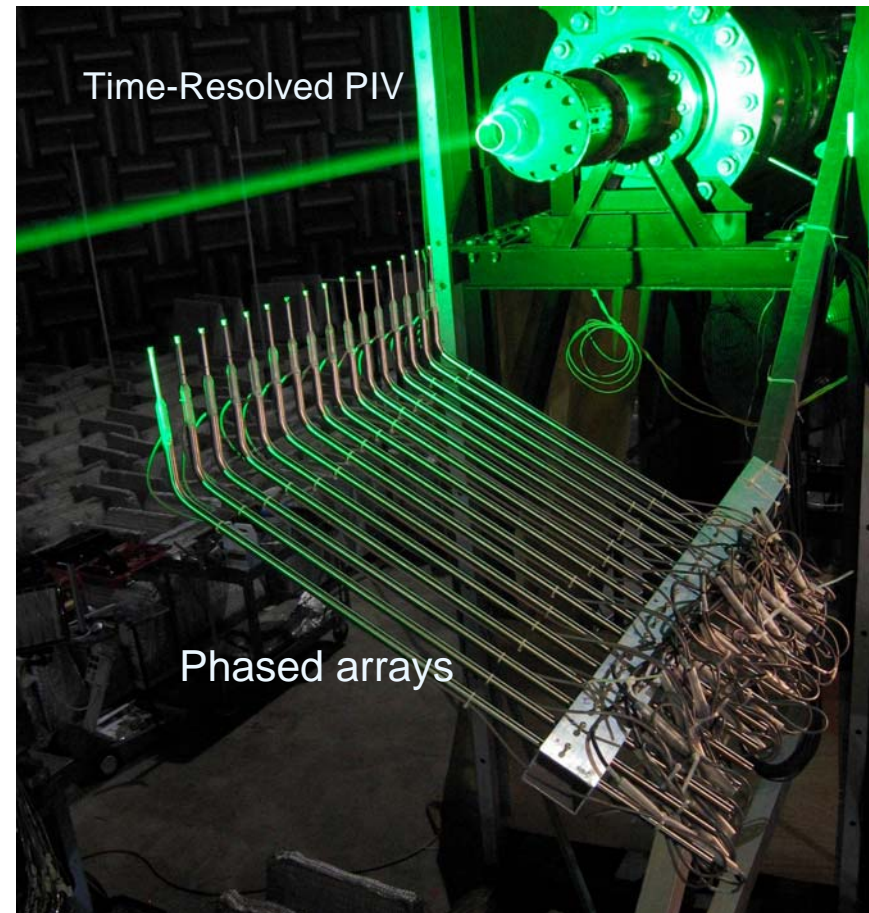 - Unsteady Actuator Validation (N+3)

Advances in Flow Diagnostics for Noise Reduction and Prediction

NASA POC: James Bridges <James.E.Bridges@nasa.gov>

**Turbulence measured in hot jets using Particle Image Velocimetry (PIV)**
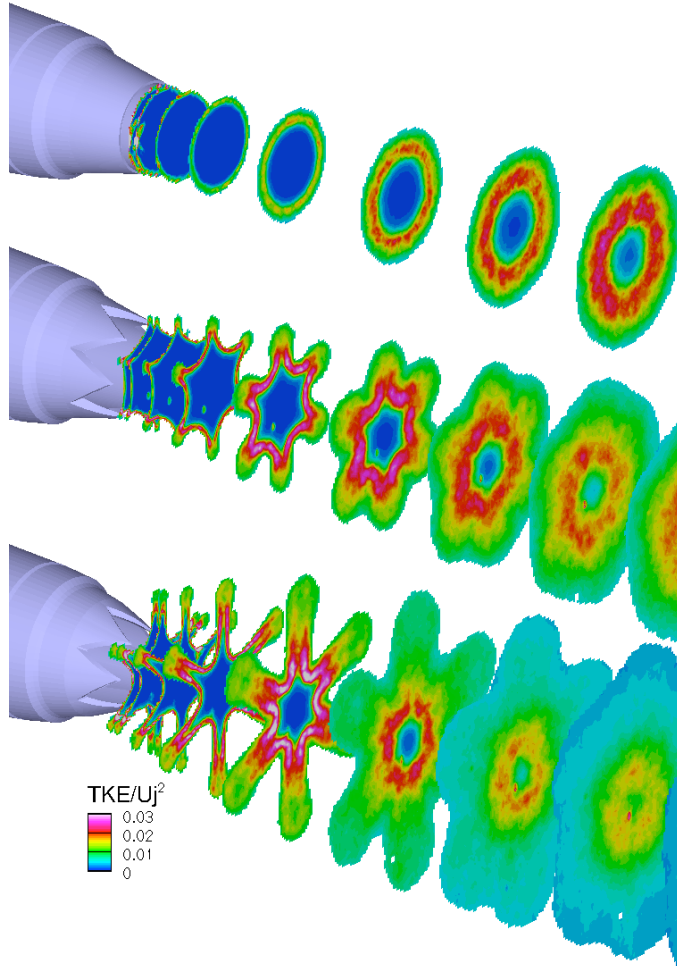
Flow-Source correlations explored using multiple advanced techniques

TKE/Uj²
0.03
0.02
0.01
0

Time-Resolved PIV

Phased arrays

Turbulent Velocity Spectra of Hot Supersonic Jets

NASA POC: Mark Wernet <Mark.P.Wernet.gov>

- Flow and acoustics documented over wide range of flow conditions, nozzle designs
- Time-resolved PIV gives velocity spectra in hot supersonic jets
- Being used for RANS, LES validations

M = 1.4,
T/T_∞ = 1.8
Convergent

Guu (dB)
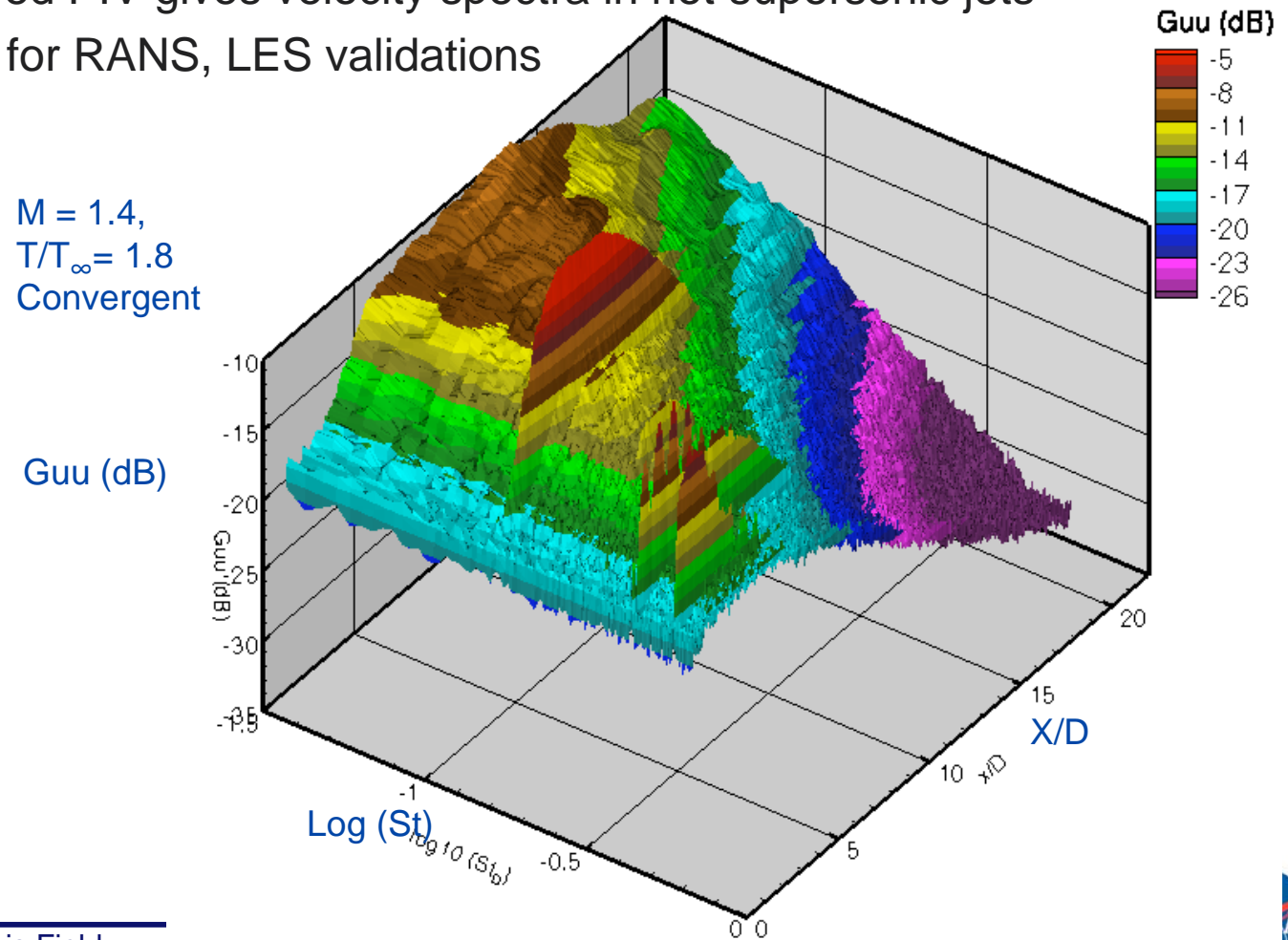
Turbulent Temperature Measurements in Hot Jets

NASA POC: Amy Mielke <Amy.F.Mielke@nasa.gov>

- Rayleigh scattering measurements in SHJAR

- Point measurement technique to acquire temporally-resolved velocity, temperature, and density in unseeded gas flows using Fabre-Periot interferometry

- $0.5 \leq Ma \leq 1.588$; $1 \leq Tt/T\infty \leq 3.2$

- Data being used in evaluating TTE model in RANS code; JeNo v2

Rayleigh instrumentation on SHJAR
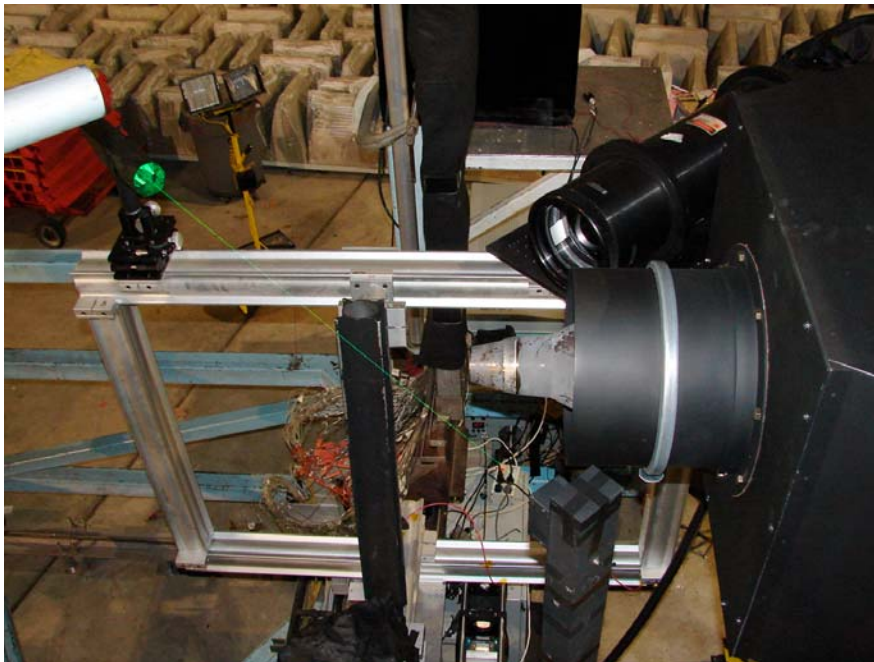
Turbulent temperature radial profile
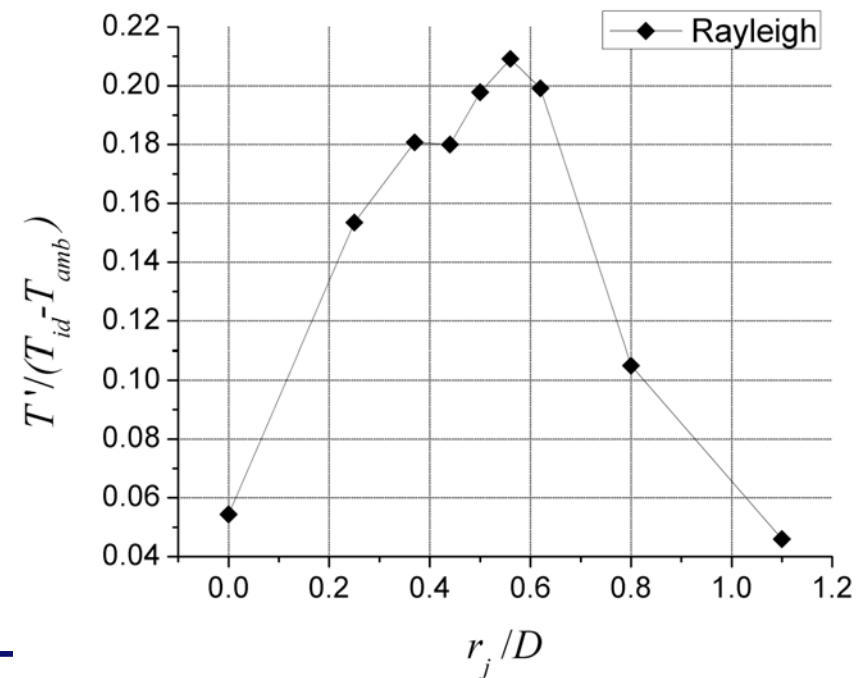
Supersonic Aeroacoustic Database

NASA POC: James Bridges <James.E.Bridges@nasa.gov>

- Systematic flow/noise database for dual-stream axisymmetric jets, varying
  - External/Internal mixing
  - Area/Bypass Ratio
  - A9/A8 (ideally expanded profiles)
  - Flight speed
  - Aero Mach number
  - Acoustic Mach number
  - Core stream temperature

- Cross-facility validation

- Status:
  - Acoustic data, pressure and temperature surveys acquired (~1500 points)
  - PIV flow data to be acquired Spring 2009.
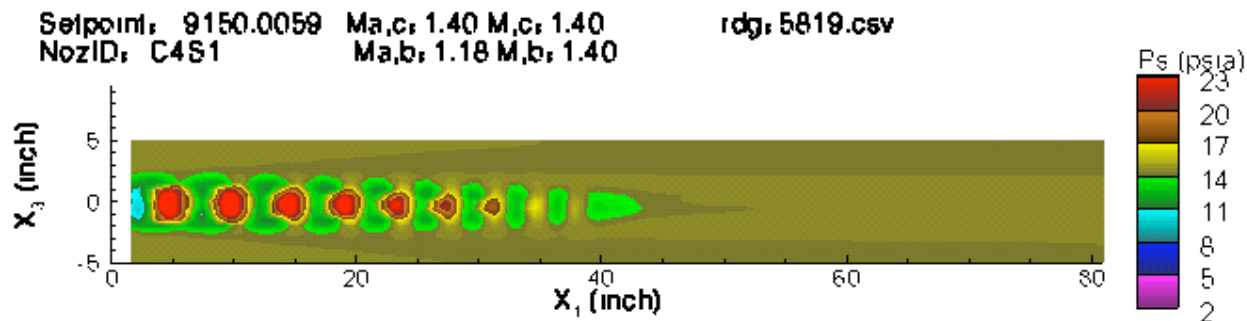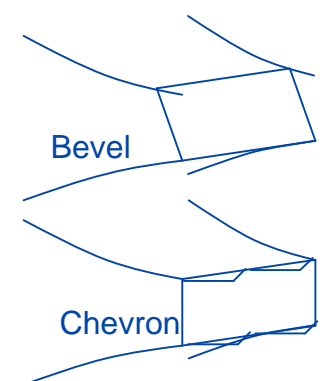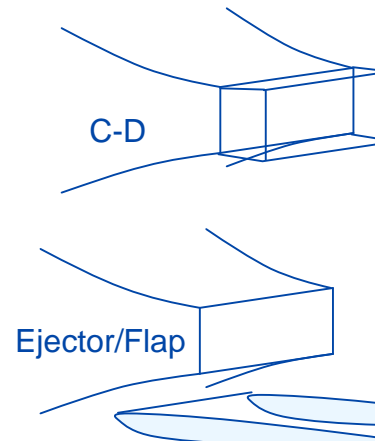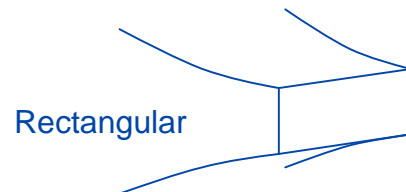
3D Jet Aeroacoustic Database

NASA POC: James Bridges <James.E.Bridges@nasa.gov>

- For validation of prediction codes, exploration of noise reduction
    - Azimuthal propagation benefits
    - Turbulent source benefits
   - Dual stream (internally mixed) complications
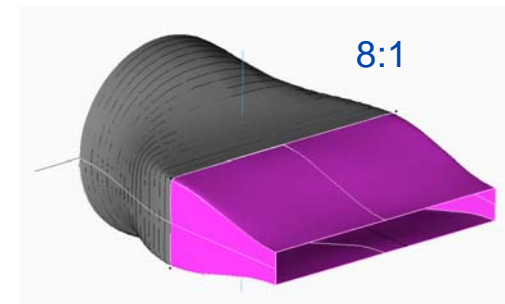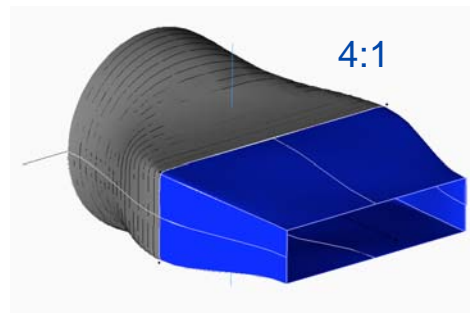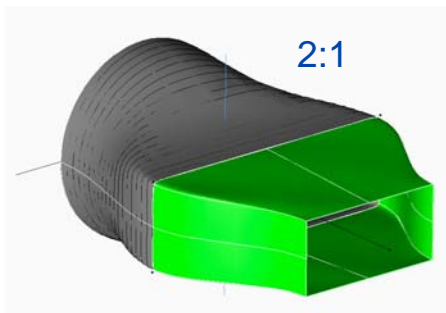
- Variations on rectangular jets
    - C-D
    - Bevel
    - Chevron
    - Ejector/flap
- Status: Nozzles in design
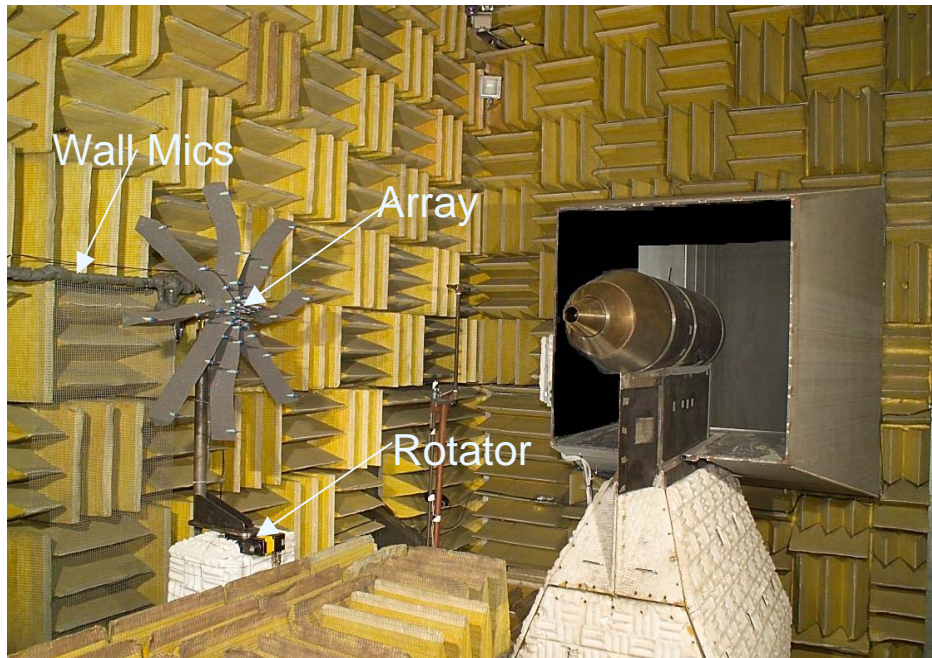
Twin Model for Jet Interaction Studies

NASA POC: Brenda Henderson <Brenda.S.Henderson@nasa.gov>

Y-Duct

S-Duct

Angle Adapter

- For validation of prediction codes, exploration of noise reduction
  - Jet plume interactions
  - Jet-by-jet shielding
- Status: Model to be delivered in 2009
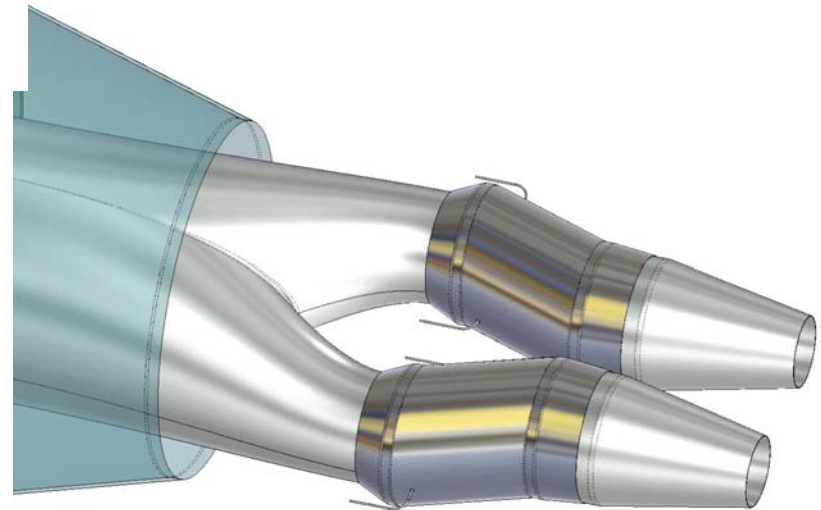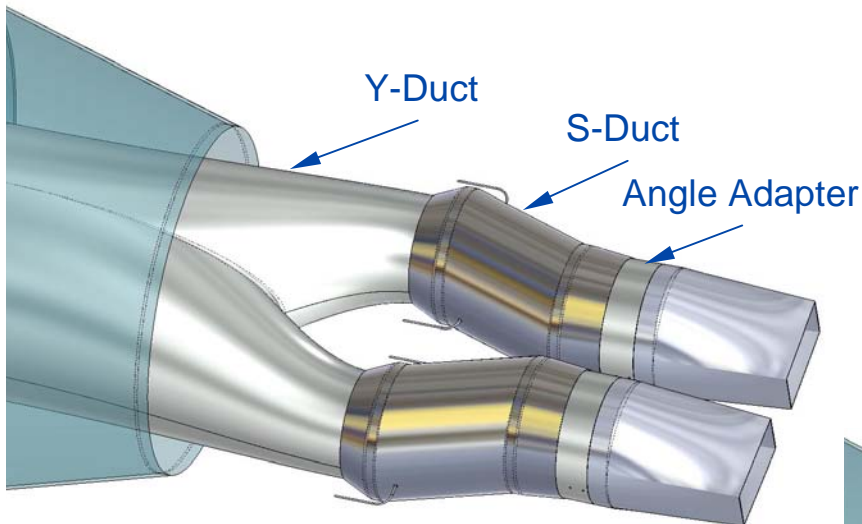
JEDA Measurements for Jet Noise

NASA POC: Tom Brooks <Thomas.F.Brooks@nasa.gov>


Array Installation in LaRC Jet Noise Lab

- Goals:
  - Develop processing methodologies to account for the influence of incoherent and coherent convecting sources in the jet
  - Characterize performance of the array
  - Obtain detailed source distribution maps for subsonic and supersonic jets
  - Obtain data for validation of prediction codes
- Status:
  - Data acquired, processing and analysis code refinement ongoing

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- **Engineering**
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Air Injection for Noise Reduction

NASA POC: Brenda Henderson <Brenda.S.Henderson@nasa.gov>

Air Supply

Pylon

Fan Nozzle

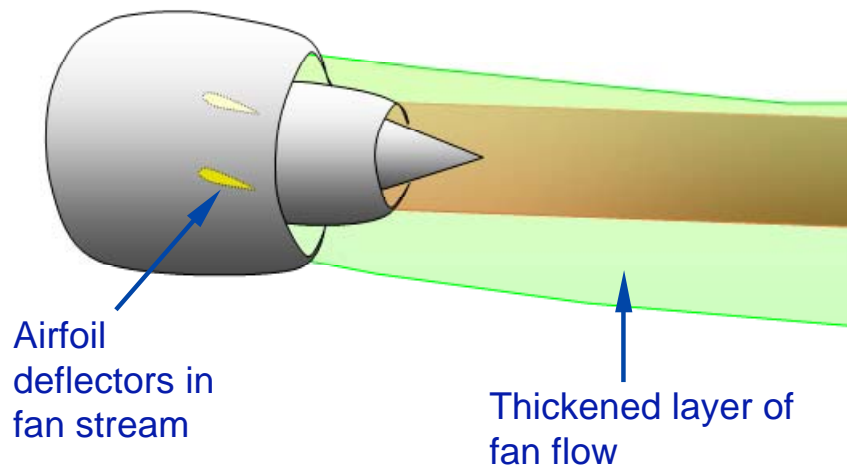**Fluidic Chevron Core Nozzle**
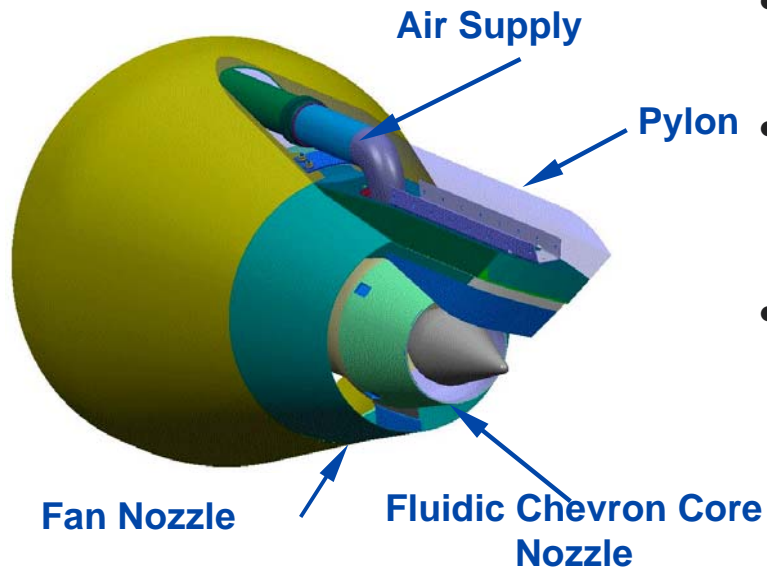
- Air injection nozzles tested at subsonic and supersonic exhaust speeds

- Mixing noise and broadband shock noise reductions achieved for some configurations and operating conditions

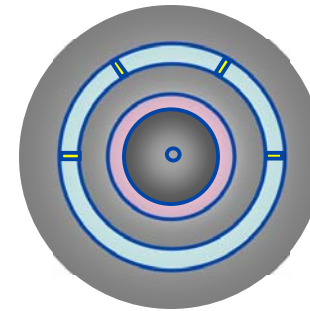- Nozzle design resulted from partnership between NASA and Goodrich Aerostructures

$\theta = 61^{\circ}$

IPR = 1.0
IPR = 2.5
IPR = 4.0

$NPR_c = 1.61$

$NPR_f = 2.23$

SPL (dB)

Frequency (Hz)
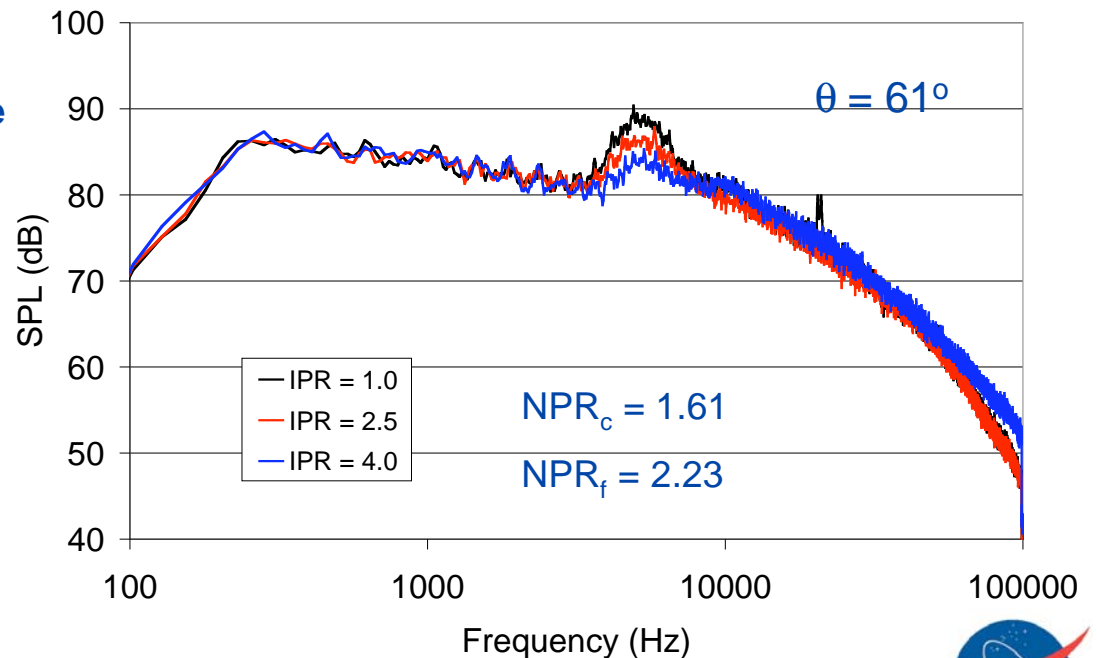
Supersonic Jet Noise Reduction via Reshaping the Exhaust Plume

NRA PI: Dimitri Papamoschou, University of California, Irvine

Cross Section of Nozzles with Four Cambered Airfoil Deflectors

Airfoil deflectors in fan stream

Thickened layer of fan flow

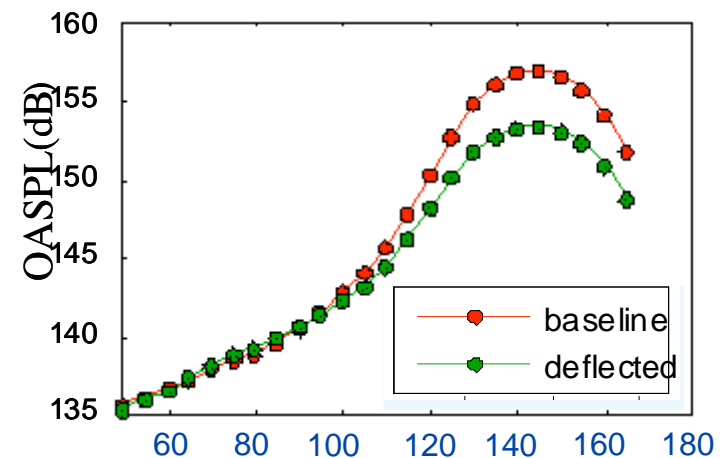**Downward OASPL Reduction**

- Thickened layer of fan flow on underside of jet hinders noise emission from hot core in downward and sideline direction

- Results of parametric testing will be used in MDOE-based prediction tool

$BPR = 2.7$, $NPR_c = 2.00$, $NPR_f = 2.25$
$\Delta EPNL = 4.1$ dB

Variable Cycle Exhaust System Design for Supersonic Aircraft

NRA PI: Jack Sokhey, Rolls-Royce North American Technologies, Inc.
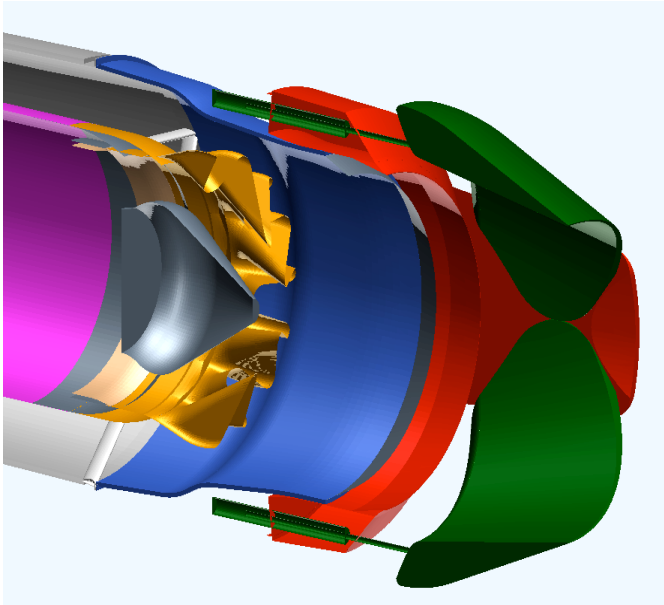
- Model will allow for the investigation of noise characteristics of different mixer configurations and ejector designs
- Data obtained from the model will be used for development of prediction codes and noise reduction technologies
- Status: CDR in October 2008

1.0

Mach #

0.0
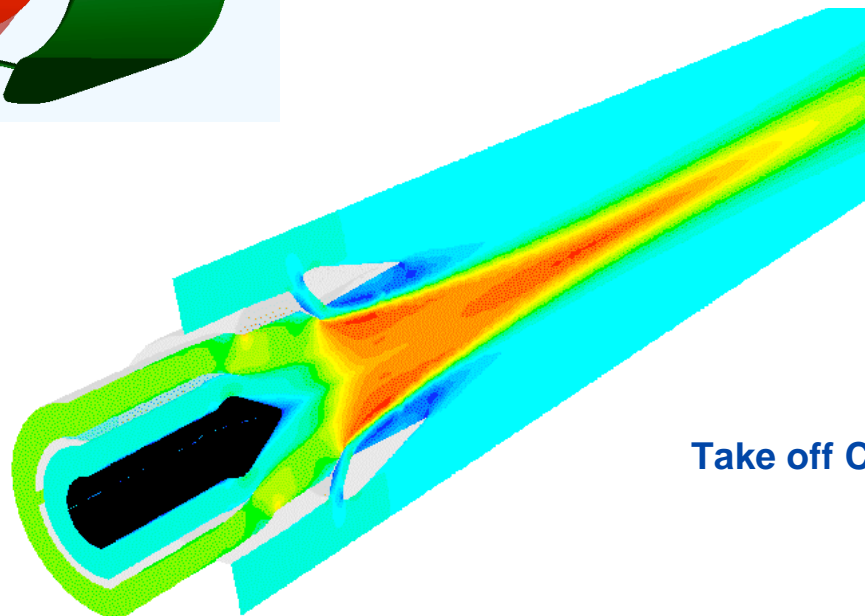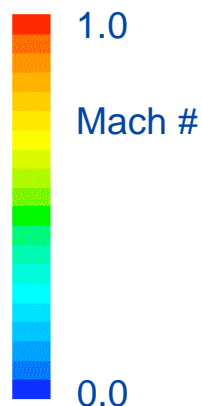
Take off Configuration

Iconic Supersonic Vehicle Exhaust System Design

NASA POC: James Bridges <James.E.Bridges@nasa.gov>

- Objective
  - Working with Systems Analysis and Propulsion Efficiency groups, design a candidate, futuristic exhaust system using latest tools.
  - Use exercise to evaluate usefulness of tools
  - Build and test model scale system to validate design.
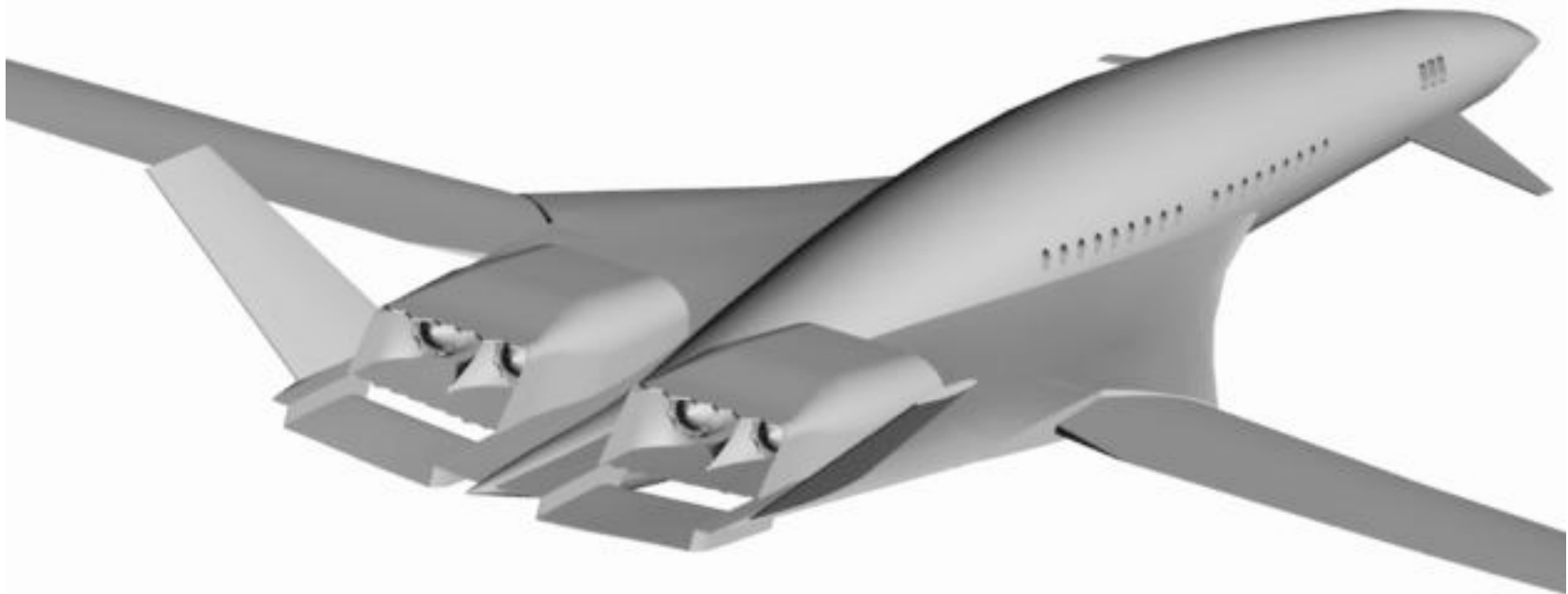
Supersonic Jet Noise Suppression Using Plasma Actuators

NRA PI: Mo Samimy, The Ohio State University

- Various jet instabilities are manipulated to manipulate noise.
- LES used to predict optimal jet forcing for noise mitigation
- Optimized jet forcing to be tested experimentally at multiple scales

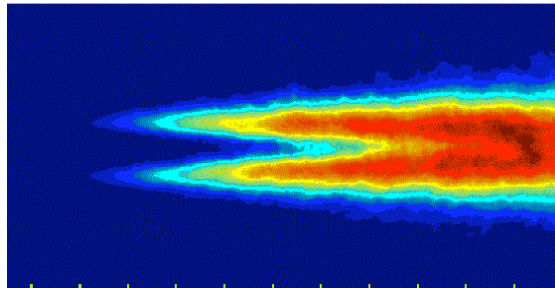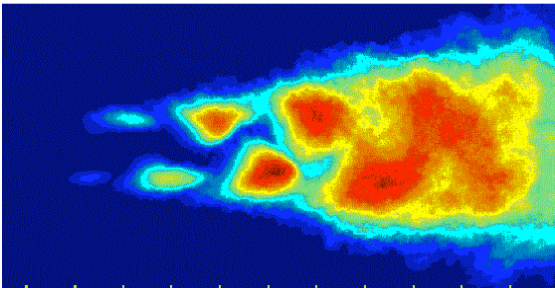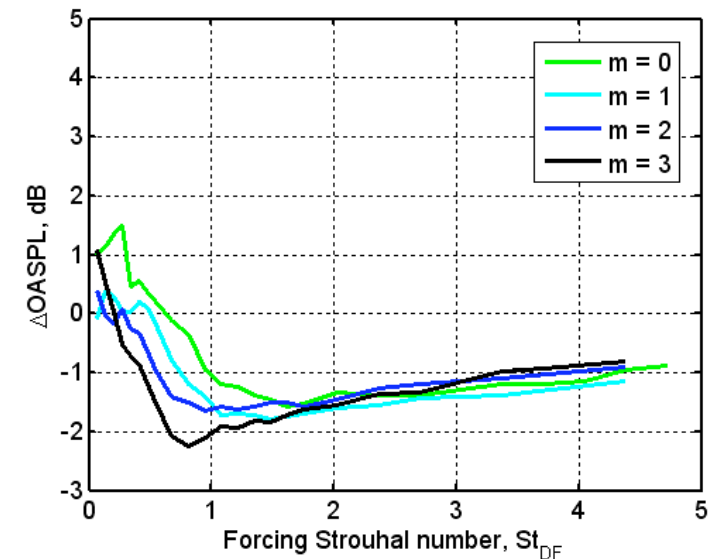**Example of actuation effects on the jet flow field**

Example of noise mitigation at Mach 1.3

Image of baseline
Mach 1.3 jet

Noise
reduction
relative to
baseline jet
(actuation
not
optimized)

Image of forced jet
at 5 kHz and at
azimuthal mode
m=±1

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