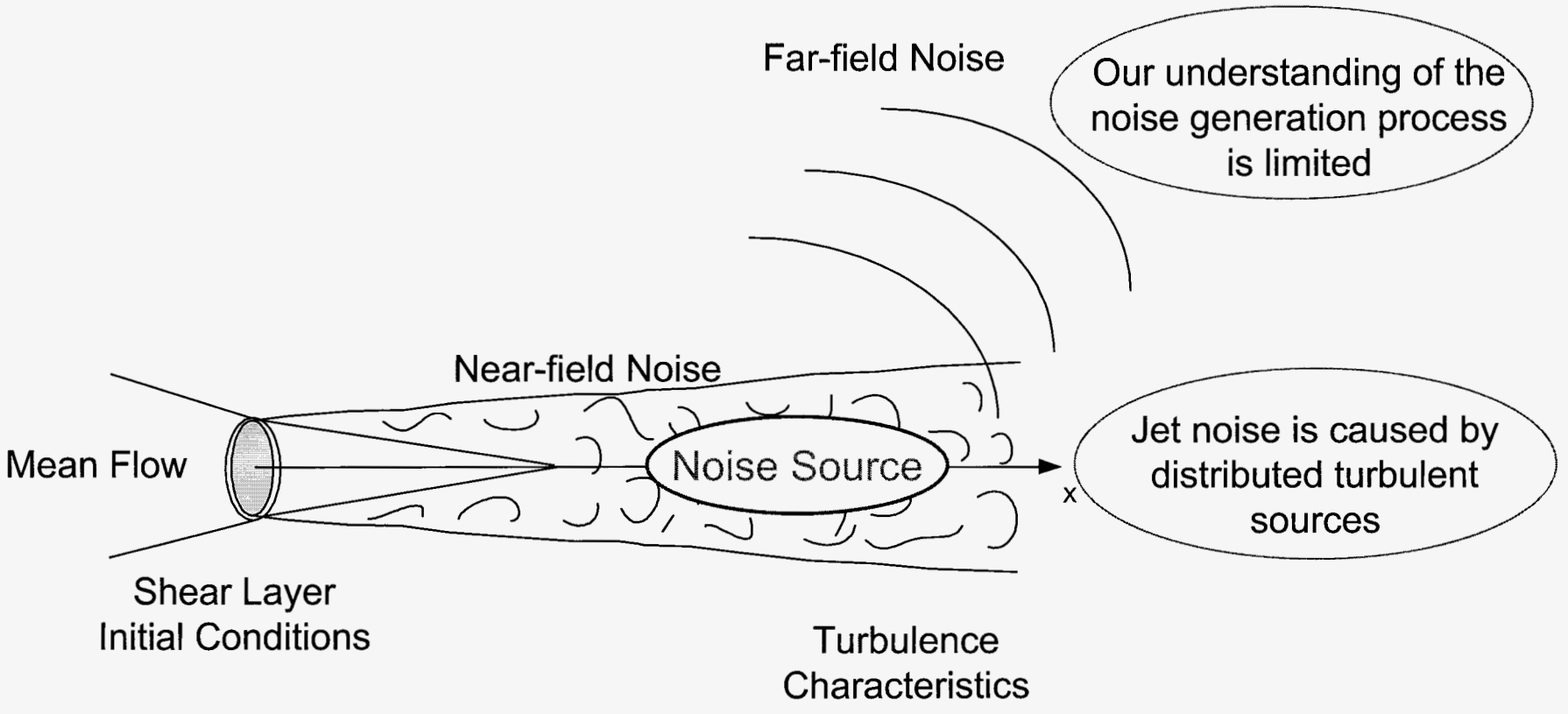
Abstract:
Until recently, the design of jet engines for quiet operation was limited by engineers' ability to predict the jet noise generated by a nozzle exhaust system. More importantly, the 'intermediate steps' between nozzle design and noise had not been understood, limiting the design process to small variations around existing solutions. In recent years NASA's Quiet Aircraft Technology (QAT) Program has advanced the understanding and modeling of jet noise to give engineers the tools they need to design quiet nozzle systems for subsonic exhaust systems. The presentation discusses the approach followed for QAT and argues that a similar effort aimed at supersonic jet exhaust systems will be needed to allow designs of quiet military aircraft in the future.

NASA's Vision for Jet Noise Engineering

Dr. Kevin W. Kinzie
Dr. Brenda S. Henderson
NASA Langley Research Center

Dr. James E. Bridges
NASA Glenn Research Center

Jet Noise Problem



A comprehensive understanding of jet flowfield is at the heart of any jet noise reduction strategy

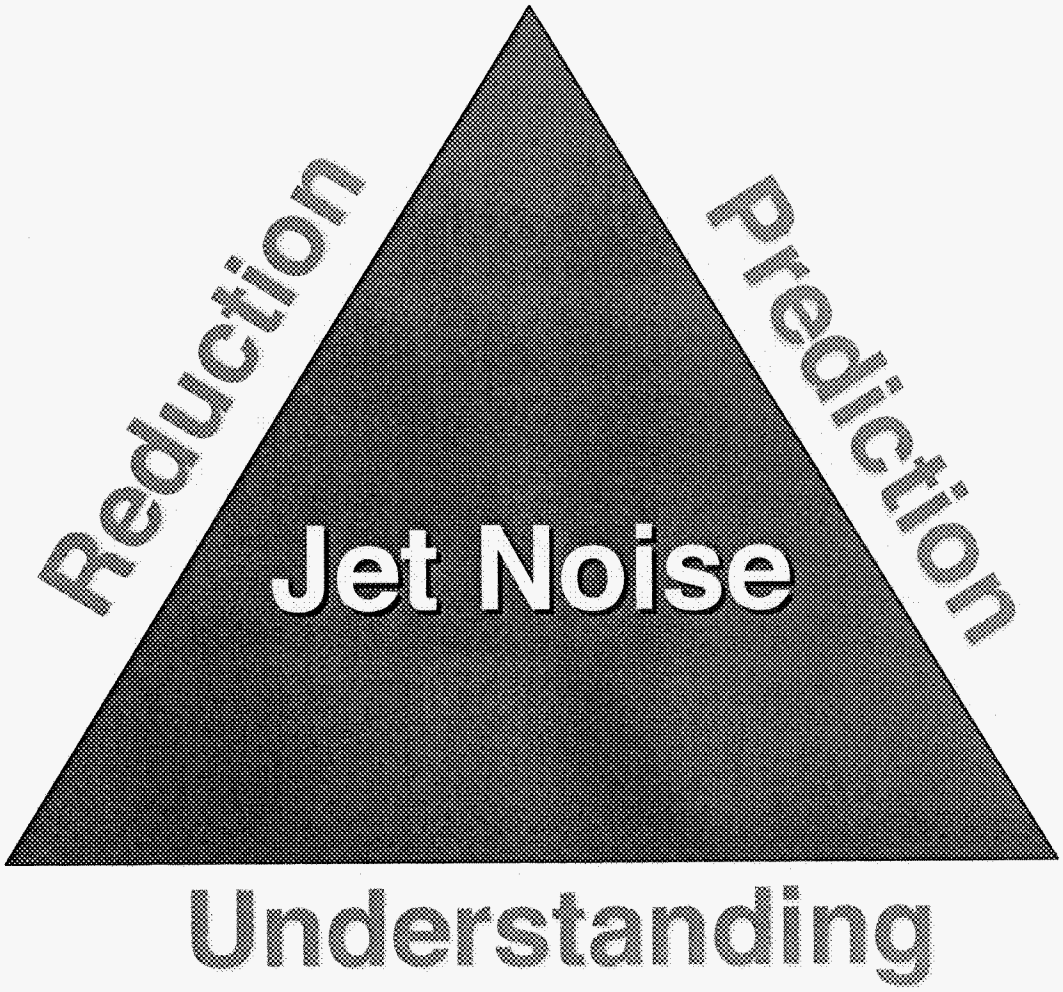
Global Scaling Laws

Single most effective jet noise reduction technique is to reduce the jet velocity

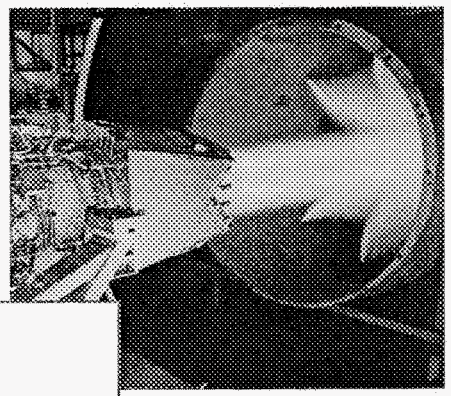
$$SPL \propto 10\log\left(\frac{\rho_j^2 D_j^2 U_j^8}{\rho_\infty c_\infty^5}\right)$$

This level of knowledge will not allow us to design a quiet aircraft

Jet Noise Focus Areas

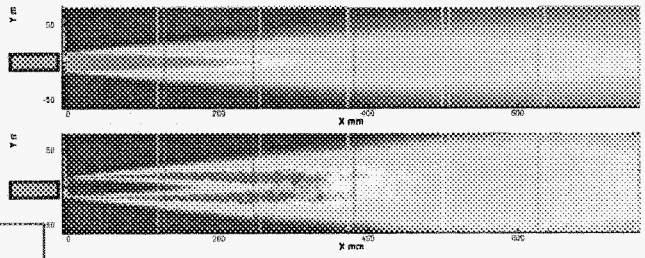


Jet Noise Research Paradigm



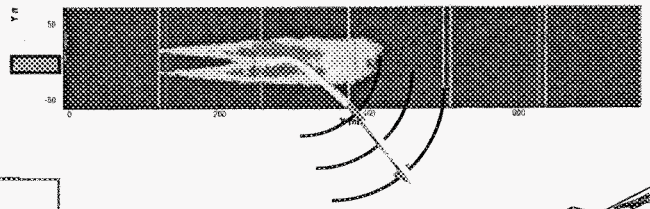
Thrust

Engine Cycle
Geometry
Active control



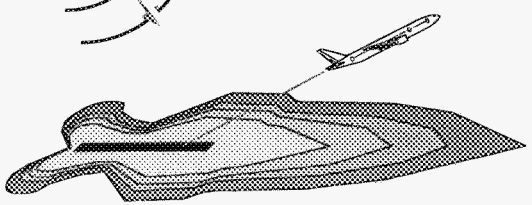
Turbulence

Anisotropy
Spectral shift
Modal content



Acoustic Source Strength

Directionality
Shielding
Atmospheric atten



Noise

Reduction

NASA Jet Noise Objectives

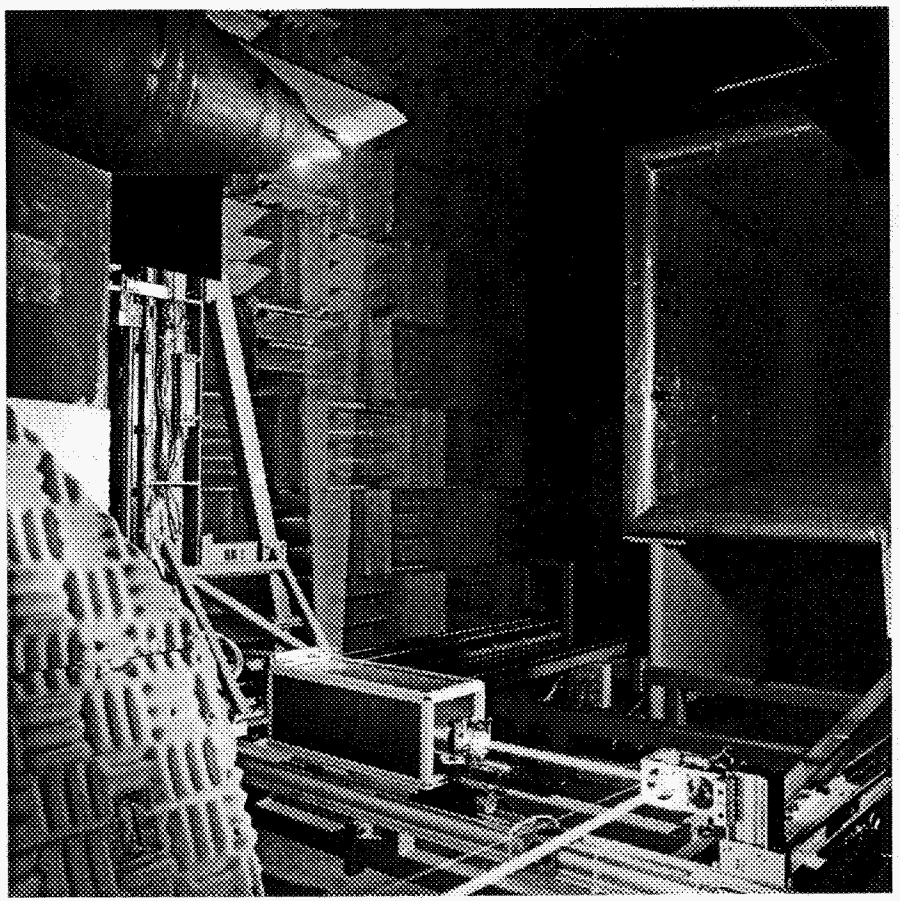
1. Develop diagnostic and analytical tools to Understand jet noise mechanisms
2. Create physics-based Predictive tools for general subsonic jets—flow and noise.
3. Use Understanding to create noise Reduction concepts and use Predictive tools to guide experiments.

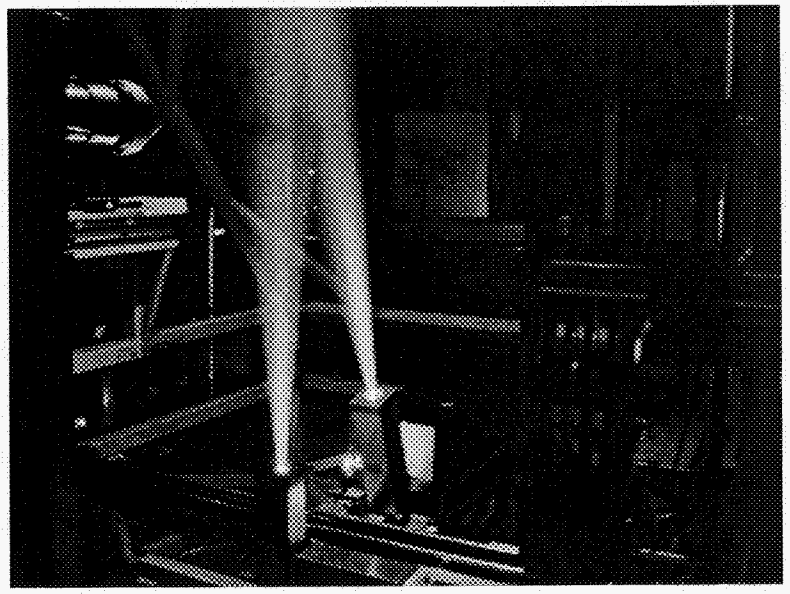
We are pursuing these objectives in the subsonic Quiet Aircraft Technology program

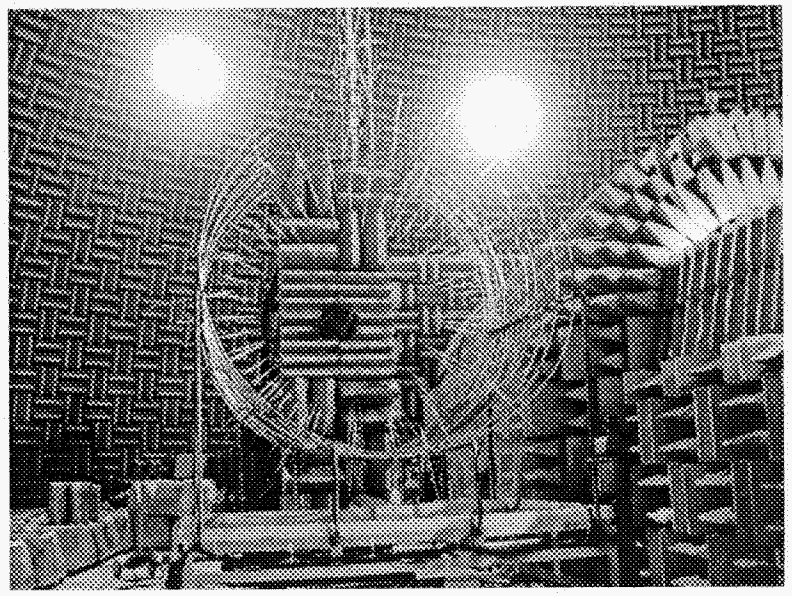
Fundamental Understanding

- Fundamental Understanding
  - How do jets make noise?

Advanced Measurement Techniques



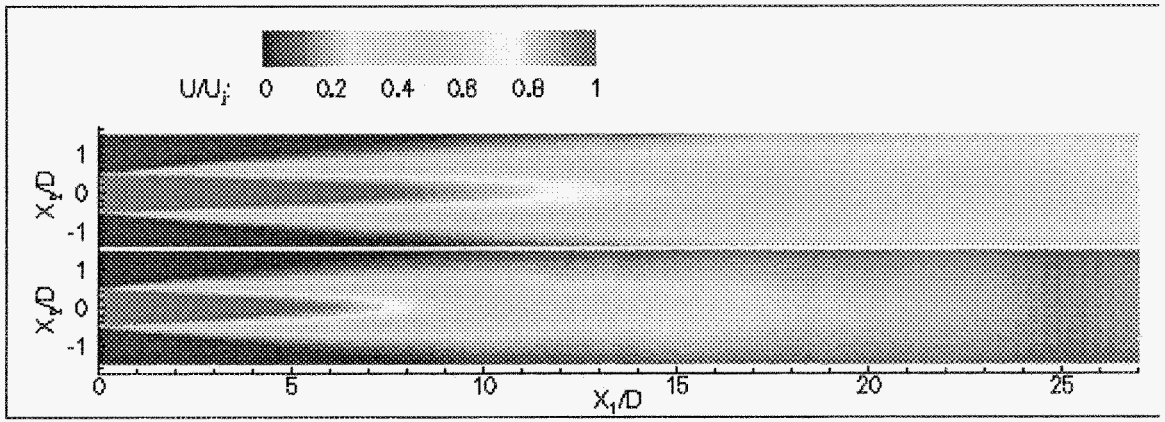




Effect of Temperature on Jet Flow

Mj = 0.9

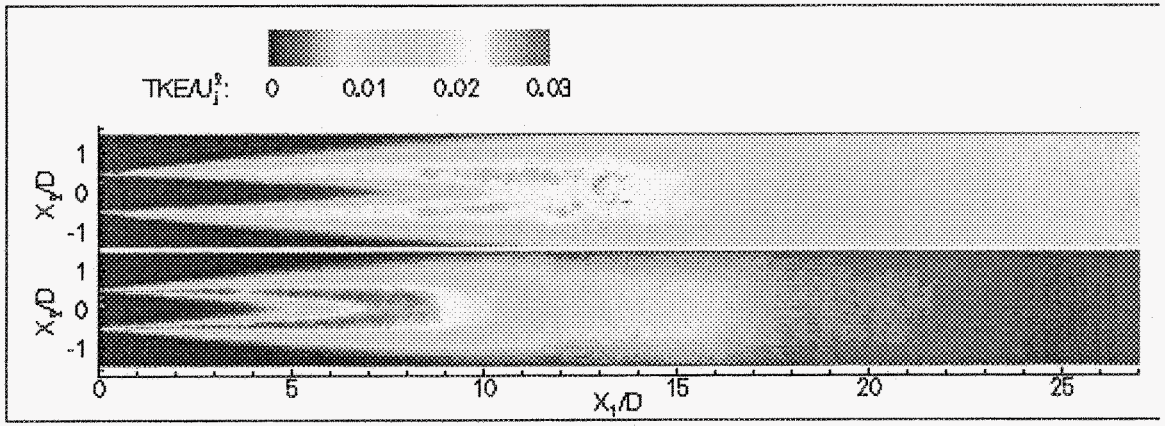
Velocity



Cold

Hot

Turbulent Kinetic Energy



Cold

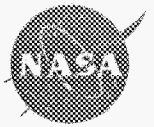
Hot

Important to account for temperature effects in modeling and experiment

Jet Noise Prediction

- Jet Noise Prediction
  - What is the flow and acoustic fields produced by a given nozzle with specified cycle conditions?

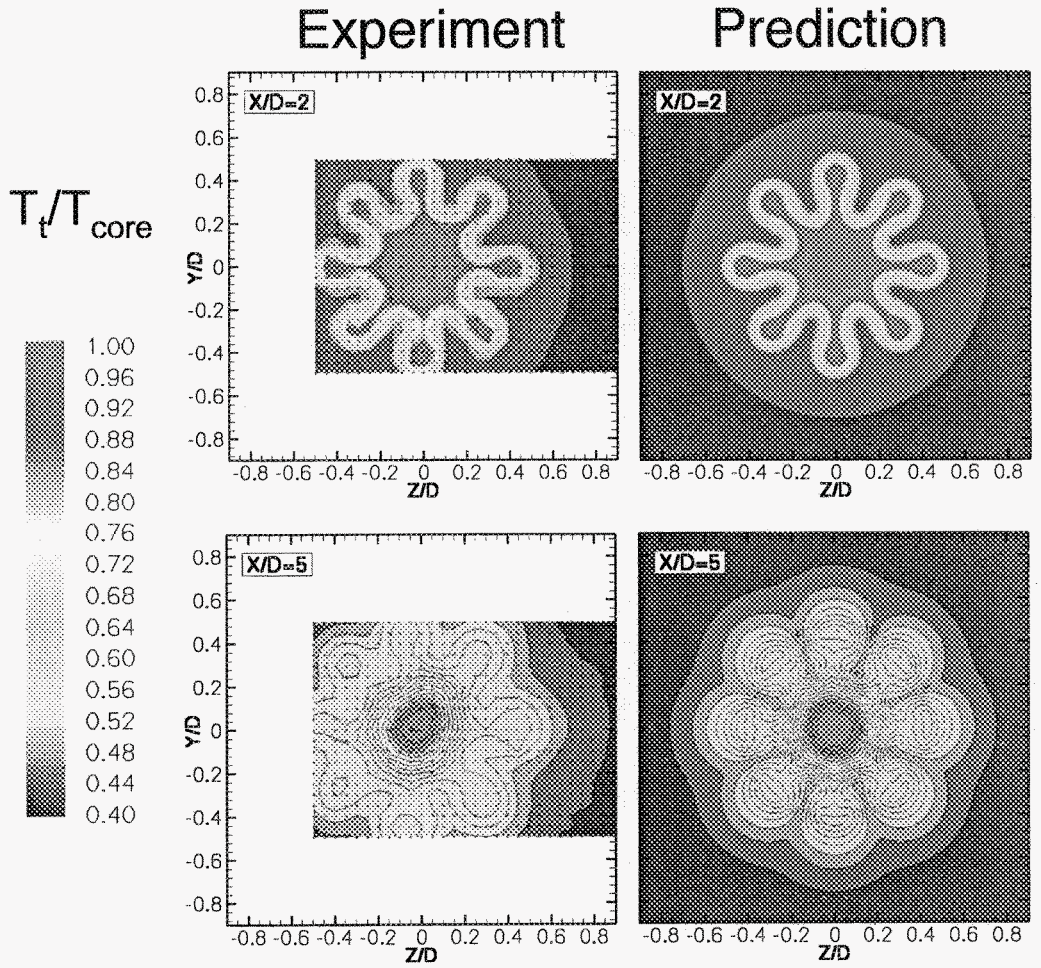
Levels of Prediction Codes



- Empirical correlation with nozzle conditions
  - NOISEMAP, ARP, SAE, ANOPP
  - Database interpolation (Noise, Power, Distance)
  - All cases approximated as simple round nozzle
- Time-averaged physics-based codes
  - Jet3D, MGBK
  - Reynolds-averaged NS + acoustic analogy
  - Can handle unique configurations
- Time-dependent full-physics codes
  - LES, DNS
  - Discrete versions of Navier-Stokes
  - Info overload; infinite cost

CFD Flowfield Prediction

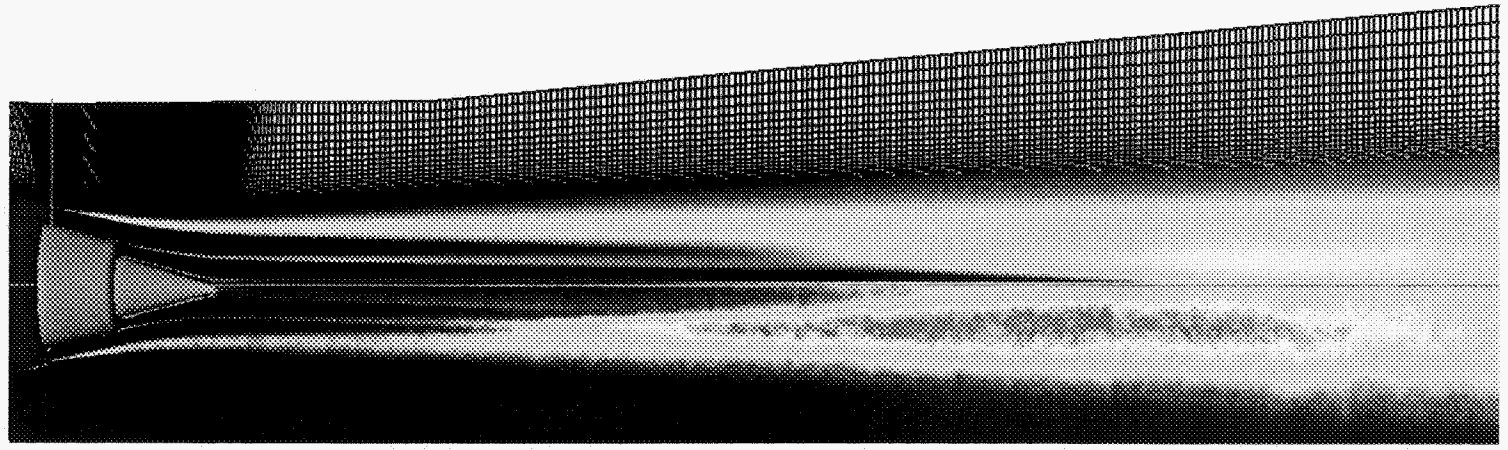
Cross-section of Chevron Flow



Good mean flow predictions

CFD Flowfield Prediction

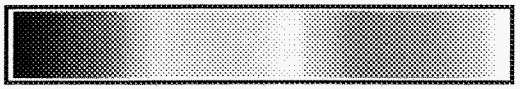
Turbulent Kinetic Energy of BPR 5 Separate Flow Nozzle



Prediction

Experiment

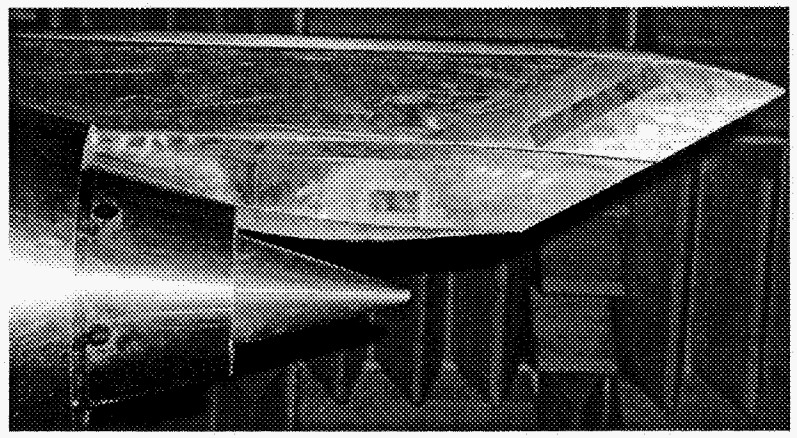
Turbulent Kinetic Energy (m^2/s^2)

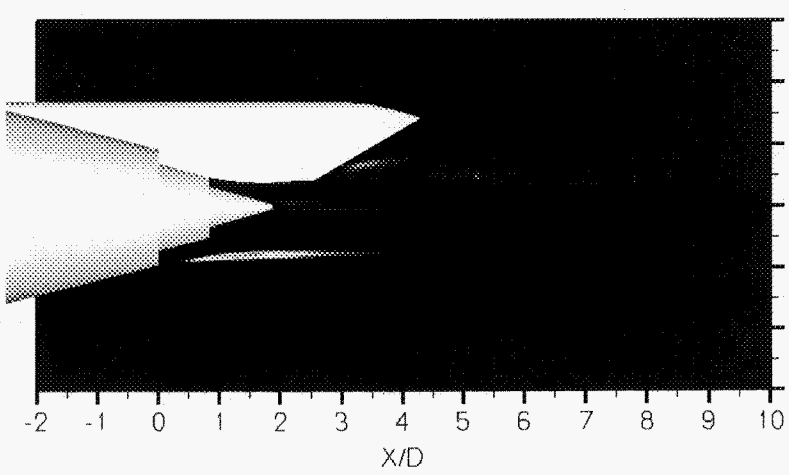


0 2500 5000

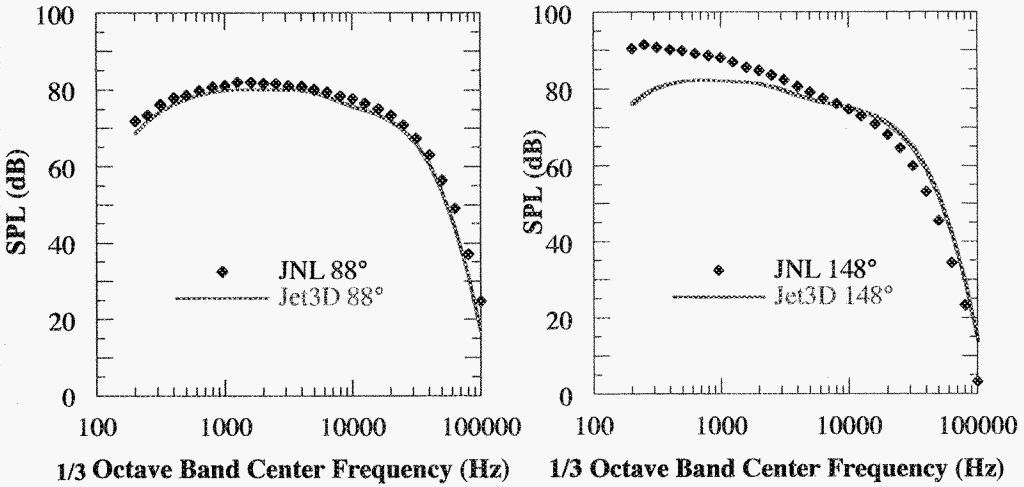
Prediction of turbulence quantities still deficient

Aeroacoustic Noise Prediction





Acoustic Source Density Prediction



Far-field Acoustic Prediction

BPR = 5

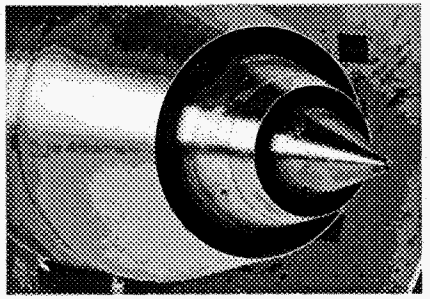
Takeoff Conditions

NASA is currently developing several CAA type codes

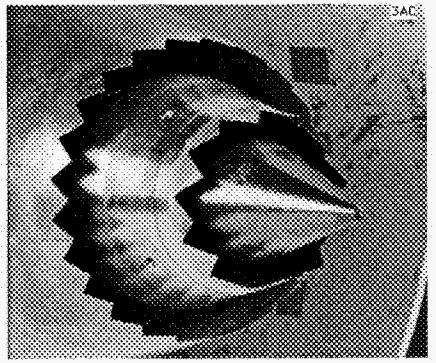
Noise Reduction Concepts

- Noise Reduction Concepts
  - How should jet be modified to reduce noise?

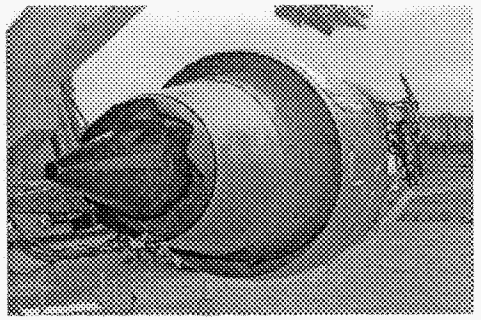
Chevron Mixing Devices



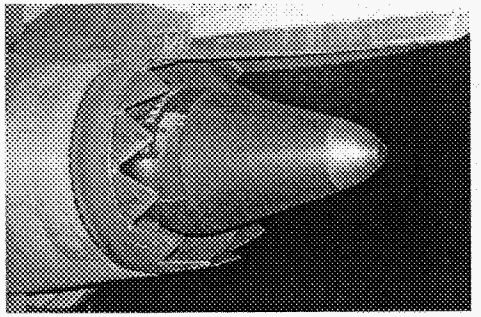
Baseline Nozzles (Flying Now)



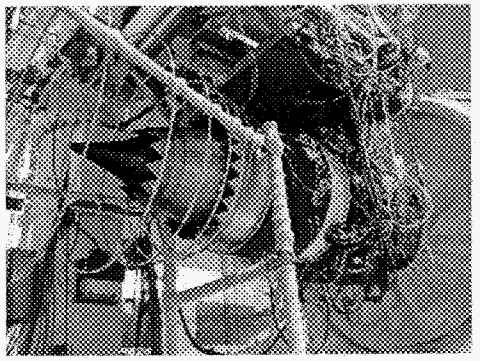
1997 Model Tests Chevron Nozzle



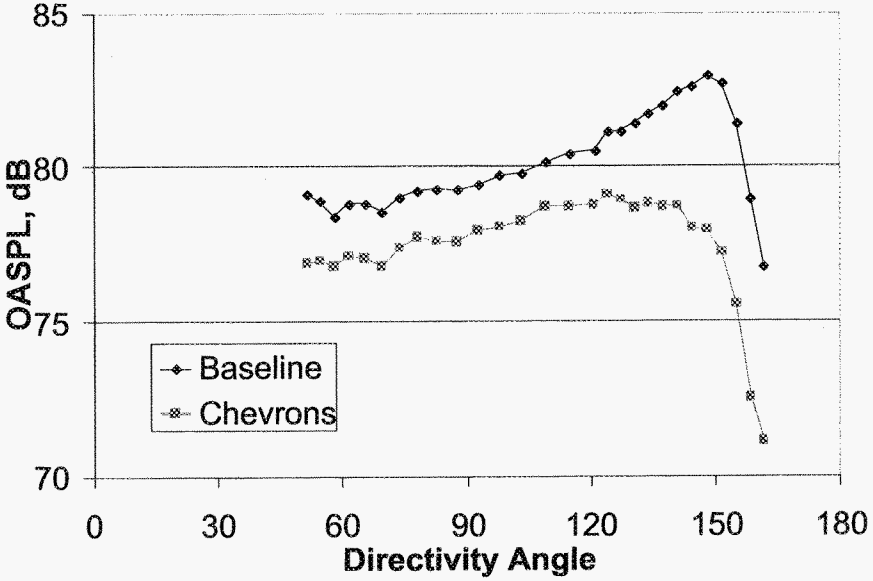
GE CF34 Engine



GE CF6Engine

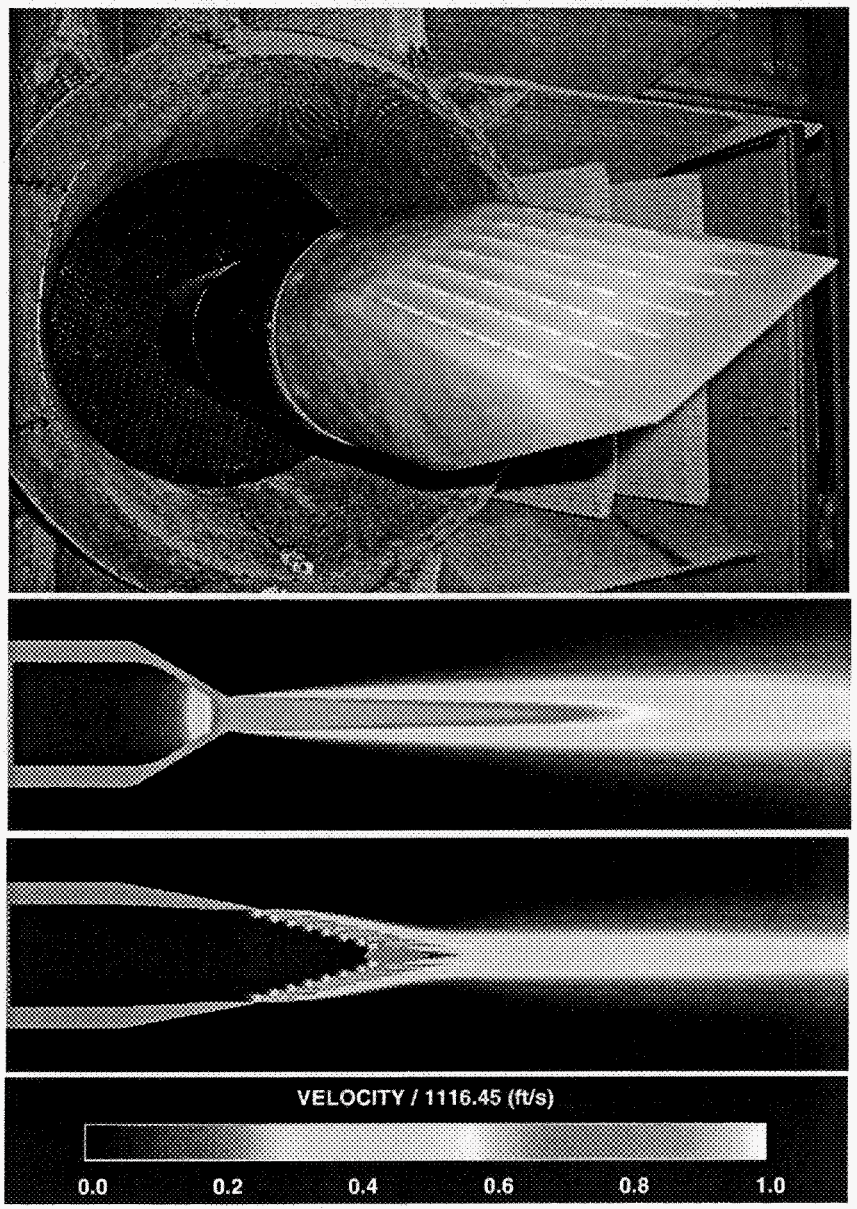


Honeywell TFE731-60 Engine

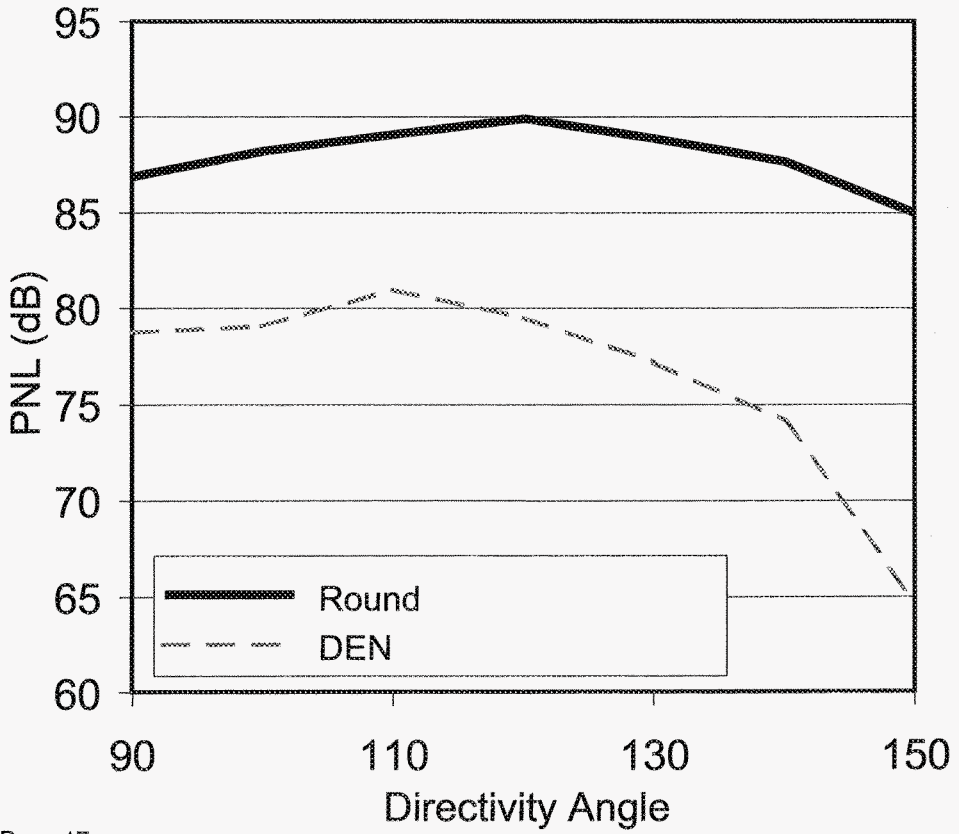


3 EPNdB Jet Noise Reduction!

Distributed Exhaust Nozzle



Use CFD and testing to optimize DEN thrust and acoustic performance



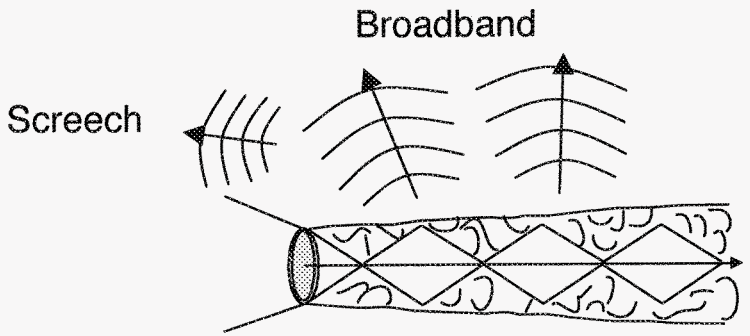
How Would NASA Approach Supersonic Jet Noise Reduction?

Extending Approach to Supersonics

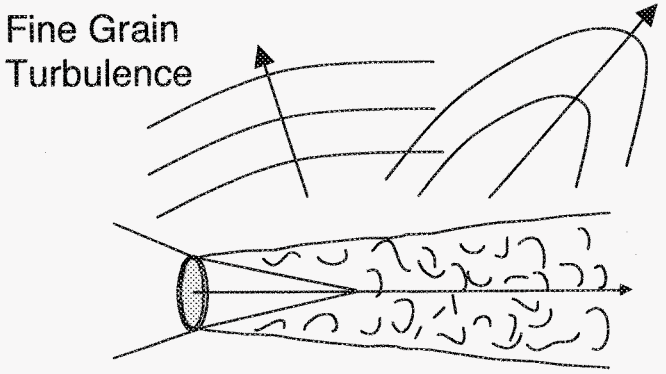
- Develop an understanding of unique supersonic noise sources and propagation
- Include additional sources in prediction tools
- Extend experimental facilities and validate techniques at higher pressure and temperature flows to test noise reduction concepts.

High Speed Jet Noise Sources

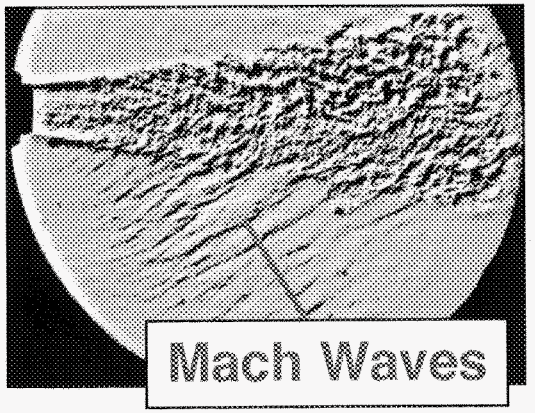
Shock Noise



Mixing Noise



- Mixing noise
- Mach wave radiation
- Shock associated noise
- STOVL noise/tones



Courtesy of D. Papamoschou

Prediction and noise reduction technology must address each of these depending on flight regime

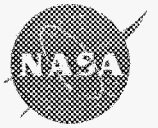
Critical Military Jet Characteristics

Exhaust Temperature – **HOT !!!**

Velocity Profile – **Non-Uniform**

These effects MUST be correctly represented to provide research relevant to military aircraft

Suggested Plan for Noise Reduction



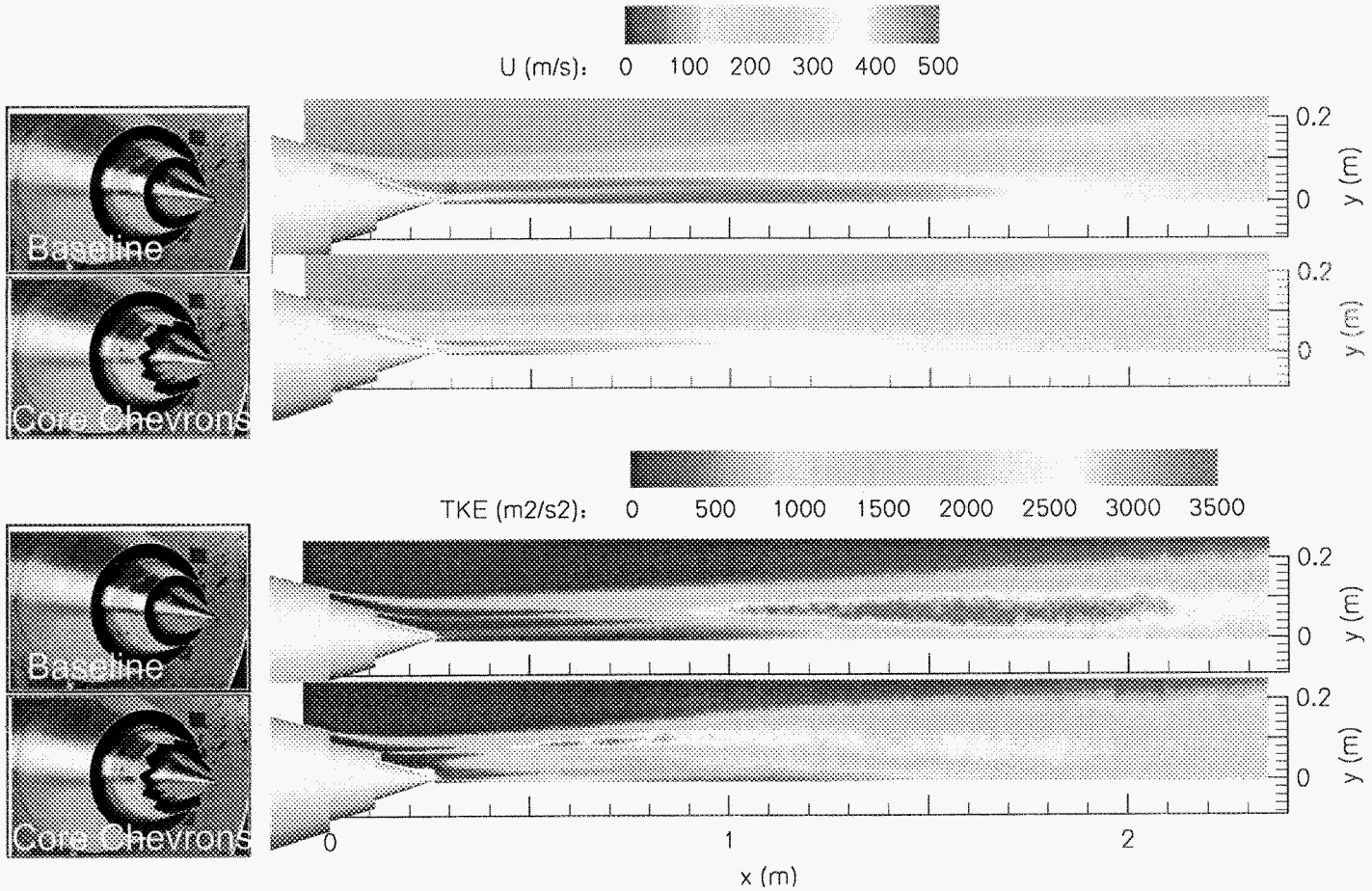
- Identify specific areas of need as they relate to aircraft mission
- Develop tools to predict shock associated and Mach wave emission noise
- Couple aeroacoustic modeling and experiments to identify and validate noise reduction concepts

Implement balanced research tasks that address understanding, predicting, and reducing supersonic jet noise

Backup Charts

Chevron Mixing Devices

Plume Turbulence is the Main Source of Jet Noise



Mean Jet Velocity is Reduced

Plume Turbulence is Reduced