Acoustic Interests and Activities of the US Navy

Russell Powers, Ph. D.
Naval Air Systems Command
Propulsion and Power
Russell.w.powers@navy.mil

Steve Martens, Ph.D.
Program Officer
Office of Naval Research
Code 35, Air Warfare and Weapons
Steven.Martens@Navy.Mil

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SYMPOSIUM
2018 | Enhancing DoD's Mission Effectiveness

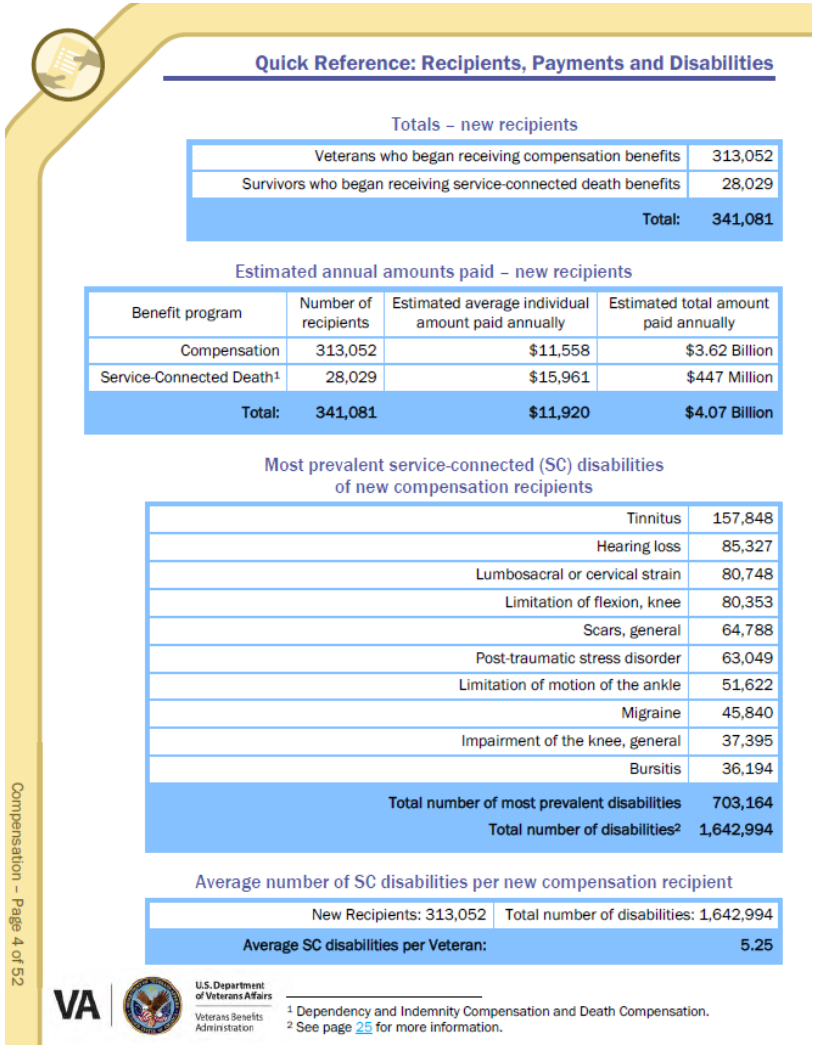
Outline

- Navy Environment
- The Cost of Hearing Loss
- Commercial vs Tactical Aircraft Engines
- Where Does Noise Come From?
- How to Deal With it
- What we are Doing
- Challenges
- Navy Capabilities
- Funded Programs
- Summary

Why am I Here?

The Cost of Hearing Loss

- Tinnitus and Hearing Most Prevalent Disabilities
- Hard to determine cost – estimates over a billion a year
- Additional Impacts to Operations/Communications etc…



Quick Reference: Recipients, Payments and Disabilities

Totals – new recipients

Veterans who began receiving compensation benefits	313,052
Survivors who began receiving service-connected death benefits	28,029
Total:	**341,081**

Estimated annual amounts paid – new recipients

Benefit program	Number of recipients	Estimated average individual amount paid annually	Estimated total amount paid annually
Compensation	313,052	$11,558	$3.62 Billion
Service-Connected Death[1]	28,029	$15,961	$447 Million
Total:	**341,081**	**$11,920**	**$4.07 Billion**

Most prevalent service-connected (SC) disabilities of new compensation recipients

Tinnitus	157,848
Hearing loss	85,327
Lumbosacral or cervical strain	80,748
Limitation of flexion, knee	80,353
Scars, general	64,788
Post-traumatic stress disorder	63,049
Limitation of motion of the ankle	51,622
Migraine	45,840
Impairment of the knee, general	37,395
Bursitis	36,194
Total number of most prevalent disabilities	**703,164**
Total number of disabilities[2]	**1,642,994**

Average number of SC disabilities per new compensation recipient

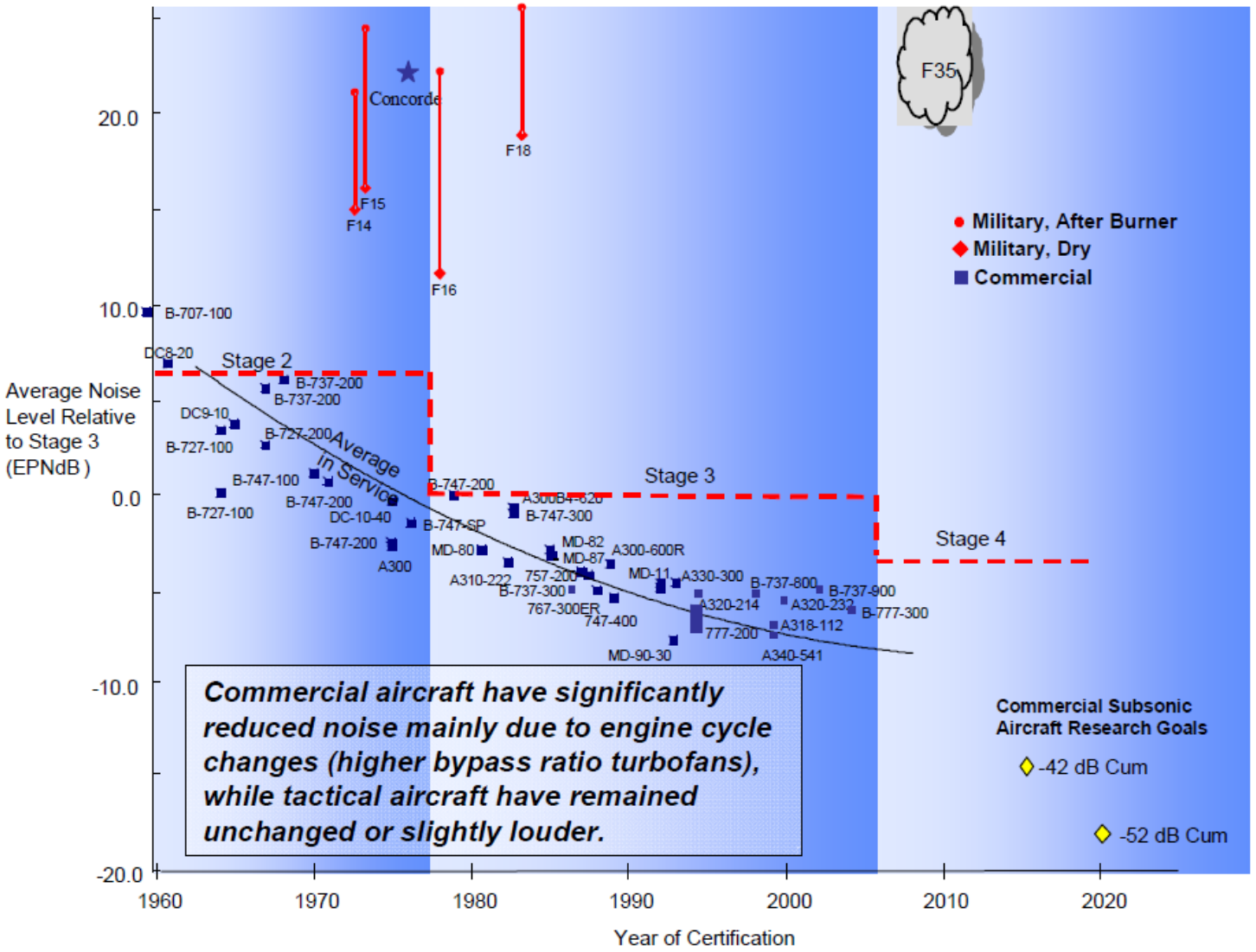
New Recipients: 313,052	Total number of disabilities: 1,642,994
Average SC disabilities per Veteran:	**5.25**

VA U.S. Department of Veterans Affairs Veterans Benefits Administration

[1] Dependency and Indemnity Compensation and Death Compensation.
[2] See page 25 for more information.

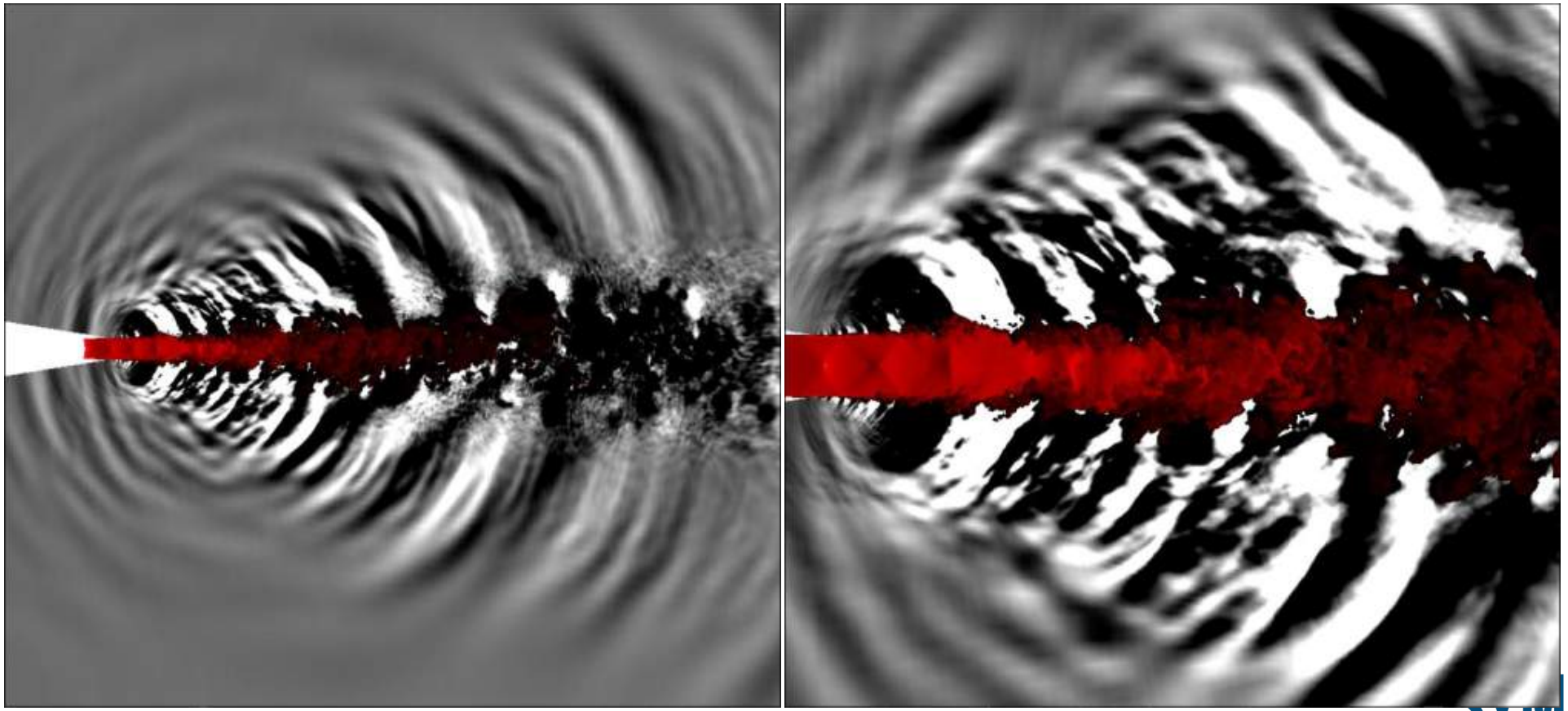
Compensation - Page 4 of 52

Commercial vs Tactical Aircraft Engines



Where Does Jet Noise Come From?

Visualization of sound waves radiated from an over-expanded hot supersonic jet;
Tr=1.74,Mjet= 1.35



How to Deal With It

- Source
  - Reduce Jet Velocity
  - Enhance Jet Mixing (like Chevrons)
  - Other Methods Show Promise in Laboratories, but need Further Development
- Path
  - Hearing Protection
  - Acoustic Enclosures/Barriers
- Operations
  - Minimize Exposure Time
  - Noise Abatement Procedures

How to Deal With It

Chevrons
In Service On Commercial Engines
Struggling to Transition

What We Are Doing

- USN Has a Noise Induced Hearing Loss Program
- Hearing Protection and Communications are being worked
- ONR Code 35 Has an S&T Jet Noise Reduction Program
  - Consistent Funding
  - Working Simulations (Prediction), Diagnostics and Noise Reduction Technologies
  - Collaborating with AF and NASA where possible
    - Full Scale Measurements, Diagnostics, Simulations

Challenges

- No Requirement or KPP
  - Noise is not considered in design/development
- Unable to trade capability for noise
  - Much harder to apply a band-aid
- Hard Problem – Physics are Physics
  - These are the highest performance aircraft
- Commercial Engines Have Designed Jet Noise out of the picture
  - High Bypass Ratio Lowers the Exhaust Velocity and is good for fuel efficiency
  - Commercial Noise Certification Requirements Continue to Become More Stringent
- $$

Navy Capabilities – NRL – High Fidelity Simulations

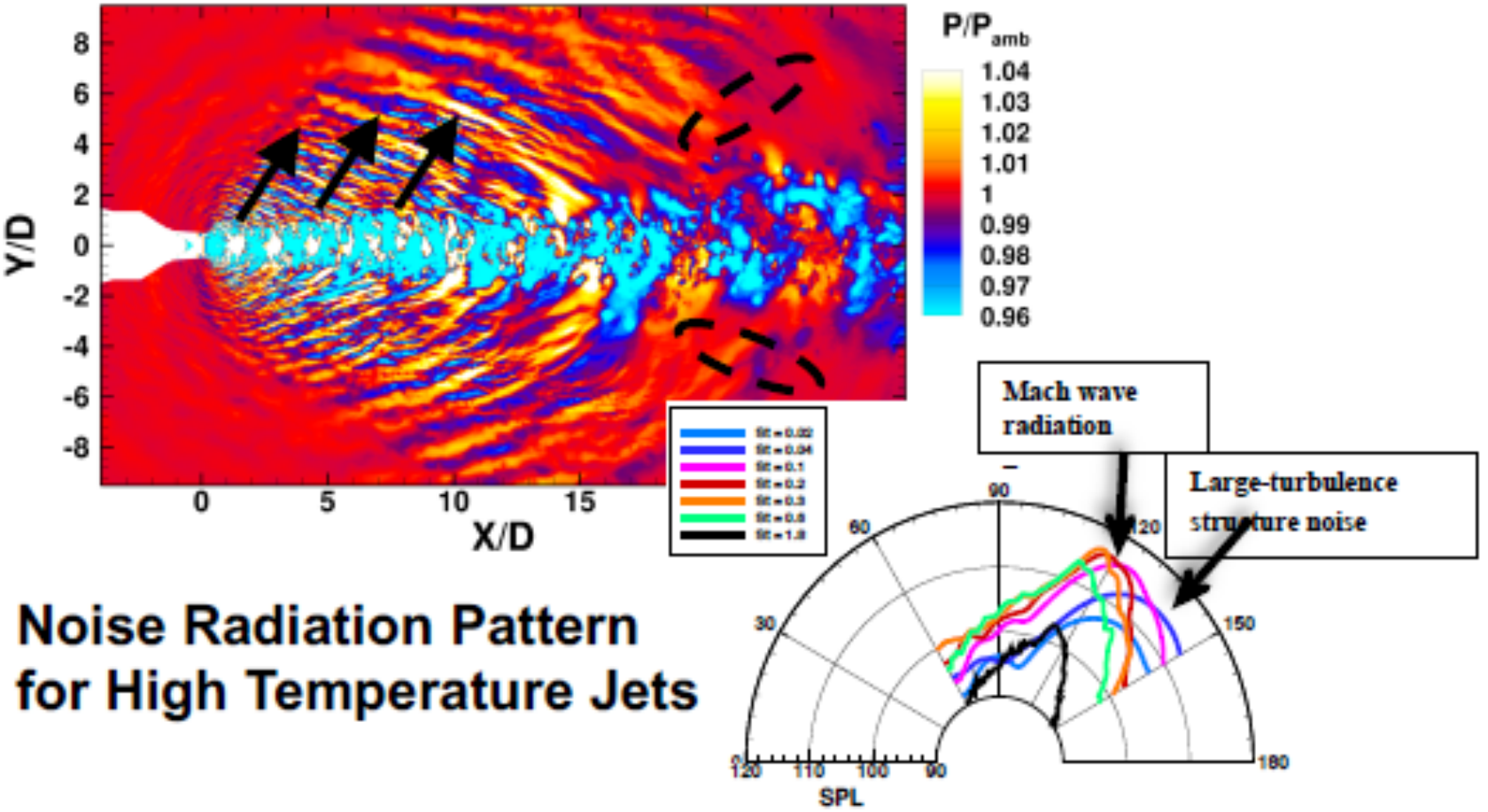
Objective/Description

– Develop , validate and apply a high-fidelity, modeling and simulation tool (called JENRE) for jet noise characterization, prediction, reduction and optimization.

Key Technologies

– Fundamental insight into sources and directivity of jet noise during Naval operations.

– Validated prediction tool for future low-noise designs.



Noise Radiation Pattern for High Temperature Jets

Navy Capabilities – NAVAIR – Full Scale Measurements and Data Analysis

Objective/Description

– Develop improved test planning guidelines / procedures / best practices for outdoor, full scale supersonic military jet noise measurements.

– Review full scale jet noise data taken on F/A-18E and F-35 and contrast and compare results.

– Develop feedback for ANSI S12.75 jet noise measurement standard committee for update of standard procedures.

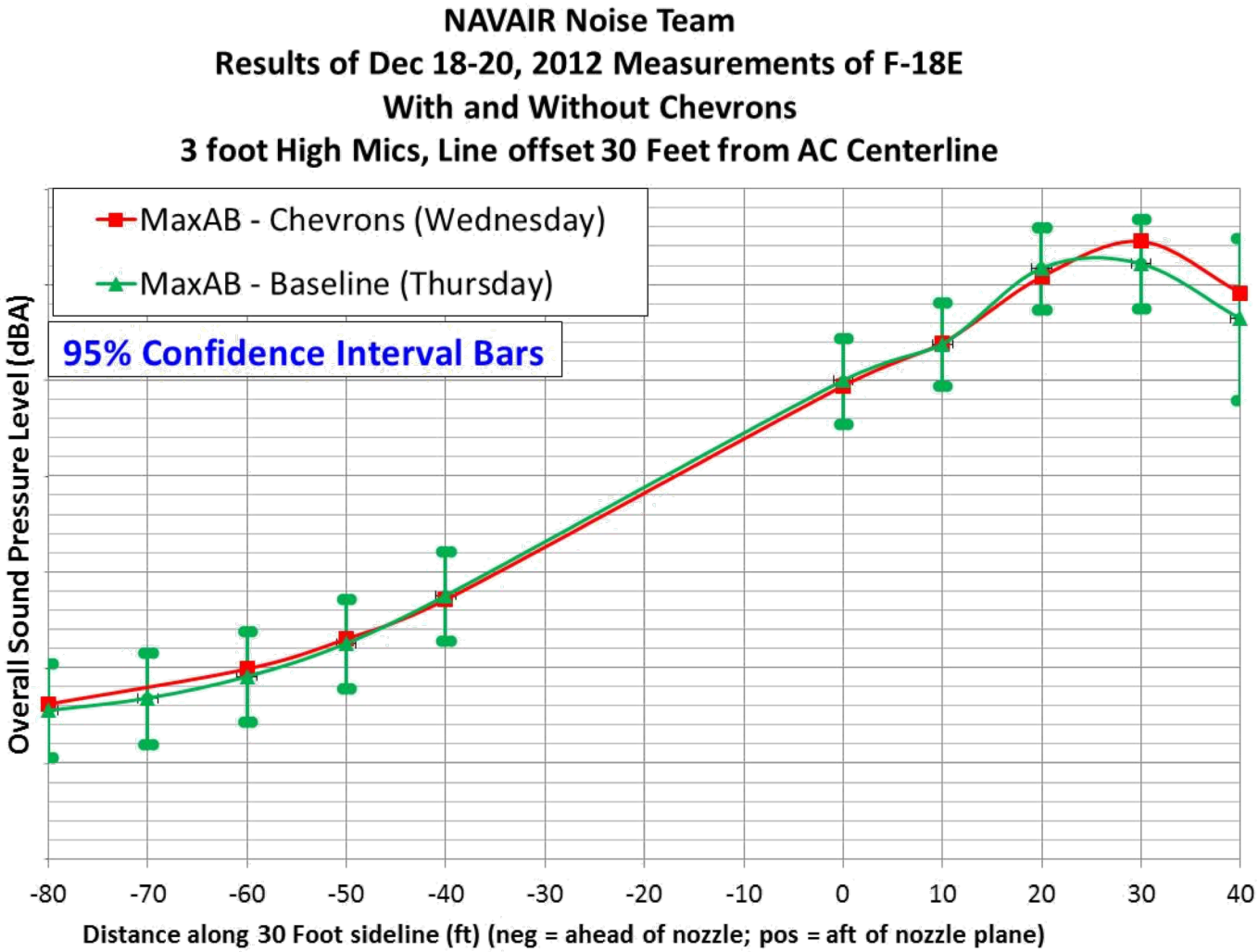
Key Technologies

– Outdoor jet noise measurement equipment and procedures leading to accurate, reliable, repeatable outdoor noise measurement results

NAVAIR Noise Measurements - Proving the Difference

- In 2012 ONR/NAVAIR and F/A-18 program office funded development of 1st intentional noise reduction treatment for supersonic military aircraft: Chevrons.
  - Aircraft testing is expensive! (~$30K/hour + + + +)
- ProNTO supported noise measurements under internal funding using current best practices.
- Challenge – prove Chevrons make a difference in back-to-back experiments.

NAVAIR Noise Measurements - Proving the Difference

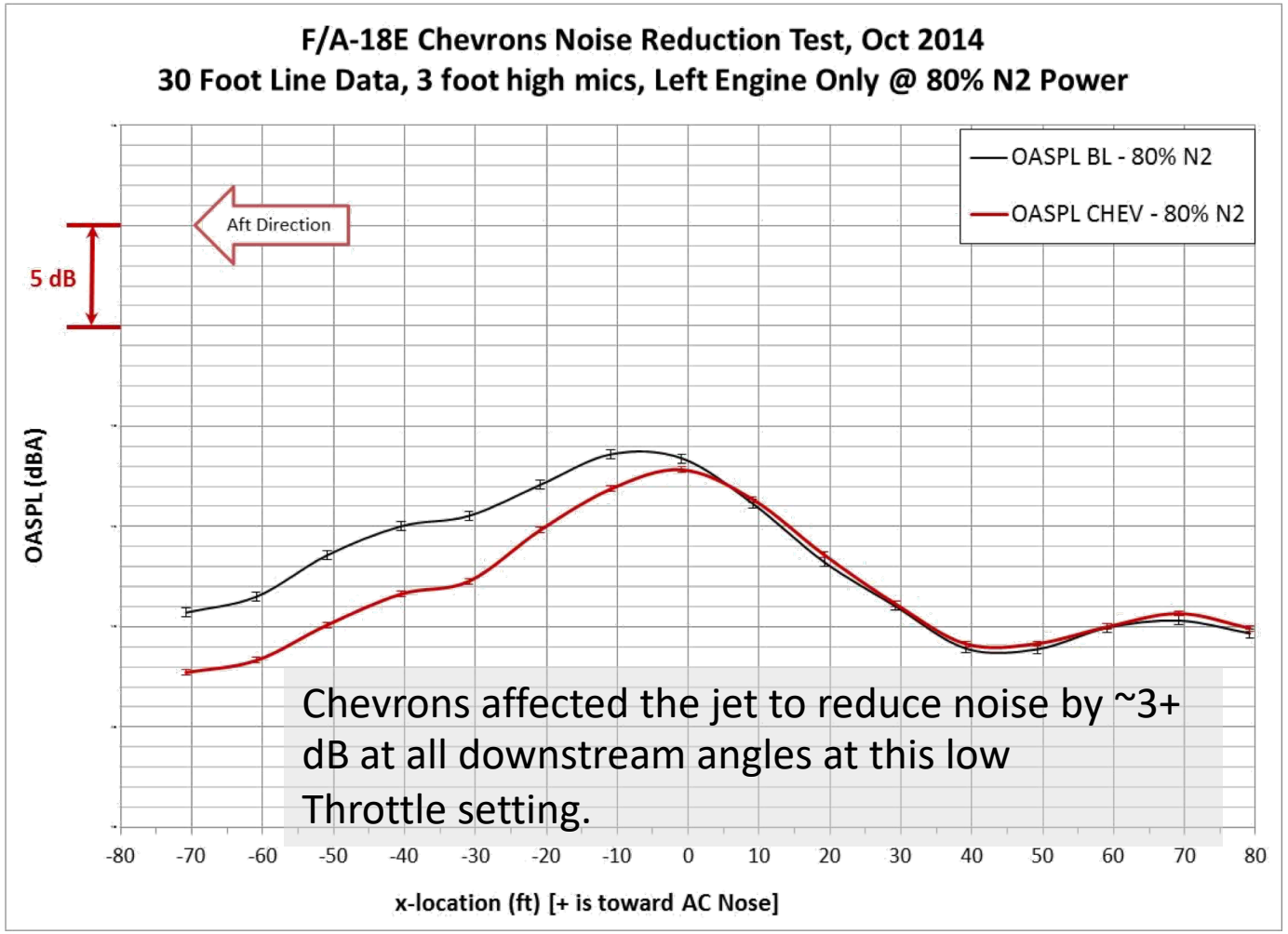


- We estimated 95% confidence interval: ± 2.8dB at the time – it's actually higher
- ANSI S12.75 standard interval is **± 5.8dB**
- Any difference within range is ***statistically insignificant*** when following minimum recommendations of ANSI S12.75-2012

NAVAIR Noise Measurements - Proving the Difference

- Program office not happy with that answer!
- Even if actually was a 3dB improvement – would not have been able to resolve it with those test methods – even though they were industry best practices! NOT GOOD ENOUGH!
- Dug into ANSI S12.75 Annex A and evaluated all the assumptions we had made – test plan, test limits
- **Key contributors to uncertainty in outdoor supersonic aircraft noise measurements:**
  1. **Wind** – causes noise source location to move – changes propagation pattern – different distortion test to test – (in 2012 moved from West to East between test days)
  2. Test Aircraft throttle setting is not scientifically repeatable – pilot difference, engine condition, FADEC, engine warmup
  3. Number of repeats
  4. Temperature gradients from sun, etc.

NAVAIR Noise Measurements – Chevrons Noise Reduction



- **2014 Program Office made new plans to retest**
- Much more careful sculpting of test plan & test limits. PMA chose Lakehurst (LKE)
  - Ability to test at night
  - Best wind
  - No temperature gradient
  - Low background noise & EMI
- Planned for max repeats within fuel budget –
- Went to single engine + careful recording of engine parameters, corrected for thrust using cycle deck
- **RESULT: Answers ± 0.22 dB 95% Confidence Interval between measurements**

ONR – Funded Programs

- Krish Ahuja – Ga Tech ‘Development of Noise Prediction Design Tools for Future Multi-Stream, Low-Noise Tactical Aircraft (TACAIR) Engine Exhaust.
- Todd Lowe – Va Tech ‘Turbulence Development in Non-Uniform, Heated Supersonic Jets for Noise Reduction’
- Tim Colonius – Cal Tech ‘Next Generation Jet Noise Models For Complex Geometry Nozzles’
- Steve Miller – U of Florida ‘Turbulent Statistics and Associated Acoustic Sources Near Shock Wave Shear Layer Interactions’
- Datta Gaitonde – OSU ‘Noise Generation Mechanisms in Imperfectly Expanded & High Speed Jets’
- Tony Pilon – LM ‘Acoustical Assessment of the Spiritech STAR Nozzle Concept

ONR – Funded Programs

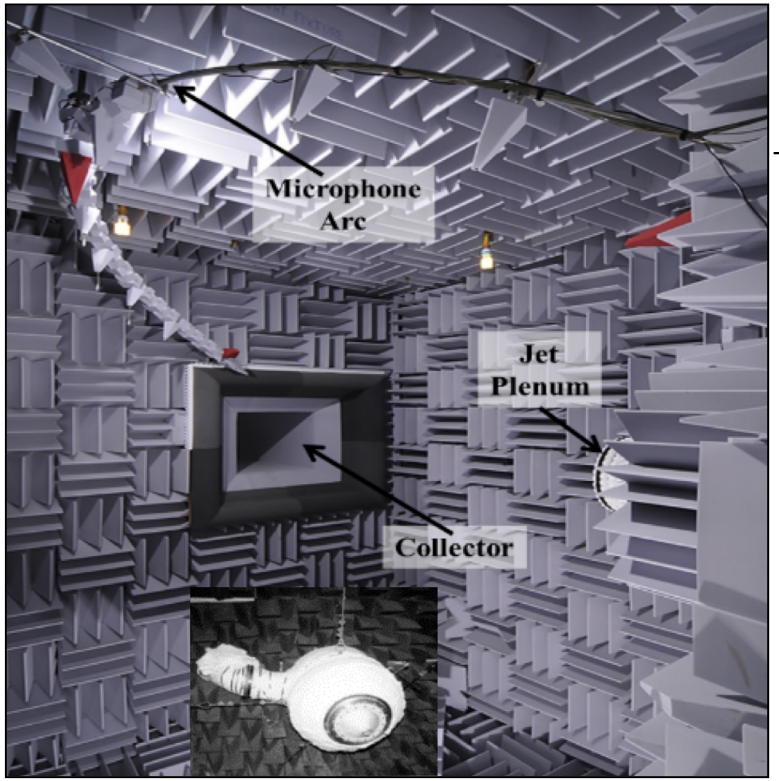
Krish Ahuja – Ga Tech 'Development of Noise Prediction Design Tools for Future Multi-Stream, Low-Noise Tactical Aircraft (TACAIR) Engine Exhaust.'

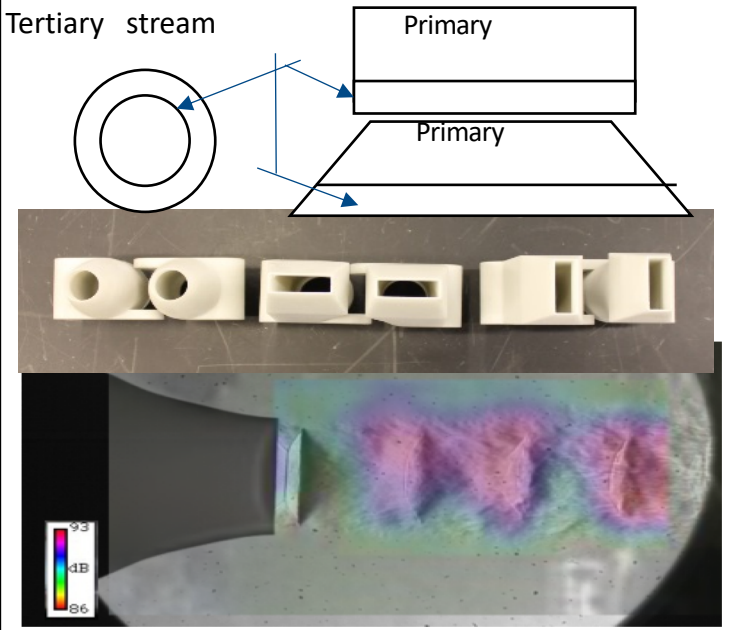
Objective/Description

Acquire a relevant jet-noise database for coannular and non-coannular multi-stream jets operated at representative tactical aircraft exhaust conditions[1] to develop a semi-empirical noise prediction tool for representative carrier deck locations and in the far-field, for static jets[2] under the Base Phase

Payoffs/Key Technologies

See items 1 and 2 above





ONR – Funded Programs

Todd Lowe & Wing Ng– Va Tech 'Turbulence Development in Non-Uniform, Heated Supersonic Jets for Noise Reduction'

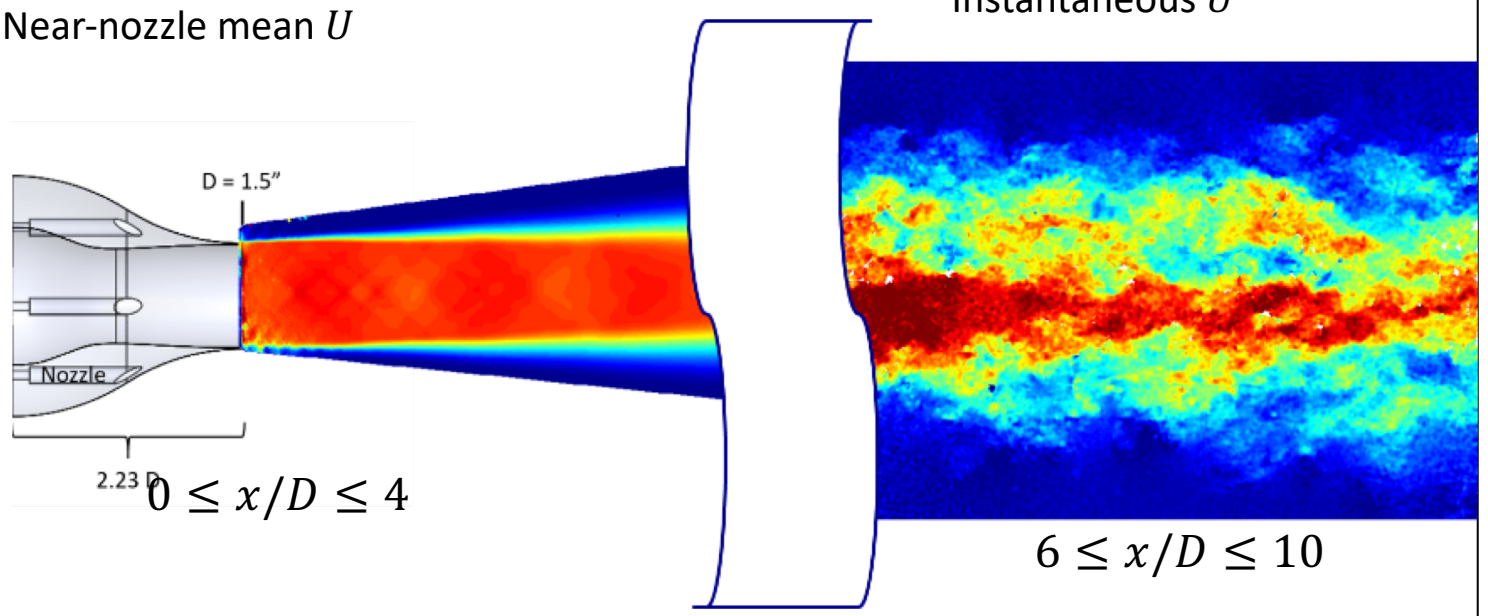
Objective/Description

Experimental study of space/time plume turbulence characteristics for interpretation of full-scale results

Payoffs/Key Technologies

Plume turbulence info for noise prediction and reduction, computational validation

Scalable flow diagnostics



Measurements can relate nozzle exit profiles to turbulence development.

ONR – Funded Programs

Tim Colonius – Cal Tech 'Next Generation Jet Noise Models For Complex Geometry Nozzles'

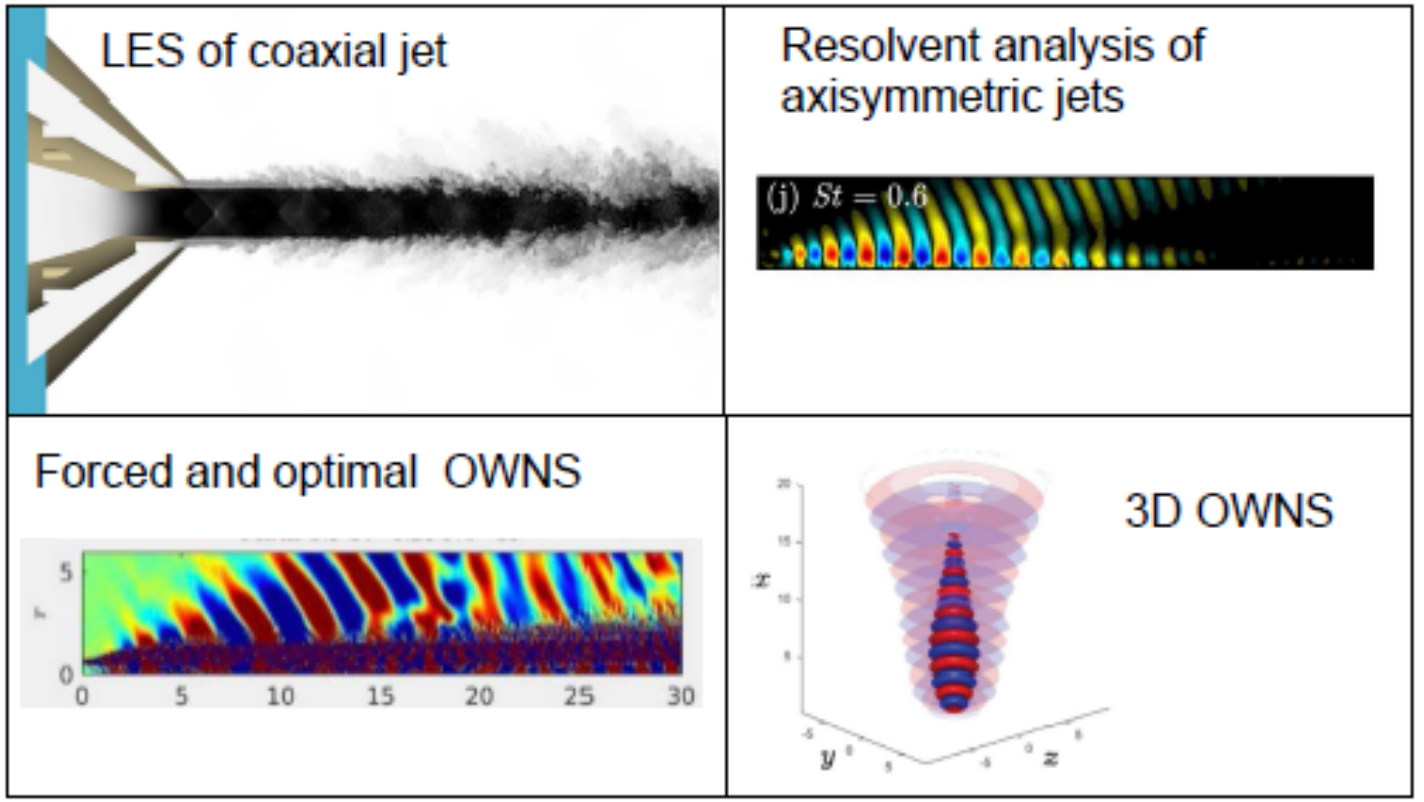
Objective/Description

– Development of accurate, next-generation reduced-order models for the mixing noise of supersonic jets issuing from complex nozzle geometries

Key Technologies

– Stochastically forced fast solvers for turbulence structure and radiated sound.

– Advanced methods for fast, spatial integration of the linearized Navier-Stokes equations (**O**ne-**W**ay **N**avier-**S**tokes equations, OWNS)



ONR – Funded Programs

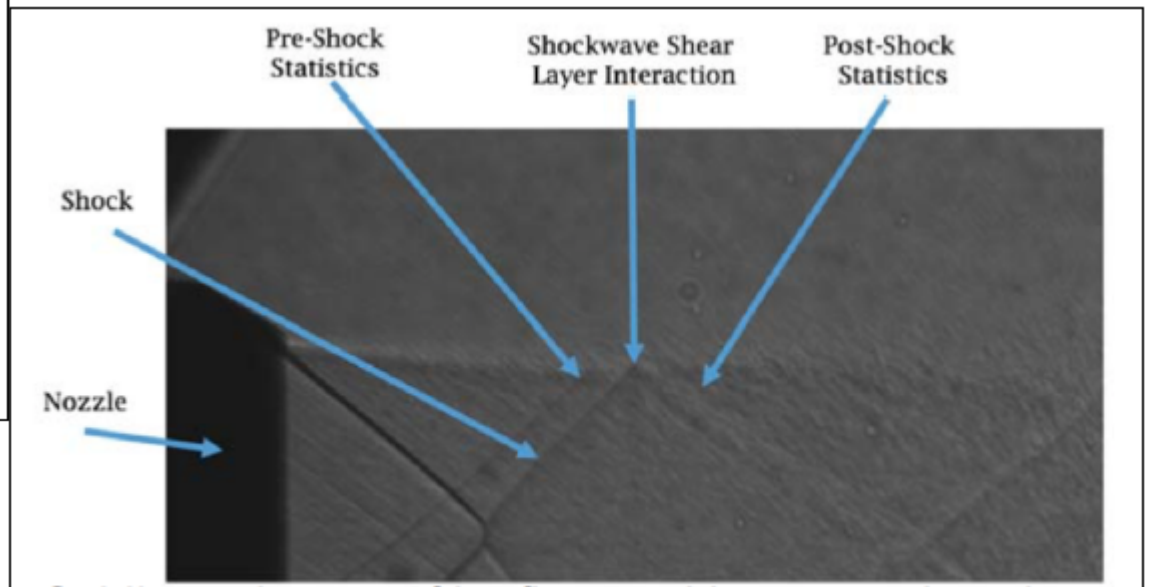
Steve Miller – U of Florida 'Turbulent Statistics and Associated Acoustic Sources Near Shock Wave Shear Layer Interactions'

Objective/Description

- Provide guidance and physical understanding to reduce near-field noise from US Navy aircraft high speed jet exhaust
- Understand how turbulence statistics, wavenumber energy spectra, and the acoustic sources are changed by the shock cell structure
- Alter operating conditions to ascertain the effect on the statistics of turbulence and radiated noise
- Analytical model for the anisotropic portion of the turbulent field and connect the entire aeroacoustic model to large eddy simulation

Pay Offs / Key Technologies

- Combined analytical acoustic source modeling with large eddy simulation for understanding source of near-field jet noise. Guidance on methods to reduce shock-noise through alteration of source statistics. Reduction of hearing loss and sonic fatigue.



Schlieren image of jet flow and important locations

ONR – Funded Programs

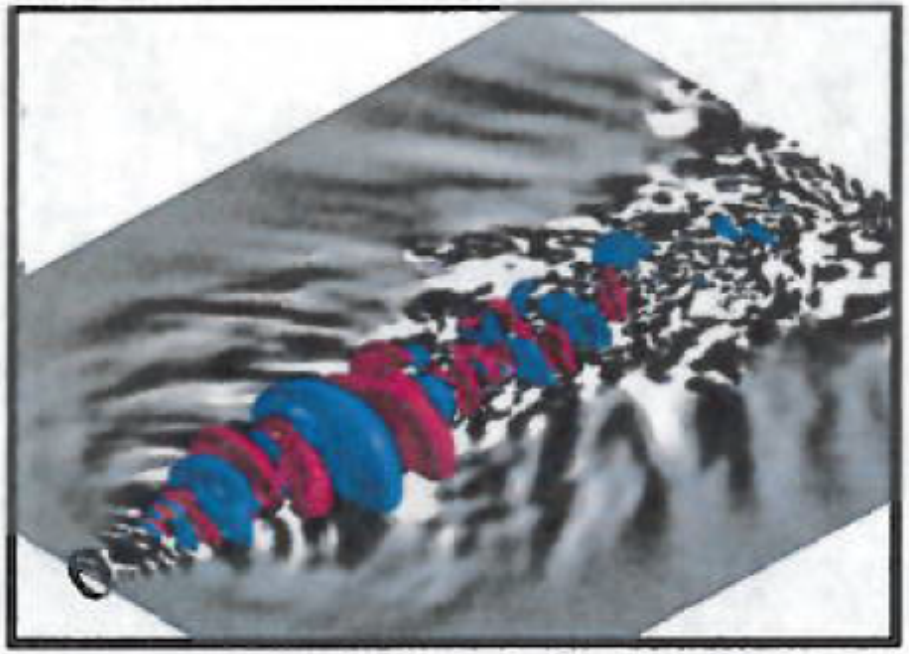
Datta Gaitonde – OSU 'Noise Generation Mechanisms in Imperfectly Expanded & High Speed Jets'

Objective/Description

- Identify kinematic and thermodynamic acoustic energy sources in broad-band shock associated noise
- Noise source localization in overexpanded jets
- Acoustic receptivity to small perturbations

Key Technologies

- Time local linear tendency through synchronized Large-Eddy Simulations
- Momentum potential theory- based identification of acoustic energy sources



Acoustic mode and nearfield noise

ONR – Funded Programs

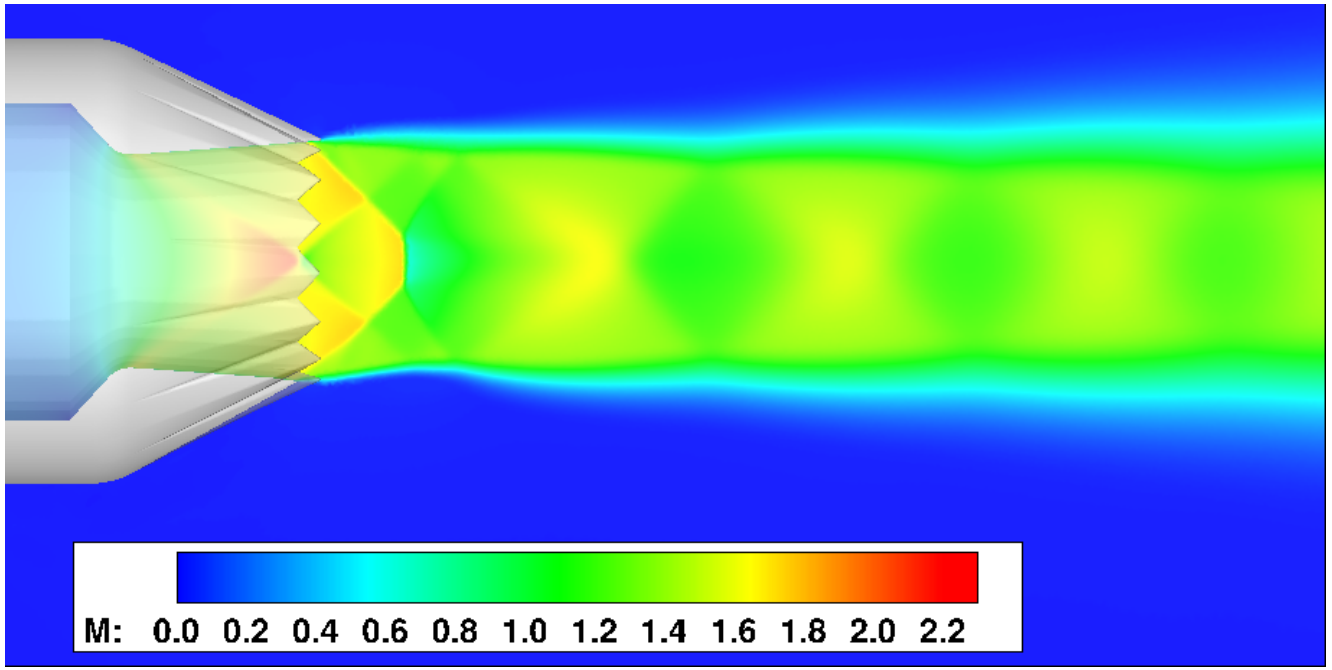
Tony Pilon – LM 'Acoustical Assessment of the Spiritech STAR Nozzle Concept

Objective/Description

- Develop a STAR (Multi-Stream Coupled Throat Variable Rotating) Nozzle for integration with contemporary tactical aircraft employing advanced variable cycle engines
  - Nozzle design & cycle optimized for fuel efficiency and thrust
- Assess the acoustical properties and noise reduction potential of the STAR nozzle with respect to baseline nozzles employed on current aircraft
  - RANS (CFD++) and LES (JENRE) CFD analysis
  - Small-scale experiments in Penn State's Jet Aeroacoustics facility

Payoffs/Key Technologies

- Low-noise, high efficiency nozzles for contemporary and next generation tactical aircraft
- Possible significant reductions in flight deck noise levels
- Industrial employment and assessment of NRL-developed *JENRE* tool



RANS Mach Contours – takeoff power, baseline nozzle

ONR – Funded Programs

- Jet Noise Remains a Safety and Good Neighbor Issue
- **Looking for innovative Jet noise reduction ideas**
- High Fidelity Simulations are Accurate But Computationally Expensive
- Looking for Opportunities for Full Scale Diagnostic Testing
- Challenging to Transition

Questions?