NASA Jet Noise Research

Brenda Henderson and
NASA Glenn Research Center

Turbine Engine Technology Symposium
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www.nasa.gov

Outline

- NASA Program Overview
- NASA Jet Noise Facilities
- Highlights of current jet noise research

NASA's Aeronautics Research Mission Directorate (ARMD)

Six thrust areas

- Safe, efficient growth in global operations
- Innovation in commercial supersonic aircraft
- Ultra-efficient commercial vehicles
- Transition to low-carbon propulsion
- Real-time system safety assurance
- Assured autonomy for aviation transformation

Four programs to address these areas

- Advanced Air Vehicles Programs (AAVP)
- Airspace Operations and Safety Program (AOSP)
- Integrated Aviation Systems Program (IASP)
- Transformative Aeronautics Concepts Program (TACP)

Advanced Air Vehicles Program (AAVP)

Studies, evaluates, and develops technologies and capabilities that can be integrated into fixed wing and vertical lift aircraft as well as explores far-future concepts that hold revolutionary improvements to air travel

Aeronautics Evaluation and Test Capabilities

- Ground test capabilities
- Subsonic, transonic, supersonic, hypersonic wind tunnels and propulsion test facilities
- Ames, Glenn, and Langley

Advanced Composites Project

Revolutionary Vertical Lift Technology Project

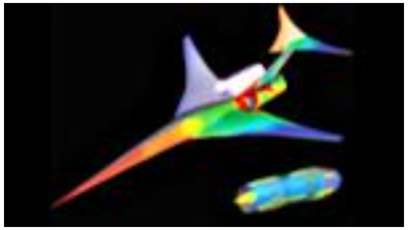
Advanced Air Transport Technology Project

- Revolutionize energy efficiency and environmentally compatible fixed wing transport aircraft
    - Fan and High-lift Noise

Commercial Supersonic Technology Project

- Low Noise Propulsion for Low Boom Aircraft

Commercial Supersonic Technology (CST) Project



Develop tools, technologies, and knowledge to help eliminate today's technical barriers to practical commercial supersonic flight: sonic boom, fuel efficiency, airport community noise, high-altitude emissions, structural weight and flexibility, airspace operations, and the ability to design future vehicles in an integrated, multidisciplinary manner

Technical Challenges (TCs)	
TC Title	**TC Description**
TC 1.1 Low Sonic Boom Design Tools	Tools and technologies enabling the design of supersonic aircraft that reduce sonic boom noise to 80 PLdB validated as ready for application in a flight demonstrator
TC 1.2 Sonic Boom Community Response Metric & Methodology	Validated field study methodology, survey tools and test protocols to support community studies with a demonstrator aircraft
TC 2.2 Low Noise Propulsion for Low Boom Aircraft	Design tools and innovative concepts for integrated supersonic propulsion systems with noise levels of 10 EPNdB less than FAR 36 stage 4 *(ICAO chapter 4)* demonstrated in ground test

Concluding with new technical challenge beginning FY2017

Integrated Aviation Systems (IAS) Program

Conducts flight oriented, integrated, system-level research and technology development that supports the flight research needs across the ARMD strategic thrusts, the programs, and their projects

Environmentally Responsible Aviation Project

- Explores and assesses new vehicle concepts and enabling technologies through system-level experimentation to simultaneously reduce fuel burn, noise and emissions
- Research Challenges
  - Advanced UHB Engine Designs for Specific Fuel Consumption and Noise Reduction
  - Advanced Airframe and Engine Integration Concepts for Community Noise and Fuel Burn Reduction

Unmanned Aircraft Systems Integration in the National Air Space System

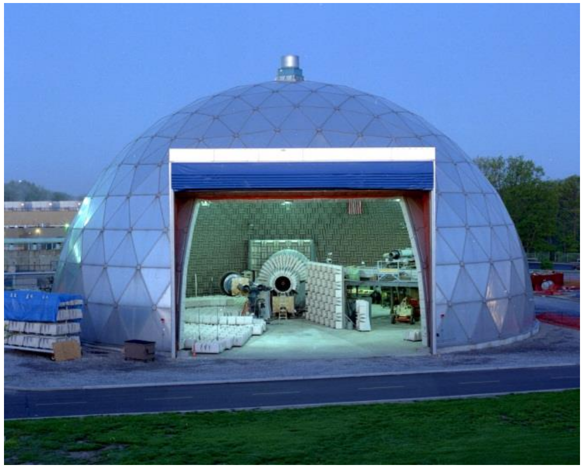
Flight Demonstrations and Capabilities Project

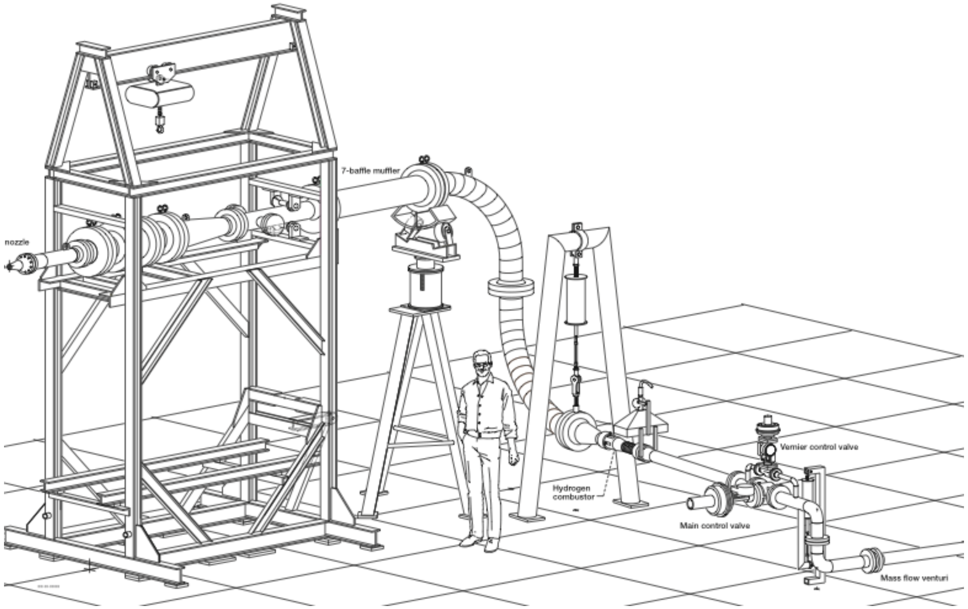
- Conducts complex and integrated small scale flight research demonstrations
- Operates, sustains, and enhances flight research test capabilities

NASA Jet Facilities
Aero-Acoustic Propulsion Lab (AAPL)

Glenn Research Center

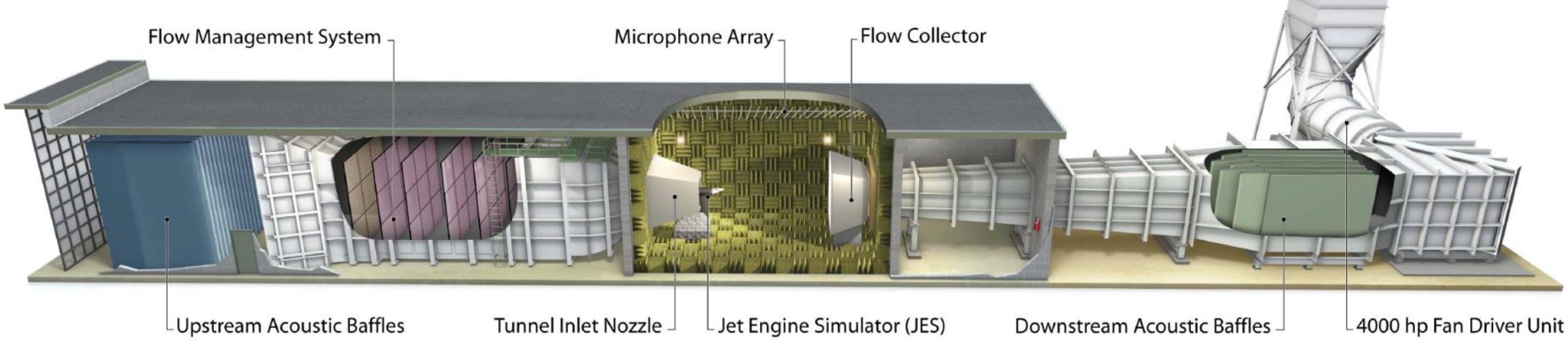
- 65’ radius anechoic dome
- Nozzle Acoustic Test Rig (NATR)
  - A three-stream jet-engine simulator (HFJER) with simulated forward flight
- Small Hot Jet Acoustic Rig (SHJAR)
  - Single-stream, specialty jet rig
- Far-field acoustics, phased arrays, flow rakes, hotwire, schlieren, PIV, IR, Rayleigh, Raman, PSP

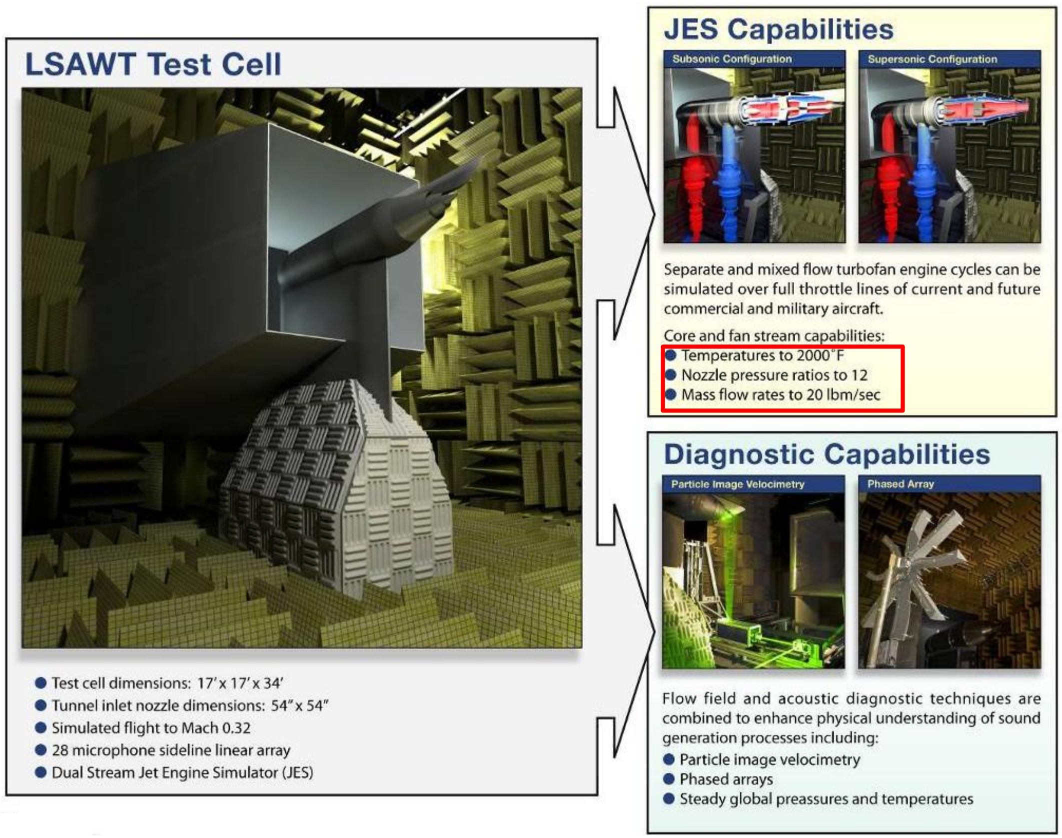


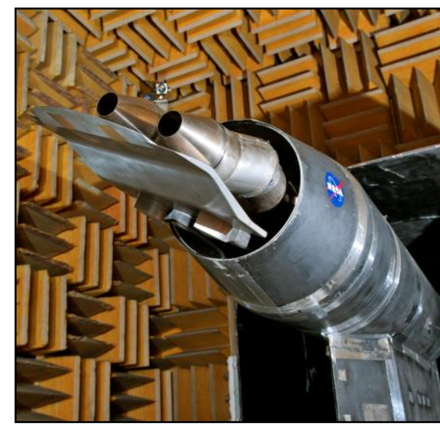


NASA Jet Facilities
Low Speed Aeroacoustic Wind Tunnel (LSAWT)

Langley Research Center







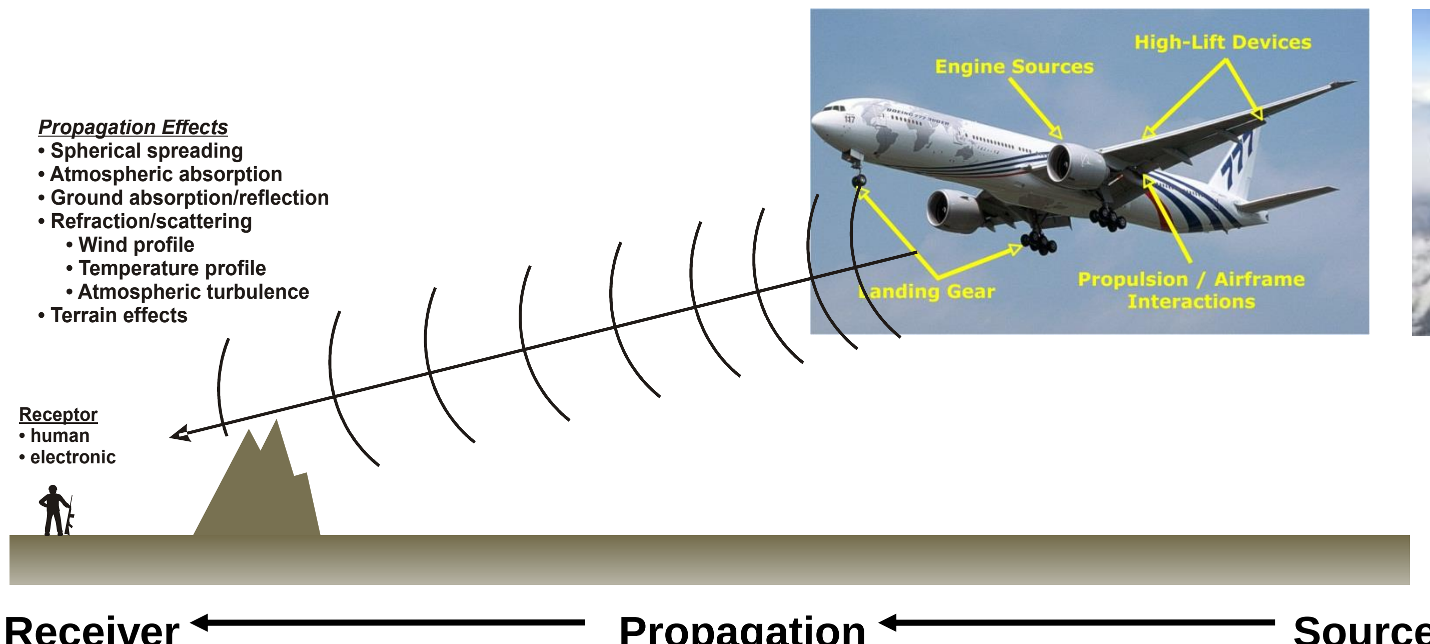
Twin jet aeroacoustic test with nozzles near aft deck fuselage section of Hybrid Wing Body

NASA Aircraft Noise Prediction Program (ANOPP2)

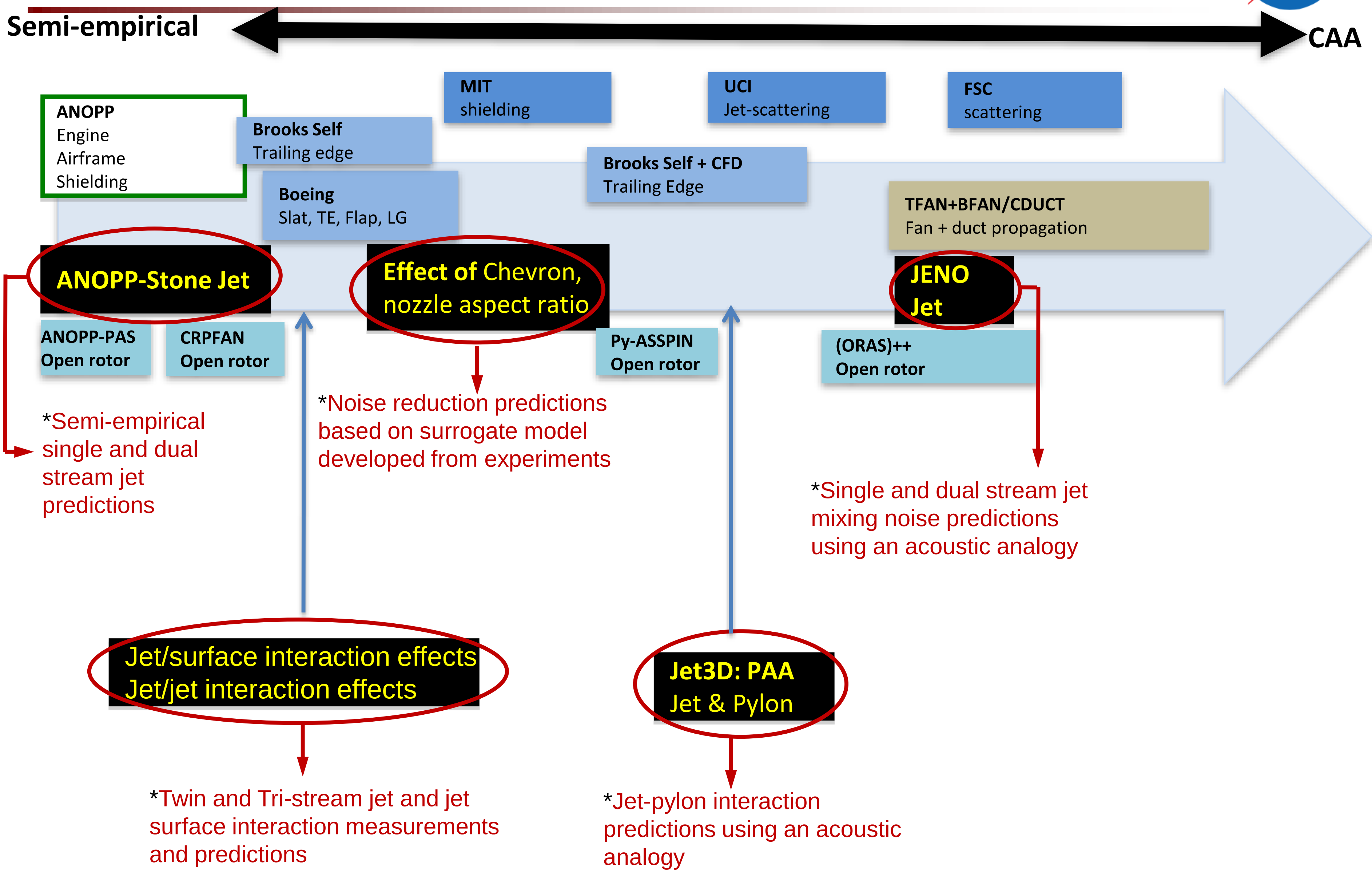
Len Lopes: Leonard.V.Lopes@nasa.gov

- **Total aircraft noise prediction capability for subsonic and supersonic aircraft**
  - ANOPP2: mixed-fidelity prediction framework that includes ANOPP and high-fidelity, physics-based analyses
  - Predict aircraft source noise, propagation and impact at receiver in near or far-field

- **Specific Capabilities for Supersonic Aircraft Applications**
  - Coupling with Model Center for high speed aircraft noise optimizations
  - Comprehensive ability to predict high speed jet mixing & broadband shock noise (JeNo, MDOE)
  - Methodologies for mixer-ejector configurations



ANOPP2: Mixed-Fidelity System Noise Framework

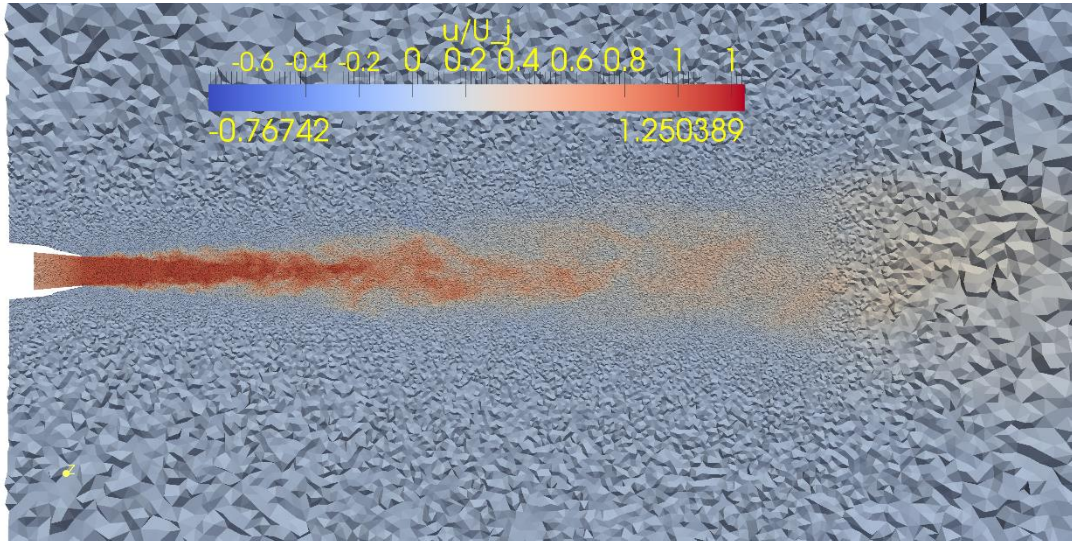


POC: Len Lopes: Leonard.V.Lopes@nasa.gov

Subsonic Jet Noise Prediction with JENRE

Daniel Ingraham, daniel.j.ingraham@nasa.gov

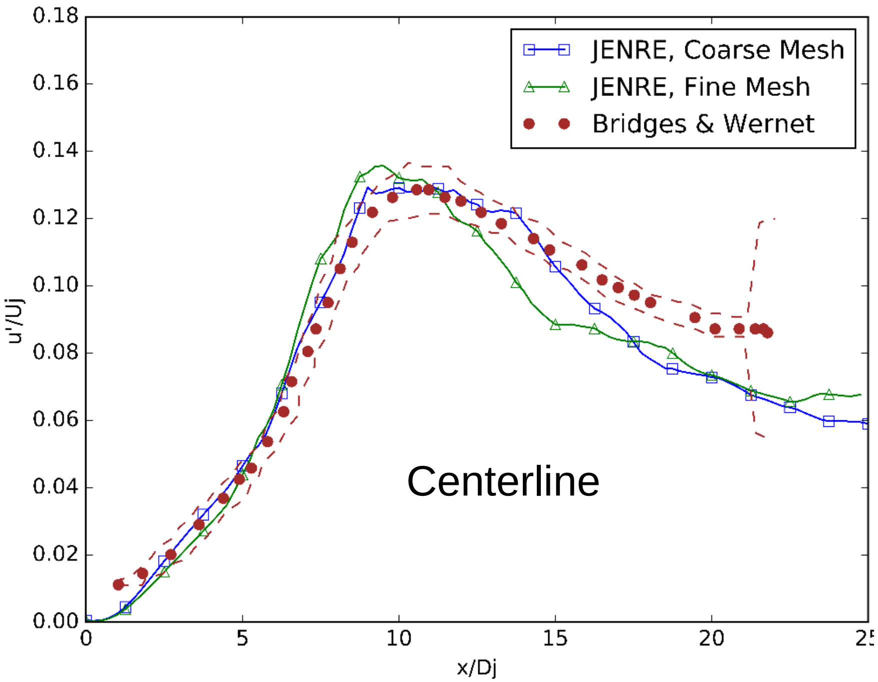
- JENRE: Jet Engine Noise Reduction code from the Naval Research Lab
  - Monotonically Integrated Large-Eddy Simulation (MILES) code using the flux-corrected transport (FCT) method to combine low- and high-order finite element schemes on unstructured meshes
  - Proven capability predicting noise from realistic supersonic jets, including chevrons, multiple streams, pylons.
  - Current work at NASA Glenn: validate JENRE capability against Glenn's considerable experimental database of subsonic jet experiments
  - Long-term plan: use JENRE to investigate flows of interest to NASA, (tone producing jets, jet-surface interaction, offset streams, etc.)

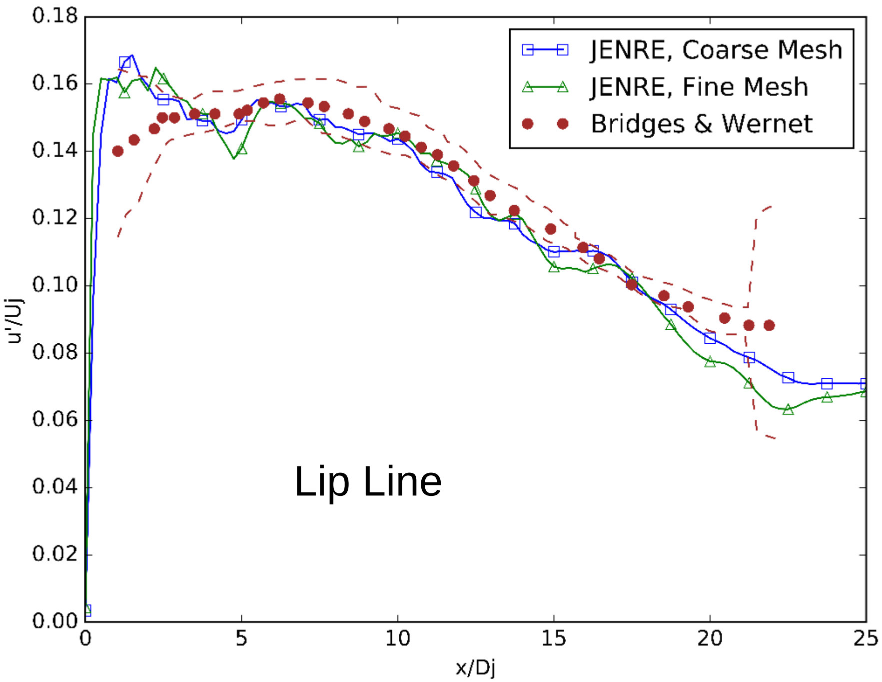


Subsonic Jet Noise Prediction with JENRE

Daniel Ingraham, daniel.j.ingraham@nasa.gov

- Preliminary test case: set point 3 from the Tanna Matrix
  - Axisymmetric nozzle, unheated jet, exit Ma = 0.513
  - Axial velocity statistics show good agreement with experiment, despite relatively coarse grids (15e6 and 27e6 nodes)
  - Noise predictions in process.





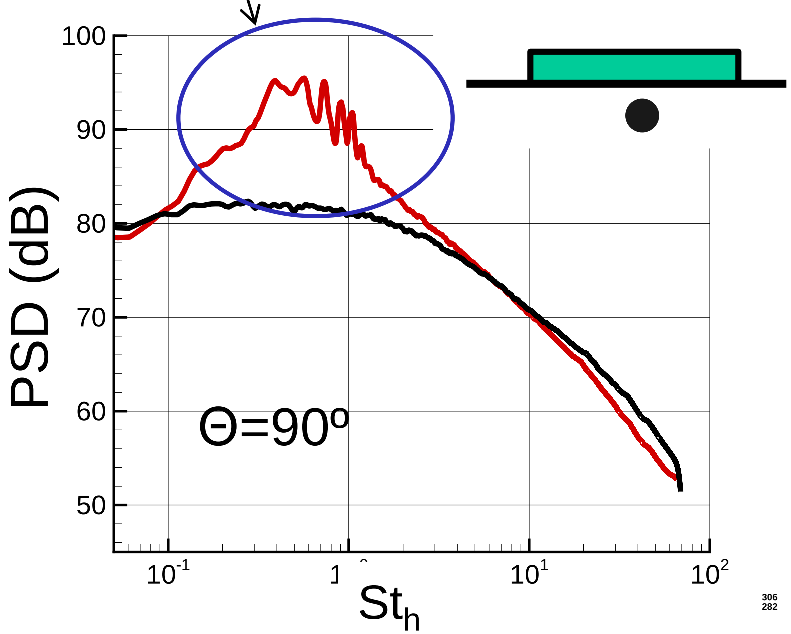
JSI - High Aspect Ratio Nozzle

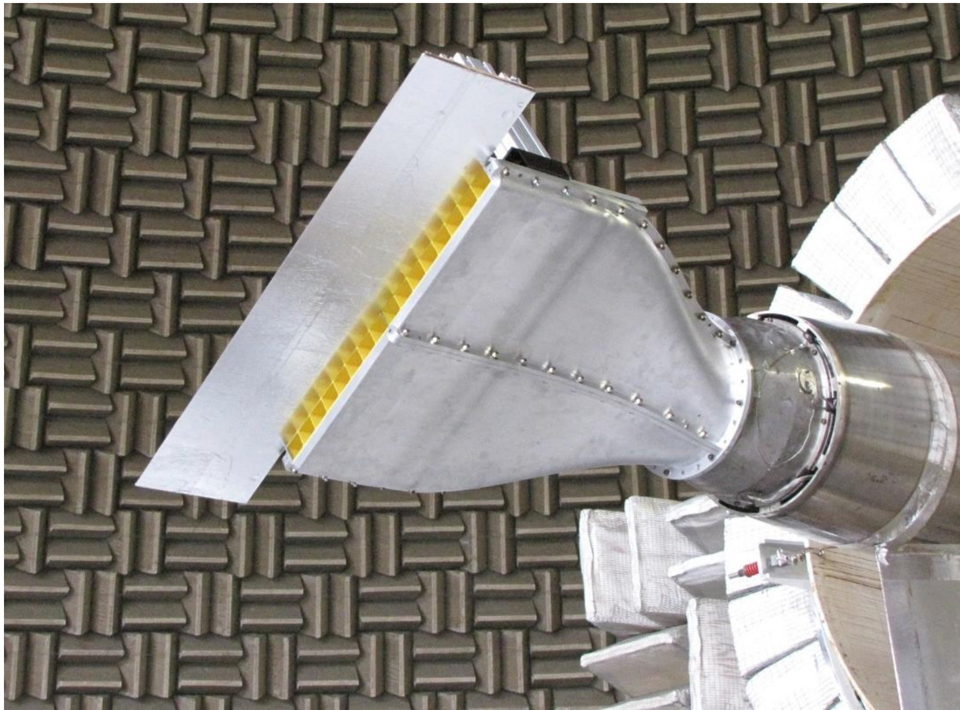
Clifford Brown, clifford.a.brown@nasa.gov

- 16:1 aspect ratio nozzle
- Flush mounted surface – vary lengths
- Acquired:
  - Far-field noise
  - Phased array noise source localizations
  - In-flow total pressure
  - Static pressure on surface

JSI trailing edge noise combined with resonance

Resonance depends on geometry and jet condition





Jet Surface Interaction Noise – Planar Exhaust

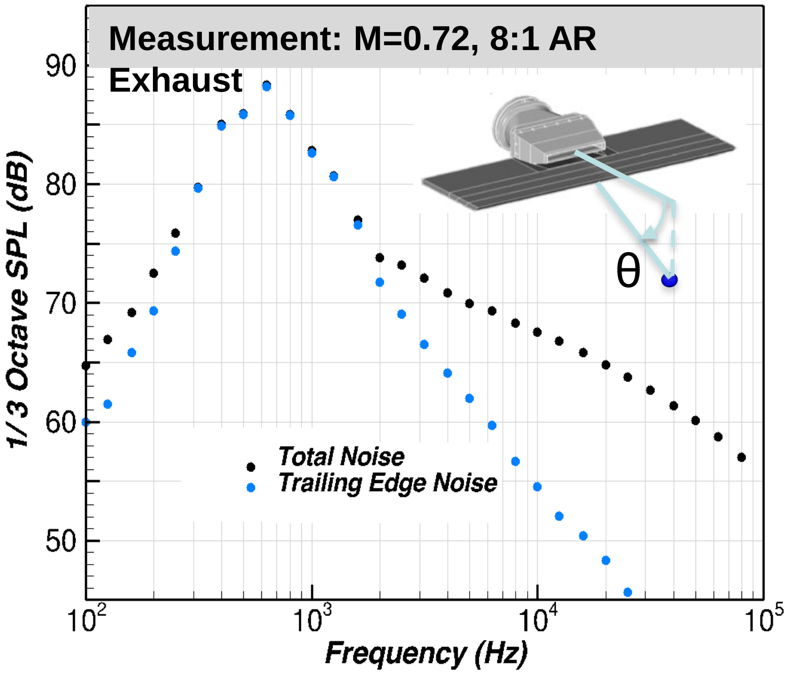
Abbas Khavaran, abbas.khavaran@nasa.gov

Interaction of exhaust noise with a nearby solid surface

- An acoustic analogy simulation approach
- Predict mixing (scrubbing) noise and Trailing Edge Noise (TEN)

Assumptions

- High aspect ratio rectangular exhaust
- Locally parallel mean flow
- Generalized Acoustic Analogy (GAA) to predict scrubbing noise
- Rapid Distortion Theory (RDT) to predict TEN



Approach

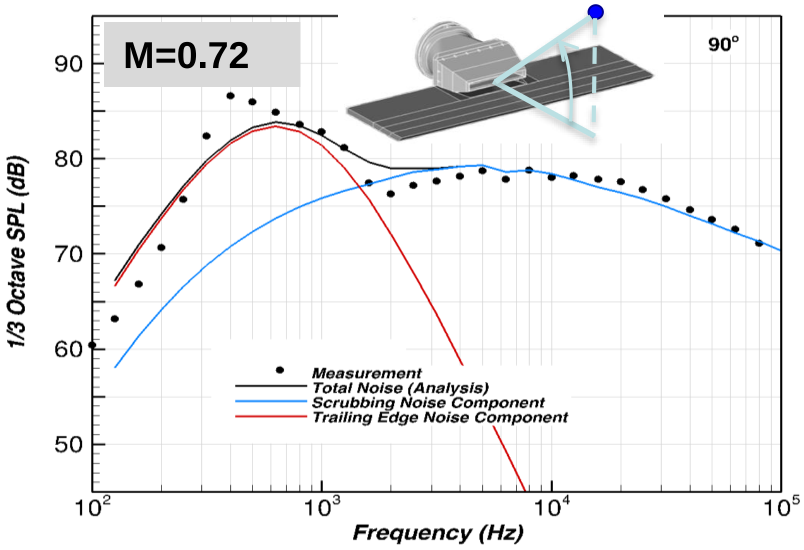
- Mean flow and turbulence – Steady RANS
- Map RANS solution to acoustic grid
- Source/GF volume integration for scrubbing noise
- Source/GF area integration at the plate tip for TEN
- Superimpose two component noise

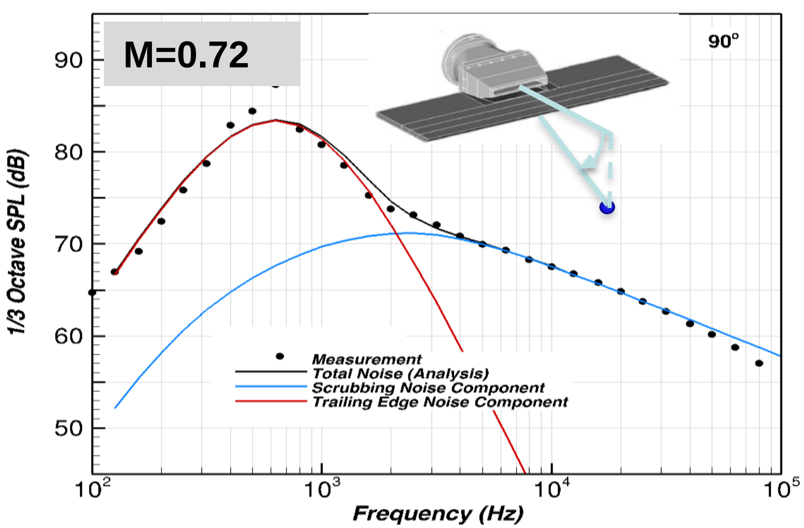
Reference: AIAA-2016-2863

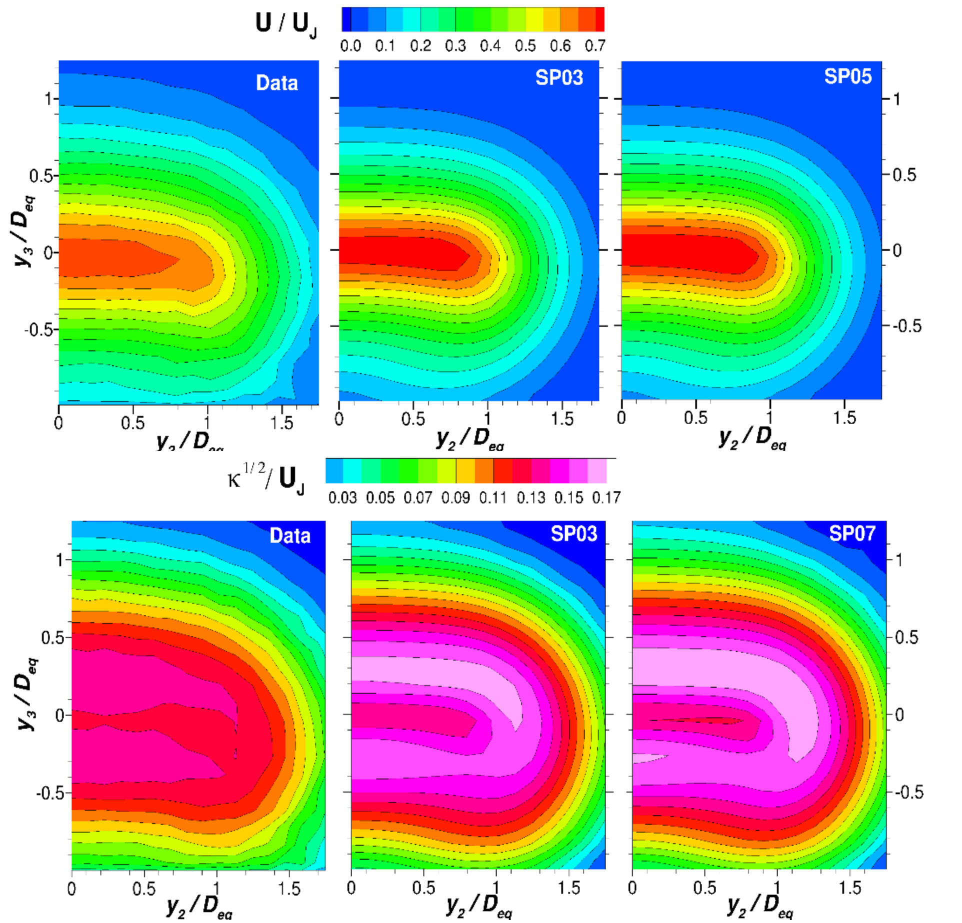
Jet Surface Interaction Noise – Planar Exhaust

Abbas Khavaran, abbas.khavaran@nasa.gov

8:1 Rectangular Exhaust, N8ZH19XTE12			
Set Point	NPR	NTR	M
SP03	1.19	1.0	0.51
SP05	1.42	1.0	0.72
SP07	1.86	1.0	0.98



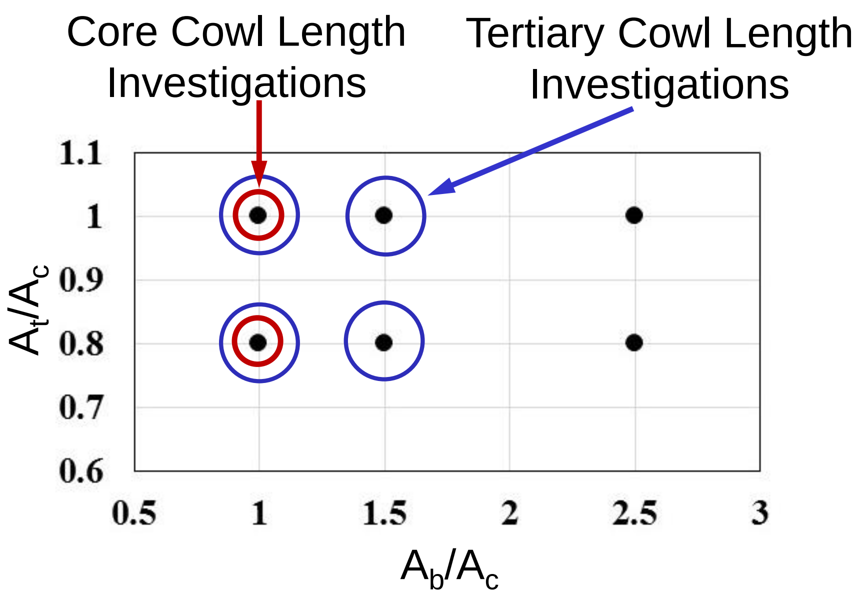




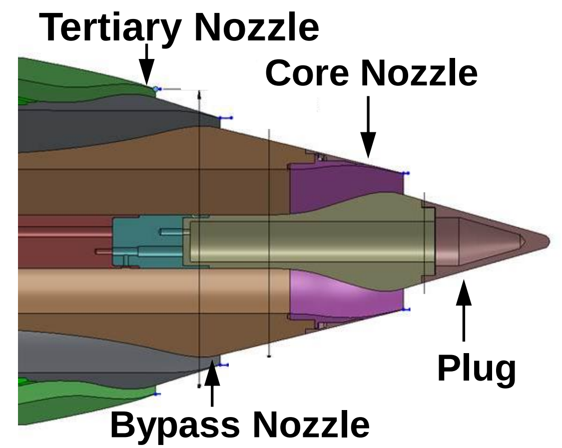
Near End of Plate

Three-Stream Nozzle Experiments

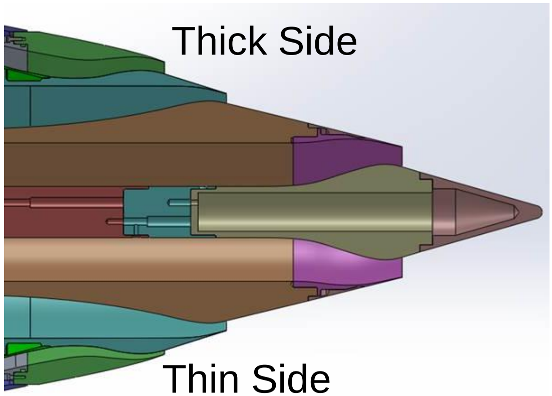
Brenda Henderson, brenda.s.henderson@nasa.gov



Nozzle Design Space



Axisymmetric Nozzle System

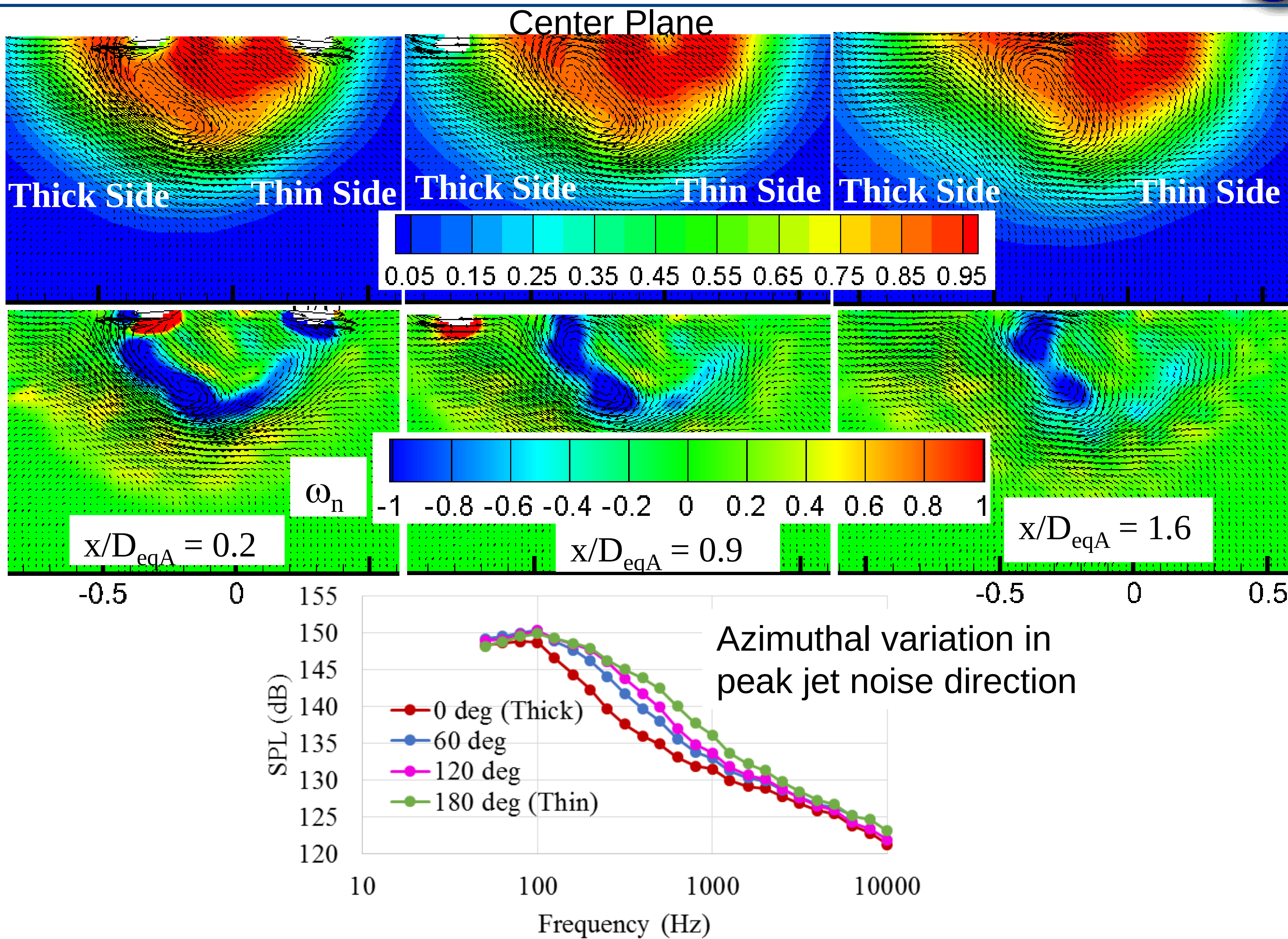


Offset Nozzle System

Jet Conditions

NPR_c	NPR_b	NTR_c	NPR_t	Jet Type	Condition Designation
1.6	1.6	3.0	1.0	Two	10% PLR
			1.4 , 1.8, 2.1	Three	
1.8	1.8	3.0	1.0	Two	Full Throttle
			1.4, 1.8, 2.1	Three	

Offset Stream Results

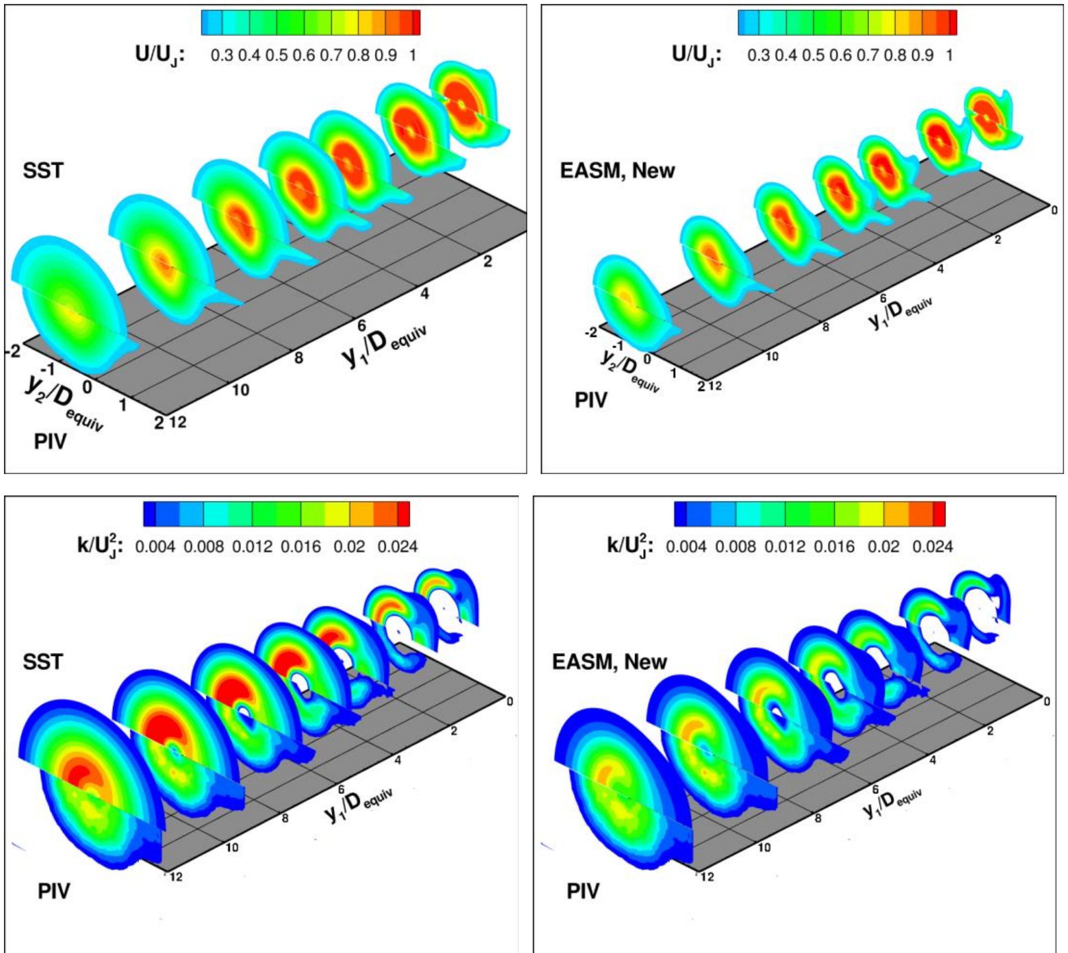


Noise Predictions for Offset Three-Stream Jets

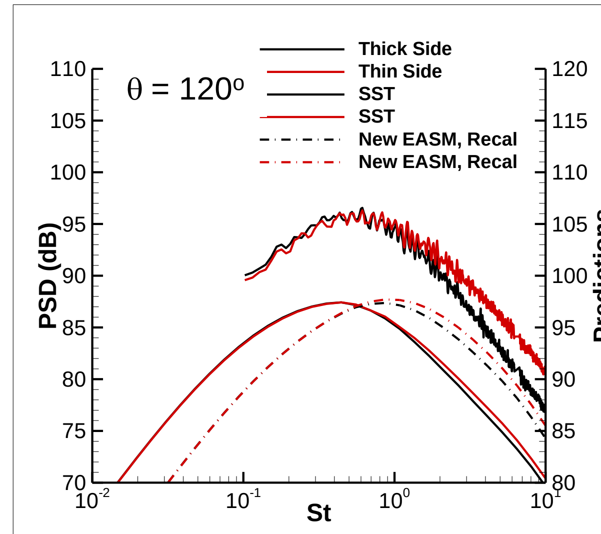
Stewart Leib Stewart.J.Leib@nasa.gov

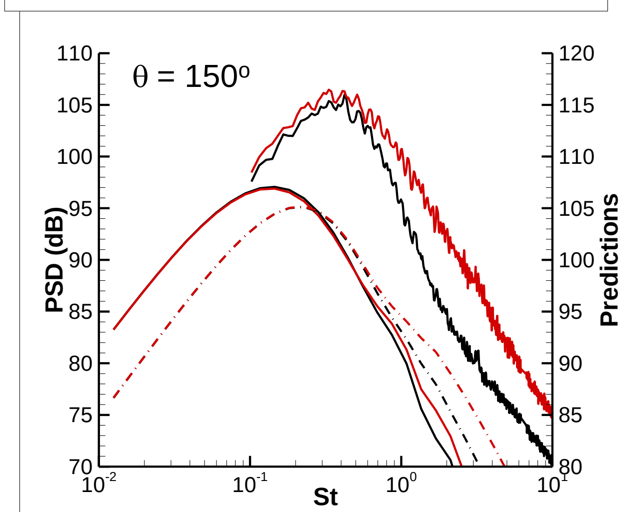
Improved turbulence modeling for three-stream jet RANS using Explicit Algebraic Stress Model

(Nicholas Georgiadis & Dennis Yoder)



Improved predictions of azimuthal variation of sound field

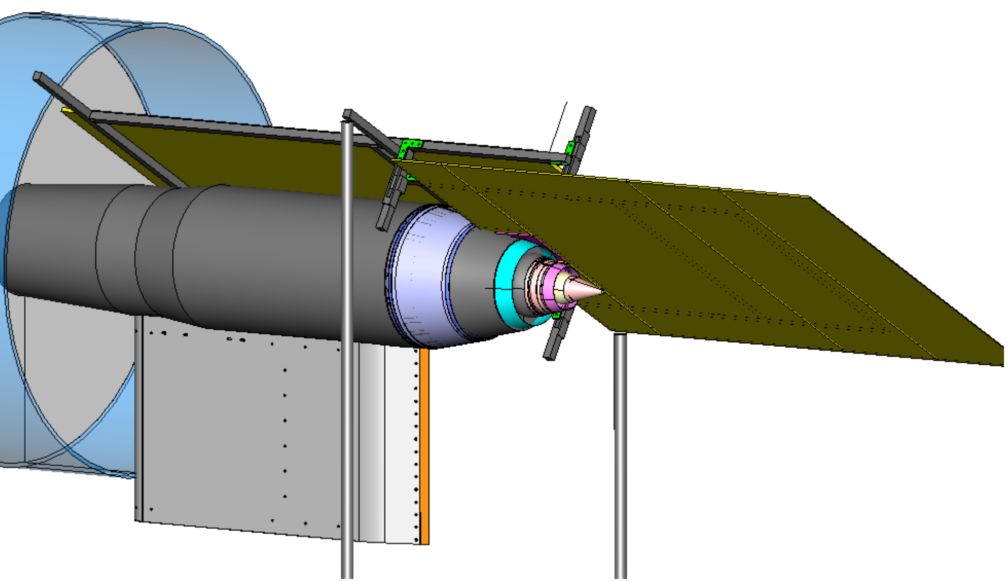




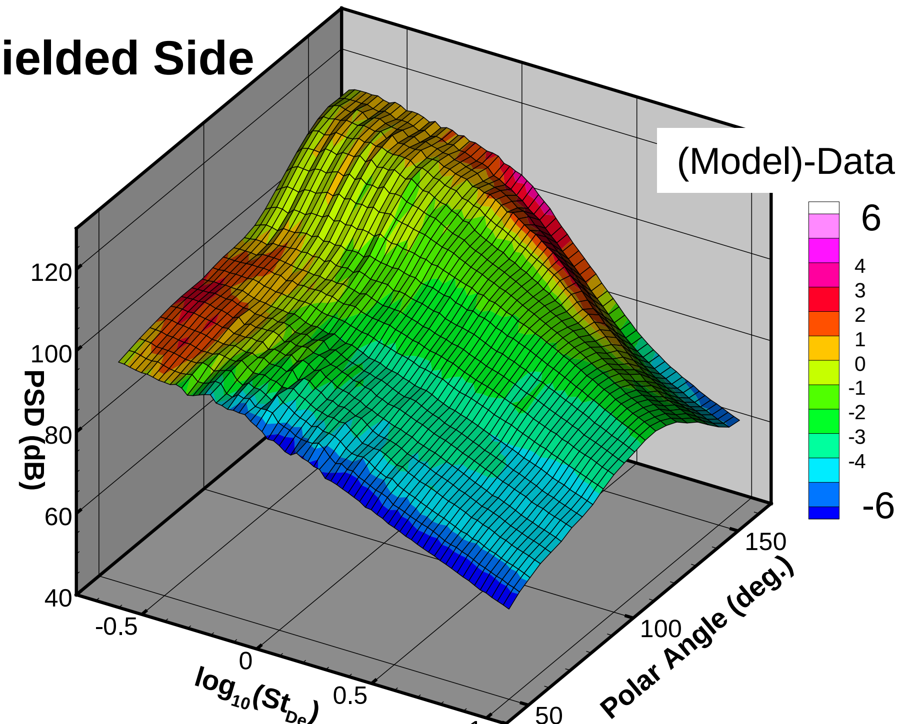
JSI - Multi-Stream Nozzle

Clifford Brown, clifford.a.brown@nasa.gov

- 2 and 3 stream nozzle systems
- Vary surface length and standoff
- Acquired:
  - Far-field noise
  - Phased array noise source localizations
- Empirical modeling of JSI noise spectra



Shielded Side



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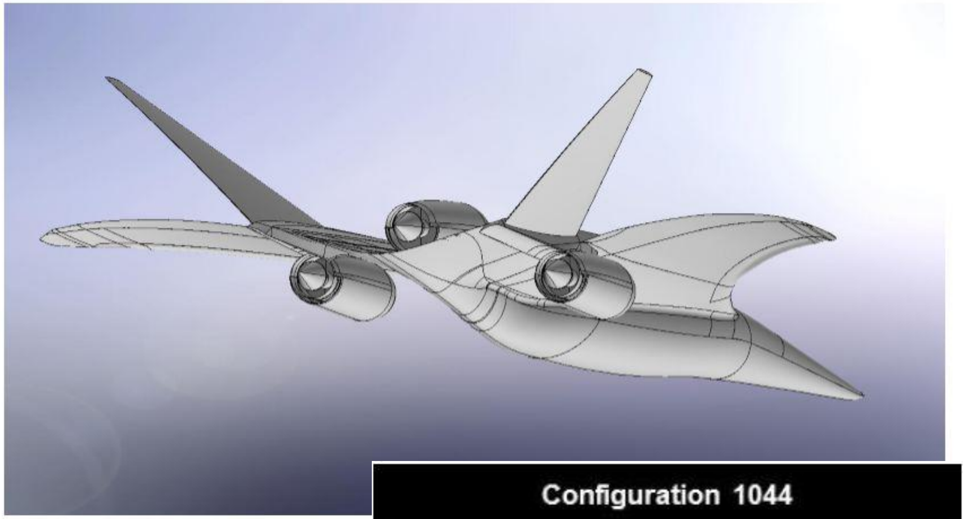
Aircraft Noise Assessments

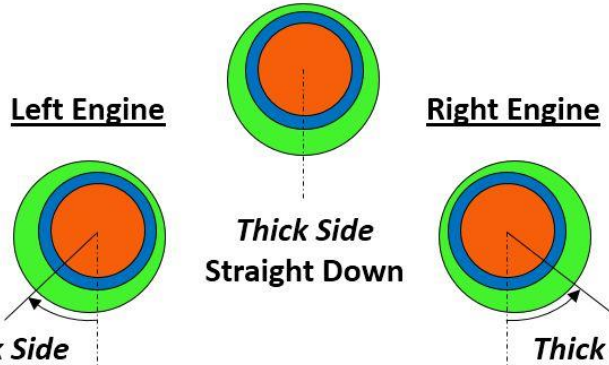
Dennis Huff, Dennis.L.Huff@nasa.gov

Lockheed Martin "1044" Aircraft



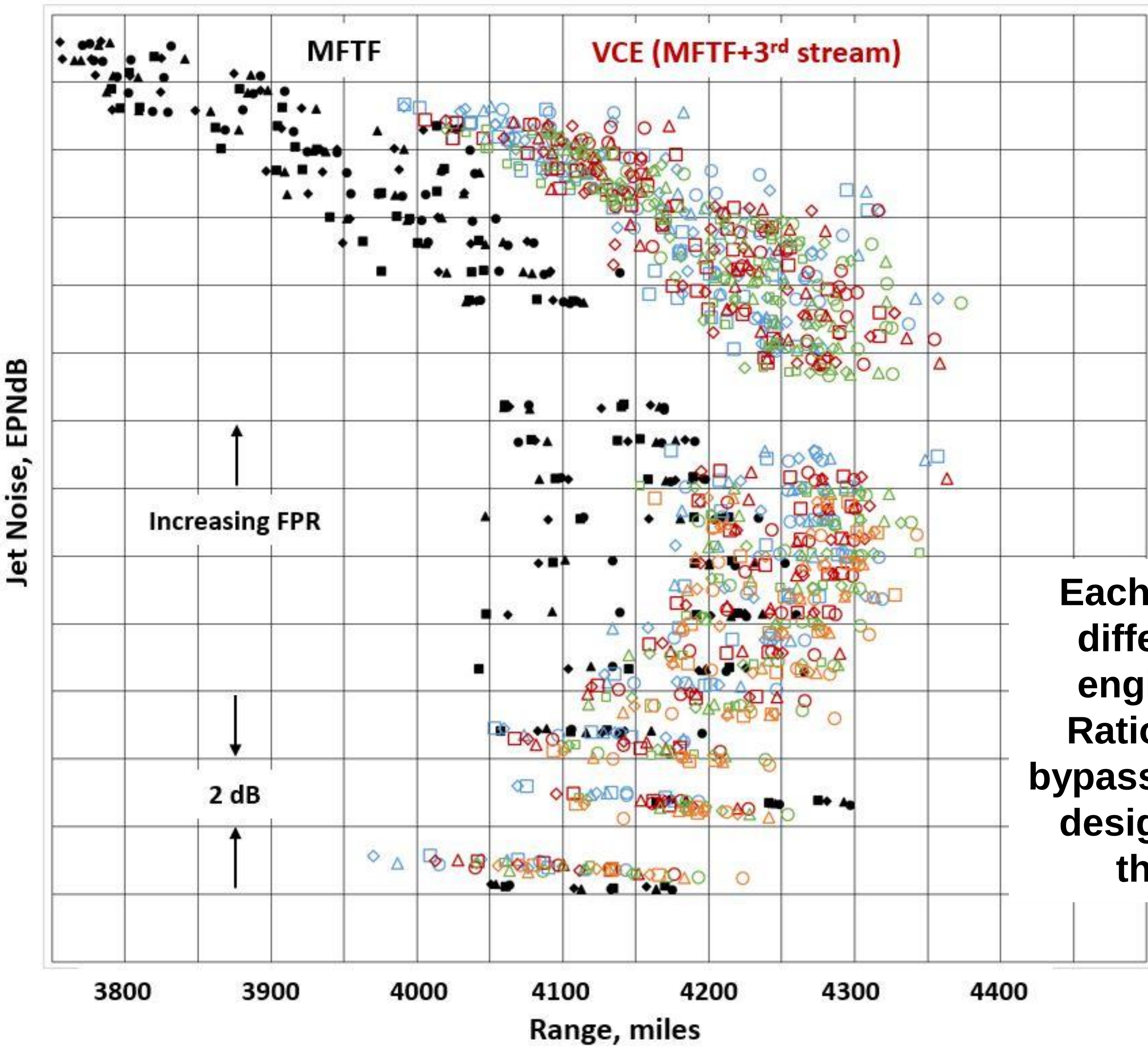
Configuration 1044	
Weight	(TOGW) 320,000 lb (Fuel) 168,000 lb (EW) 136,000 lb
Cruise	M1.7 L/D 8.7
Cabin	Two-class, 80 pax
Range	>5,000 nm
Boom Strength	(Full carpet) <85 PLdB

Offset Nozzle Orientations



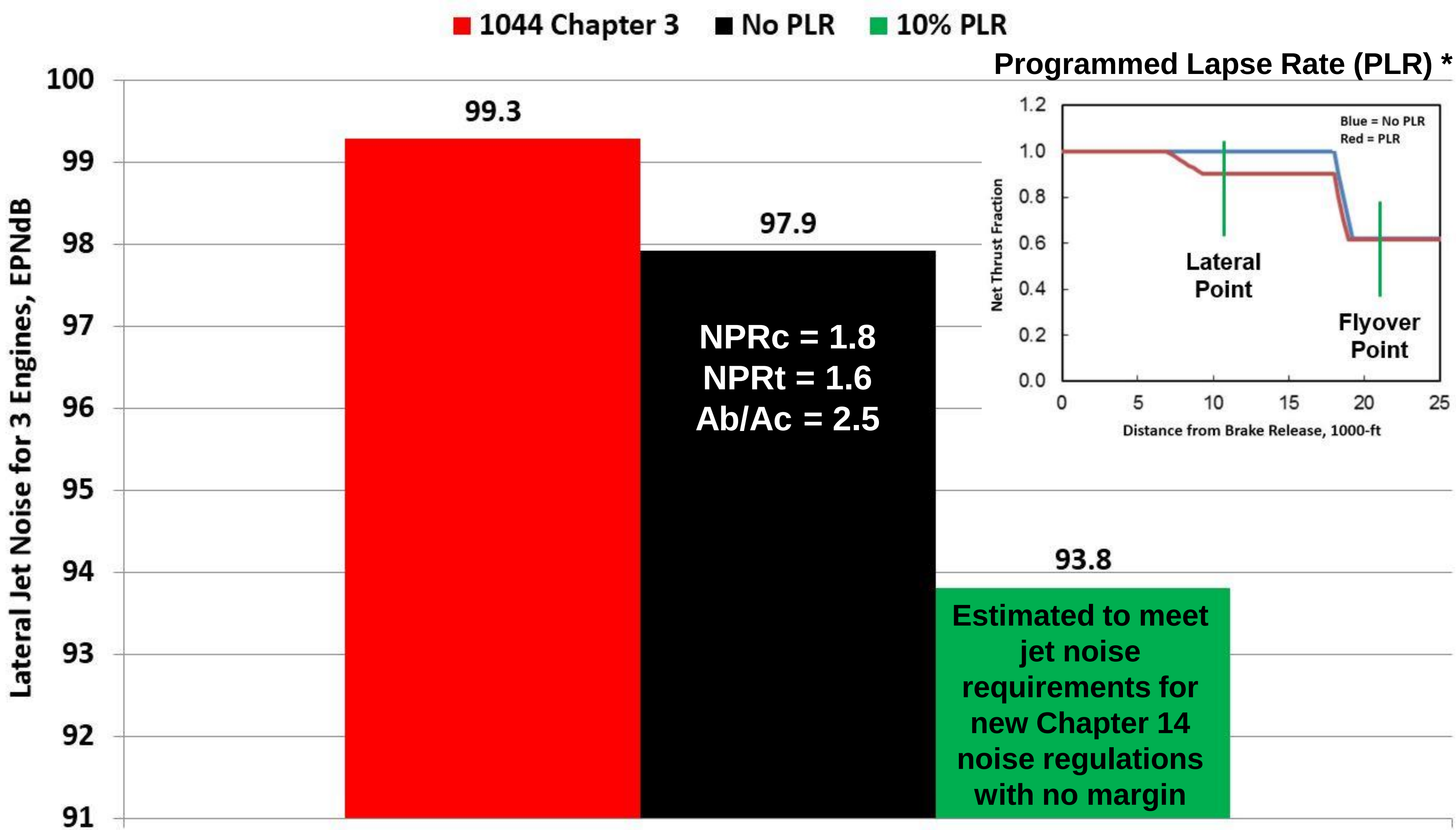
Morgenstern, J., et al., "Advanced Concept Studies for Supersonic Commercial Transports Engine Service in the 2018-2020 Period Phase 2," NASA CR-2015-218719, July 2015.

Engine Parametric Study



Each symbol represents a different combination of engine Overall Pressure Ratio (OPR), main engine bypass and throttle ratio, and design bypass ratio of the third stream (BPRt).

Effective Perceived Noise Levels



* Not approved by the FAA

Low Noise Propulsion for Low Boom Aircraft

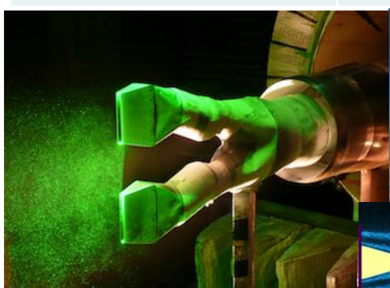
Technical Challenge To Be Completed Sep. 2016

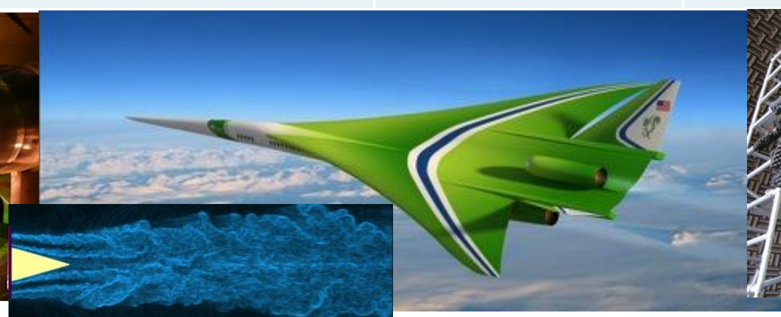
James Bridges james.e.bridges@nasa.gov

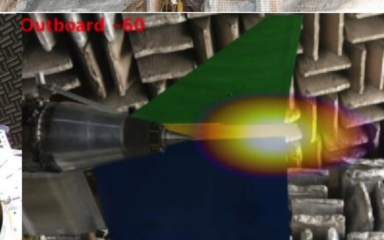
Design tools and innovative concepts for integrated supersonic propulsion systems with noise levels of 10 EPNdB less than FAR 36 Stage 4 demonstrated in ground test.

Deliverables:
1) Validate noise prediction and system modeling tools for prediction & optimization of N+2 supersonic airliner
2) Integrated aircraft solutions meeting airport noise requirements with viable range and low boom
3) Validation of acoustic performance and predicted design trades.

2013	2014	2015	2016
Multiple jet acoustic effect documented, modeled. Non-axisymmetric jet noise code created. IVPv2 design confirmed with LES.	Three-stream nozzle and IVPv2 tests completed. IVPv2 tests meet expectations First empirical models for three-stream and IVP nozzle systems	Aft-deck noise database acquired. Optimized engine cycle determined. Final candidate nozzles created.	Final isolated nozzles, system models validated. Integrated acoustic test articles created and tested. System predictions, acoustic goal validated.







Integration of noise prediction, innovative nozzles, and system modeling to achieve aggressive goals.

Conclusions

- **Modeling and predictions**
  - Modified Explicit Algebraic Stress Model (EASM) provides improved RANS solutions and leads to improved noise predictions for offset three-stream jets compared with the Shear Stress Transport (SST) model
  - Noise radiation from jet-surface interactions is predicted with a combination of an acoustic analogy and Rapid Distortion Theory (RDT)
  - NASA's ANOPP2, a total aircraft noise prediction capability for subsonic and supersonic aircraft, has been released
  - Empirical models for jet-surface interactions have been developed and are incorporated in ANOPP2
  - Validation of NRL's JENRE code for subsonic jets continues and has provided promising initial results

- **N+2 Supersonic Aircraft studies**
  - Offset streams provide slight effective perceived noise level reduction over that of axisymmetric jets for flyover certification point
  - Variable cycle engines provide increased range over mixed flow turbofans but do not meet Chapter 14 noise level requirements
  - Alternative takeoff procedures such as PLR will be needed to meet noise regulations
  - Low Noise Propulsion for Low Boom Aircraft Technical Challenge concludes in September 2016