Designing Supersonic Airliners to Meet Airport Noise Regulations

AIAA Aviation 2016

APA-37. Low Boom Activities II (Invited)

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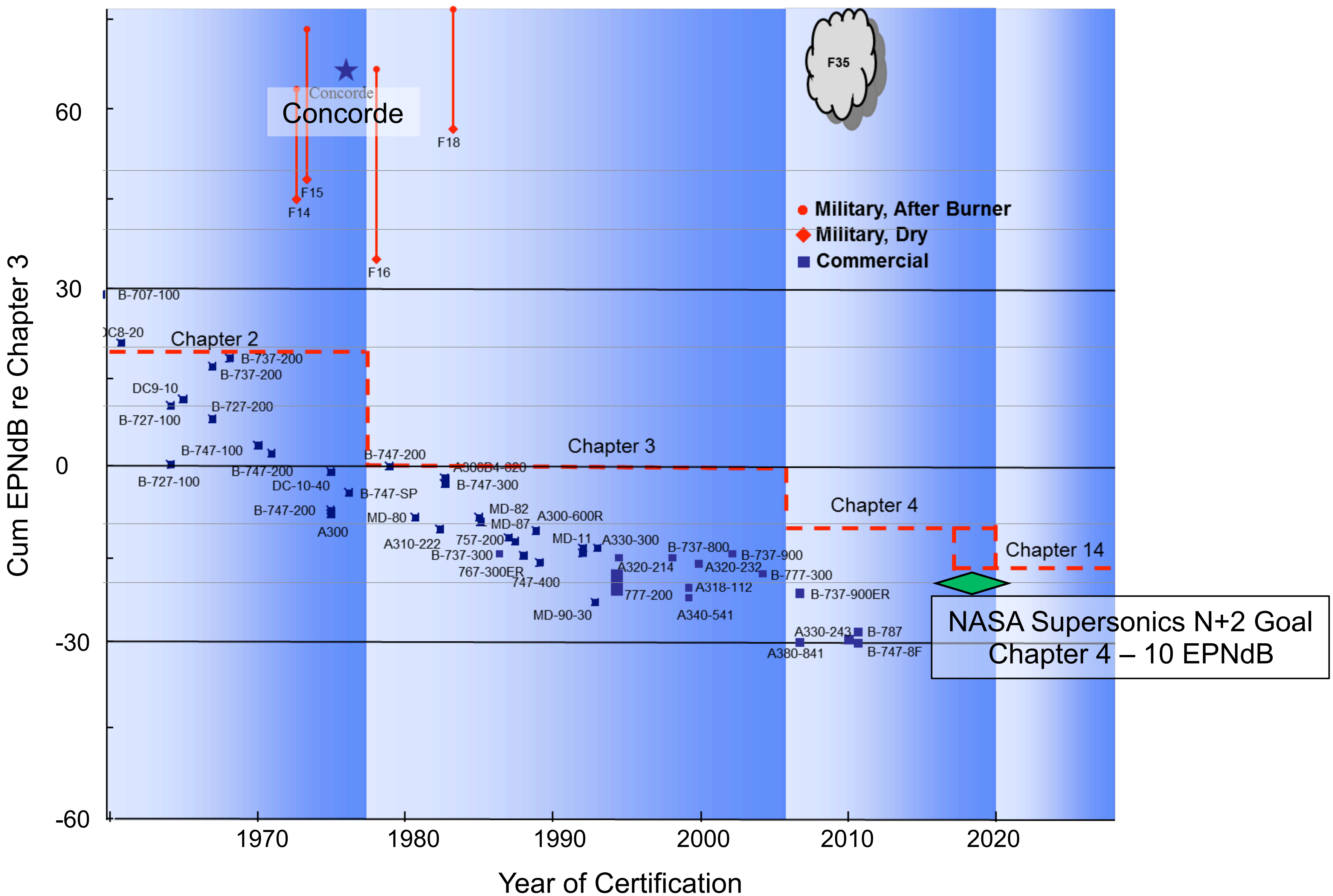
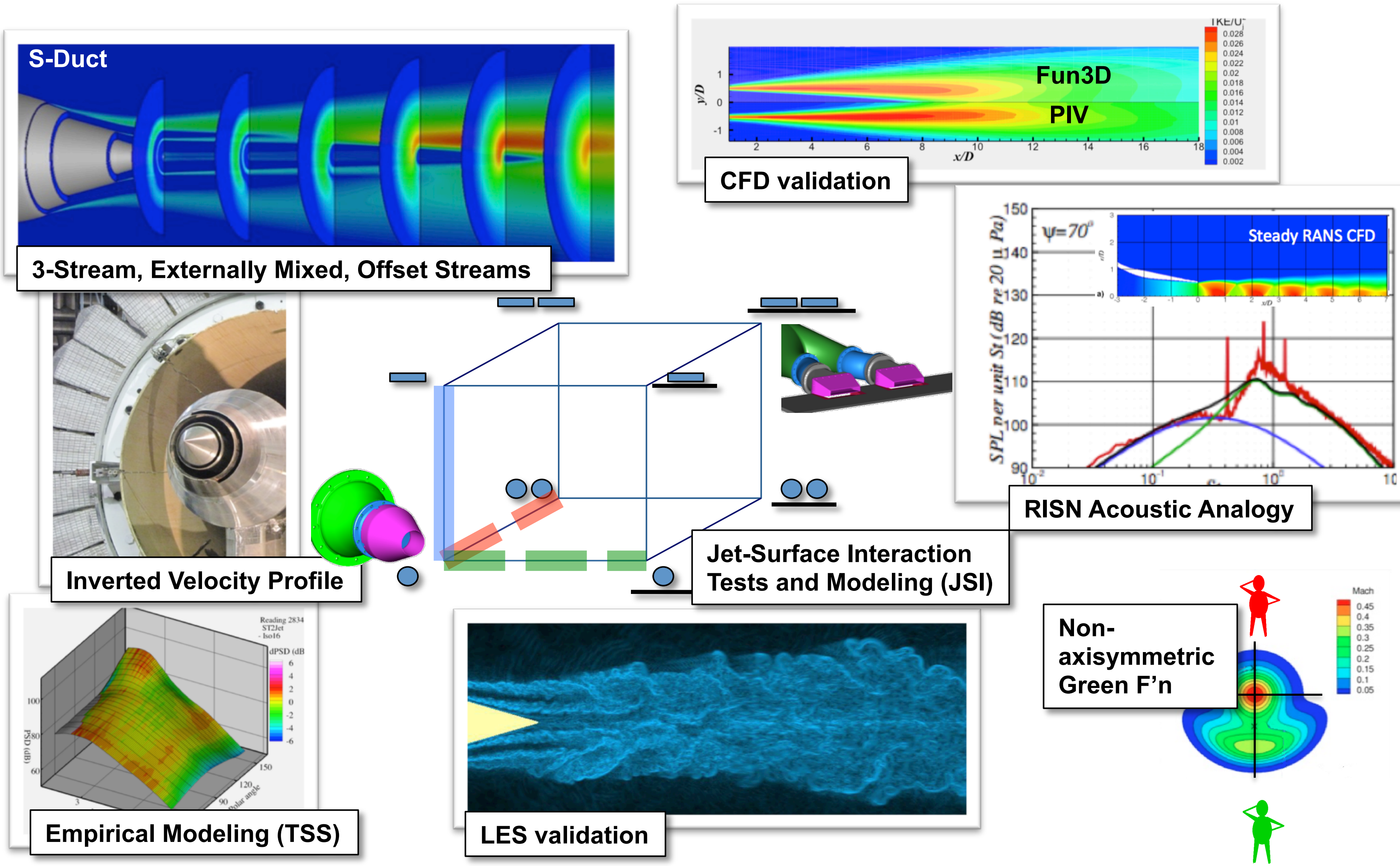
NASA AAVP/Commercial Supersonics Technology Project

Airport Noise—A Commercial Supersonics Challenge



Low-Noise Propulsion Tech Challenge 2016

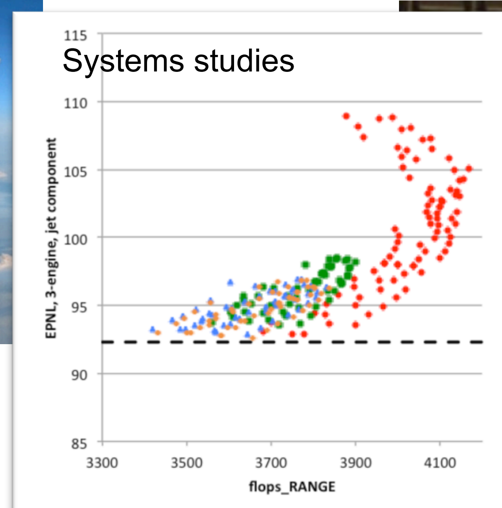
- **Supported by years of research:**

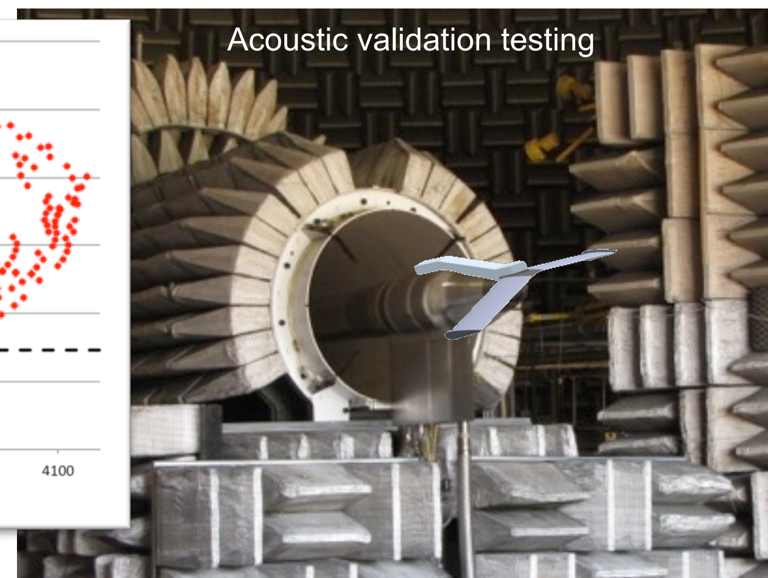


CST Project Level 1 Milestone

- CST1.1.02.L1: Low Noise Propulsion for Low Boom Aircraft
- **Exit Criteria:** 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.

- Based on Lockheed-Martin 1044 airframe (L/D, cruise, boom)
- Explore propulsion cycle/nozzle options; focus on installed exhaust noise
- Validate in scaled model test with simulated planform





Design Tools

- Empirical Codes
  - Creation of NPSS engine model, ModelCenter aero model
  - Developed & validated codes to predict noise of many VCE nozzles
  - Developed & validated code to predict acoustic impact of installation
  - **Used to design low-noise/low-boom vehicle, final Tech Challenge configs**
- RANS-based Acoustic Analogies
  - Developed non-axisymmetric Green's function, hot jet source models
  - Validated several RANS codes (Wind US, FUN3D, FloEFD)
  - Quantitatively apply to isolated nozzles and qualitatively to installed propulsion
  - **Primarily used for design guidance, insight (relative noise prediction)**
- Large Eddy Simulations
  - Supported external community of developers (academic, SBIR, industry)
  - Explored spectrum of schemes from URANS to LES for noise capability
  - Making NRL's JENRE code, and Ames's LAVA codes operational at NASA
  - **Primarily used to diagnose unexpected resonance phenomena**

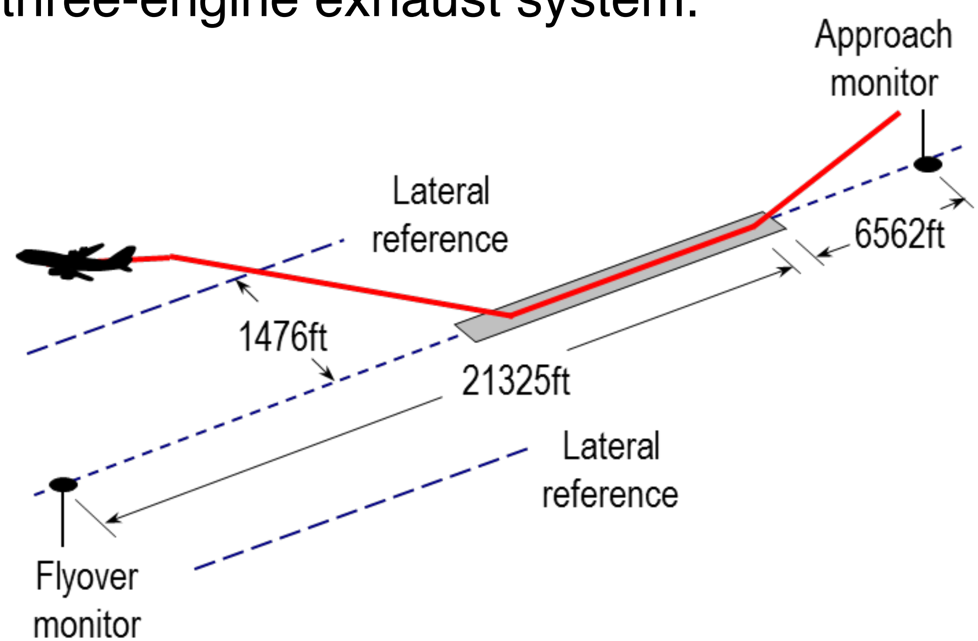
Innovative Concepts

- Variable Cycle Engine (VCE)
  - Innovative variable cycle architecture based on DoD investment
  - Variable specific thrust attractive for higher BPR at airport, lower BPR at cruise
  - In-house and industry exploration. In-house designs used for Tech Challenge
  - Compare against state of art mixed flow turbofan (MFTF)
- Multiple nozzle concepts explored
  - Externally mixed nozzles
  - Offset stream tertiary nozzle
  - Inverted velocity profile (IVP)
  - Buffer flow on IVP
  - Mixer-ejector
- Impact of installations explored
  - Benefit of shielding/Cost of reflection
  - Jet-by-jet shielding
- Optimization of noise vs range vs sonic boom

10dB below Stage 4

Relating modelscale, component measurements to real-world metrics:

- Assume **exhaust noise** dominates at Lateral certification point
- FAR Part 36 **Chapter 3** requires **99.3EPNdB** max at Lateral for LM1044 airliner.
- **Chapter 4** is 10dB (cumulative) below Chapter 3, with reduction at all points. (Lateral < 96 EPNdB)
- **Chapter 4–10dB** equates to **92.7EPNdB** for the Lateral observer with an installed three-engine exhaust system.

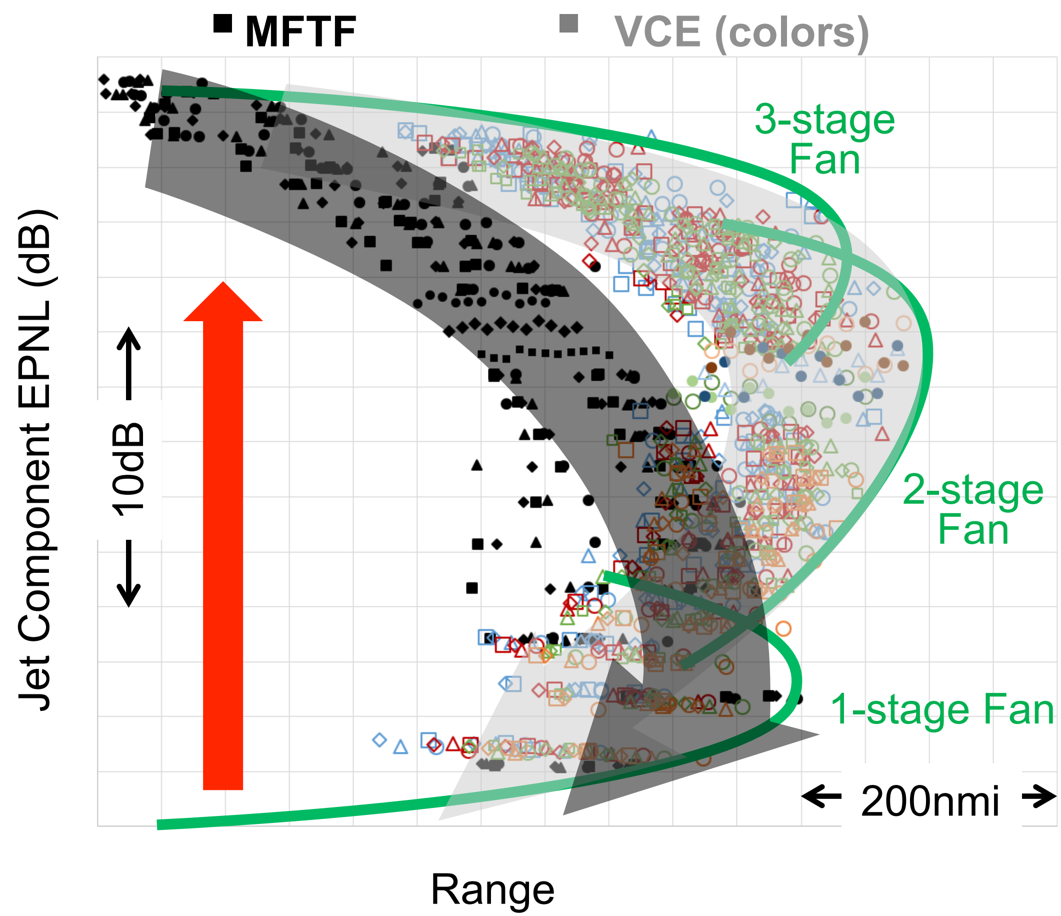


Getting to Airport Noise Goal

- Engine cycle/System design — 5 – 10 dB
  - Noise ~ $(\text{jet velocity})^8$
  - Programmed Lapse Rate (PLR)
  - Flight speed
  - High lift features
- Nozzle features — 2 – 4 dB
  - Enhanced mixing
  - Sculpted velocity profiles
  - Ejectors
- Installation — 1 – 3 dB
  - Shielding
  - Jet-by-jet interaction

Engine Design—Major Trades

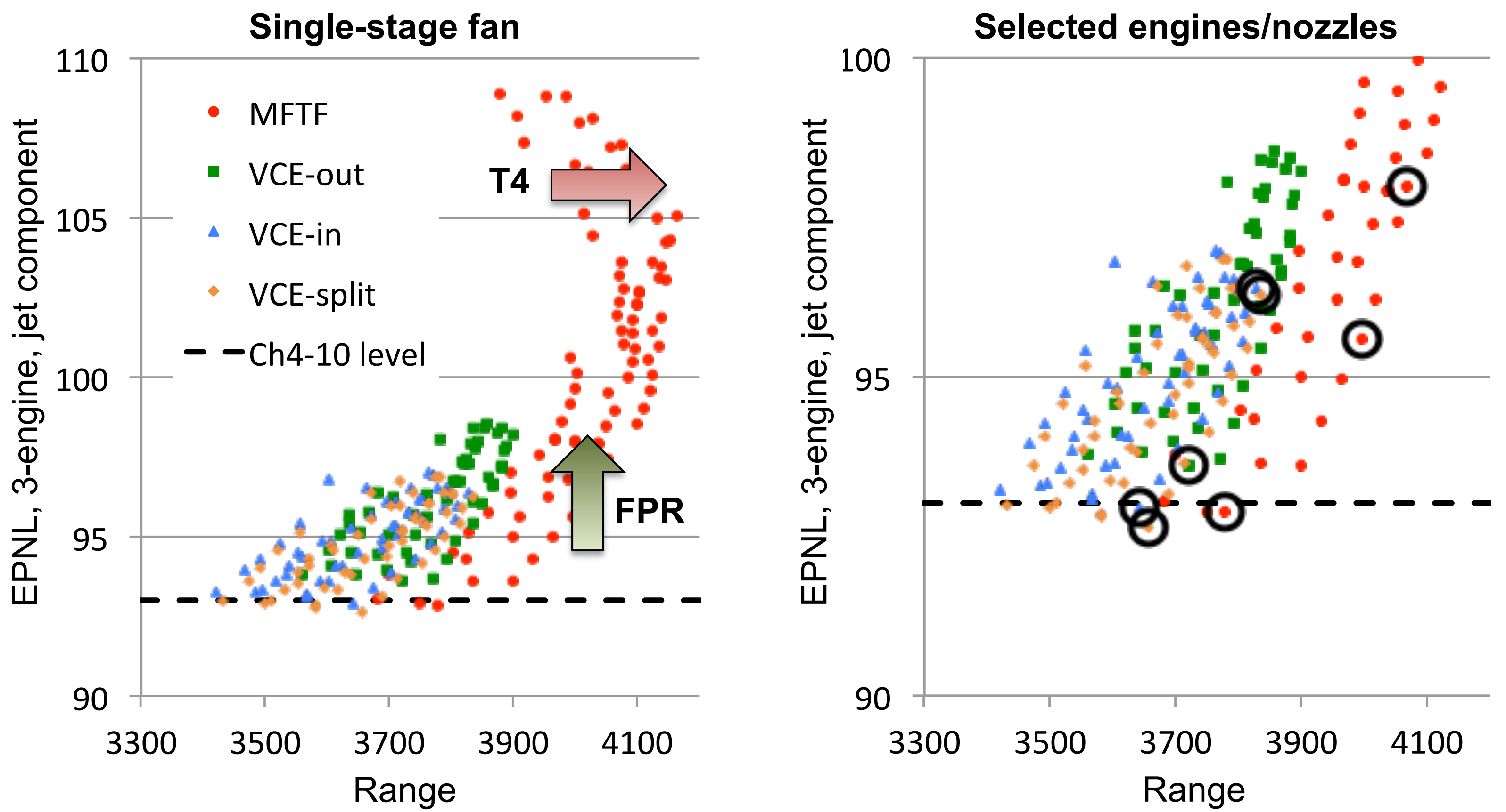
- 1000’ max power fly-over (lateral observer) used to assess noise.
- Overloading FPR per stage debits efficiency
  - Yields smaller engine
  - But reduced range
- Underloading FPR per stage increases engine weight & size (Fan & LP turbine)
- Outer 3rd stream (Tip-Fan) has diminishing acoustic & range impact as main FPR approaches that of Tip-fan.



- *Increasing FPR*
- *Decreasing BPR for mixed-flow*
- *Higher installed Thrust / Airflow (higher Vjet)*

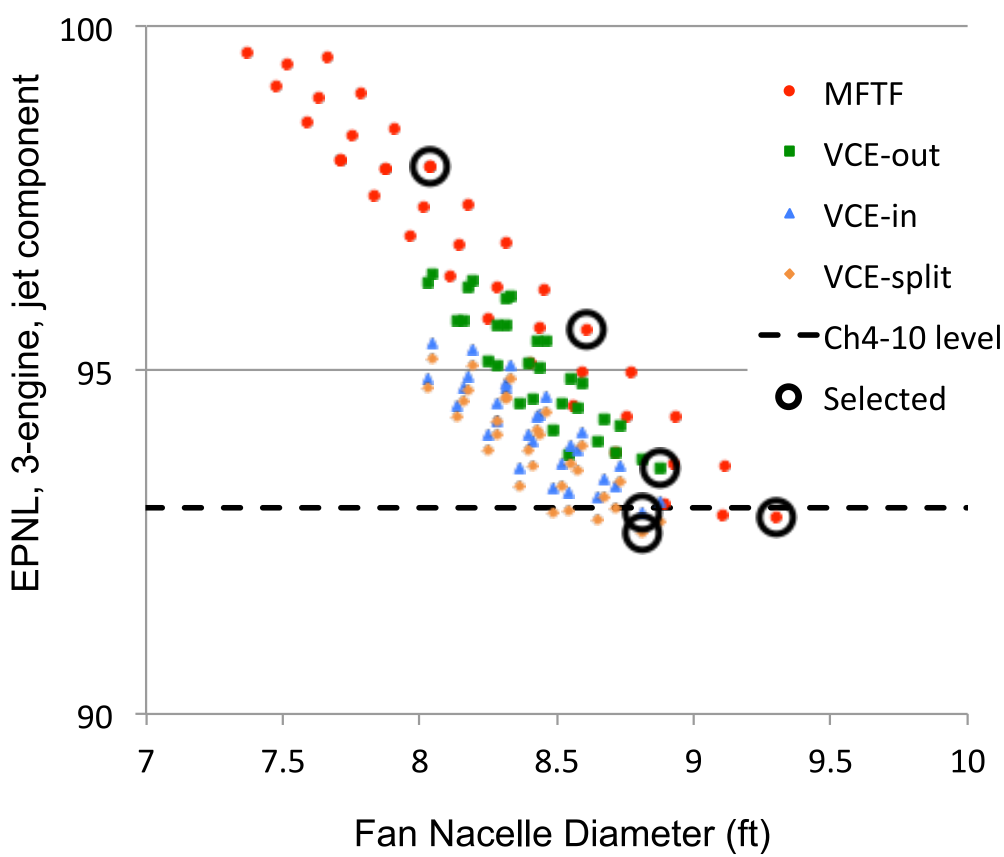
Engine/Nozzles for N+2 Goal

- Engine model exercised using design variables: # fan stages, nozzle type, FPR, tip BPR, T4
- Output lateral noise EPNL, range, engine diameter, emissions index
- Pick designs that meet noise goal with and without PLR.



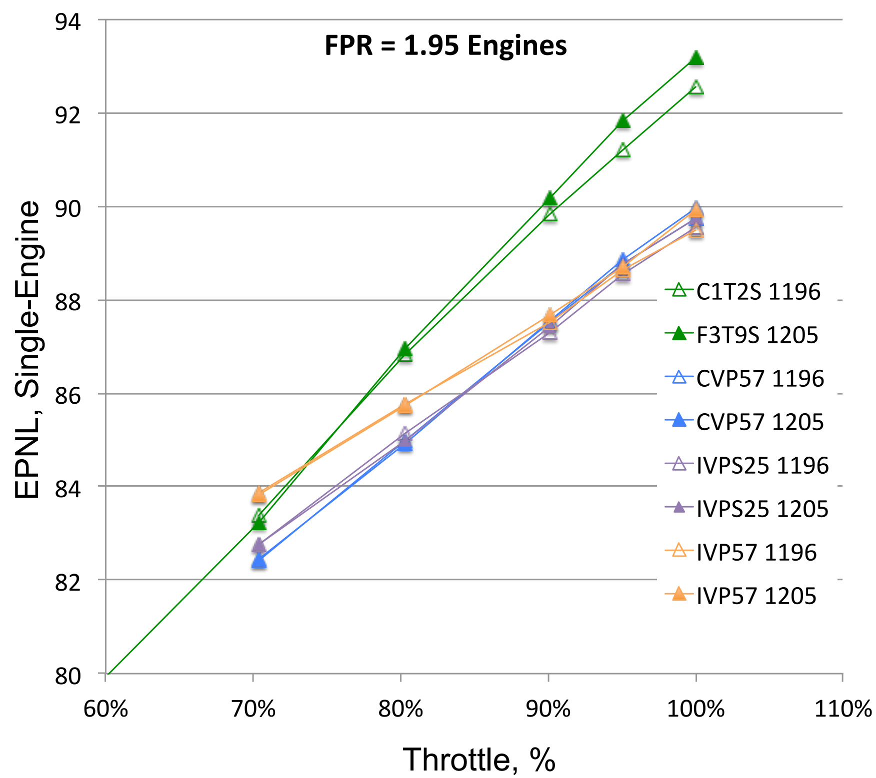
Noise vs Nacelle Diameter

- Engine diameter quantitatively impacts Range
- Engine diameter is soft limiter on sonic boom
  - Boom optimized by optimal airframe reshaping, wing reflexing.
  - At some point adjustments to airframe shape cannot compensate for engine area.



Impact of Nozzle Types on VCE engines

- Given cycle that gets close to target, compare impact of nozzle type
- ENPL vs throttle for two FPR = 1.95 engines (differ in BPR), different nozzle types in color
  - IVP, CVP nozzles make same noise at full throttle; IVP diverges at low throttle
  - Externally mixed is louder at full throttle; joins internally mixed nozzles at lowest throttle
  - Bypass ratio relatively unimportant



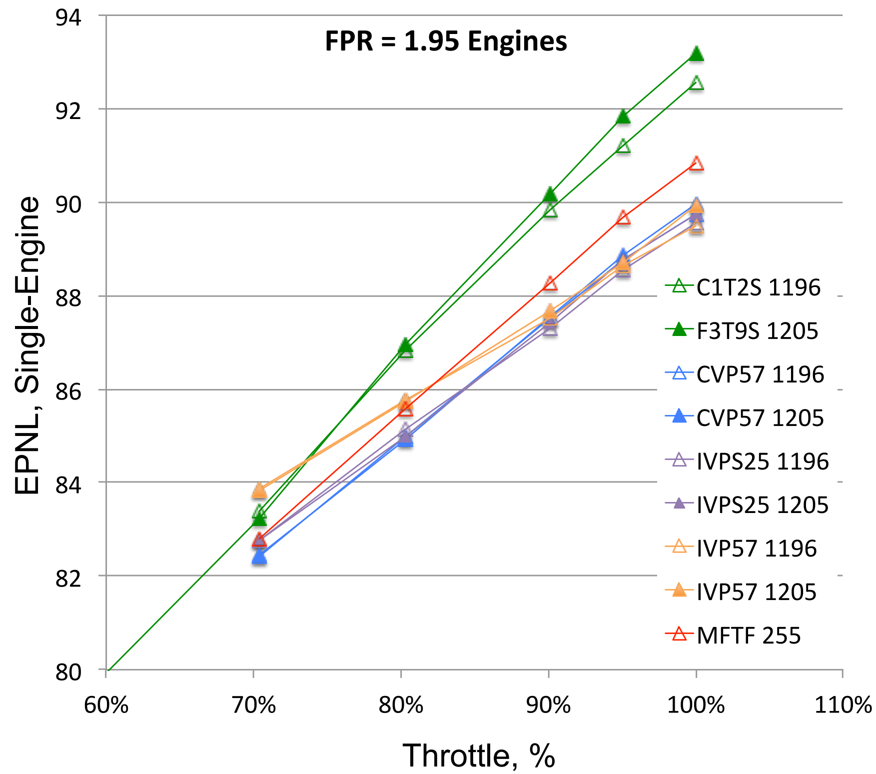
Setpoint	At/Ap	Ab/Ac	At/Ac	(Ab+At)/Ac
1196	0.53	1.78	1.52	3.30
1205	0.53	1.33	1.26	2.59

VCE vs MFTF

- Compare MFTF at FPR = 1.95
- Add MFTF engine/nozzle at same FPR

Compared to VCE with IVP or CVP nozzle:

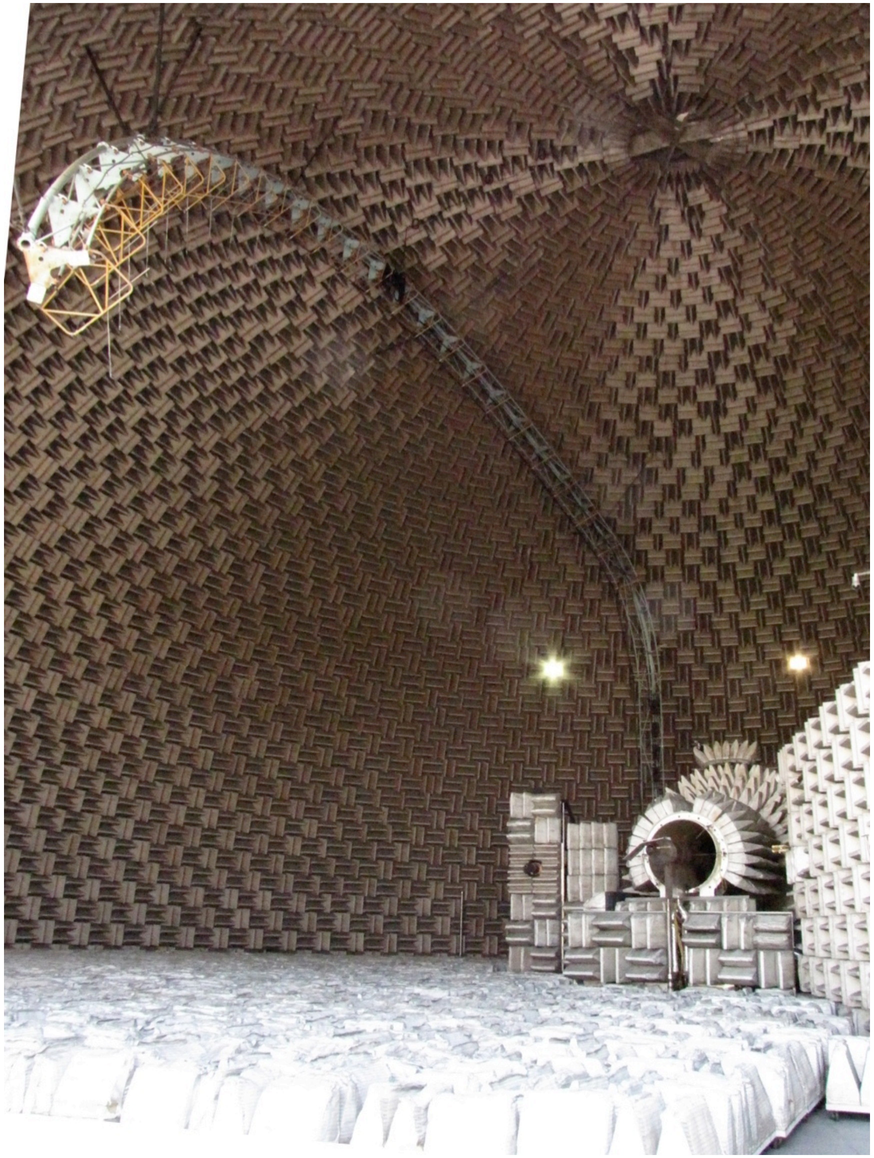
- MFTF is EPNdB louder than IVP/CVP
- MFTF gains 50nmi
- MFTF is 6% larger diameter



cycle	fanD	range
MFTF	8.177	4297.1
VCE	7.708	4241.4
VCE	7.685	4211.9

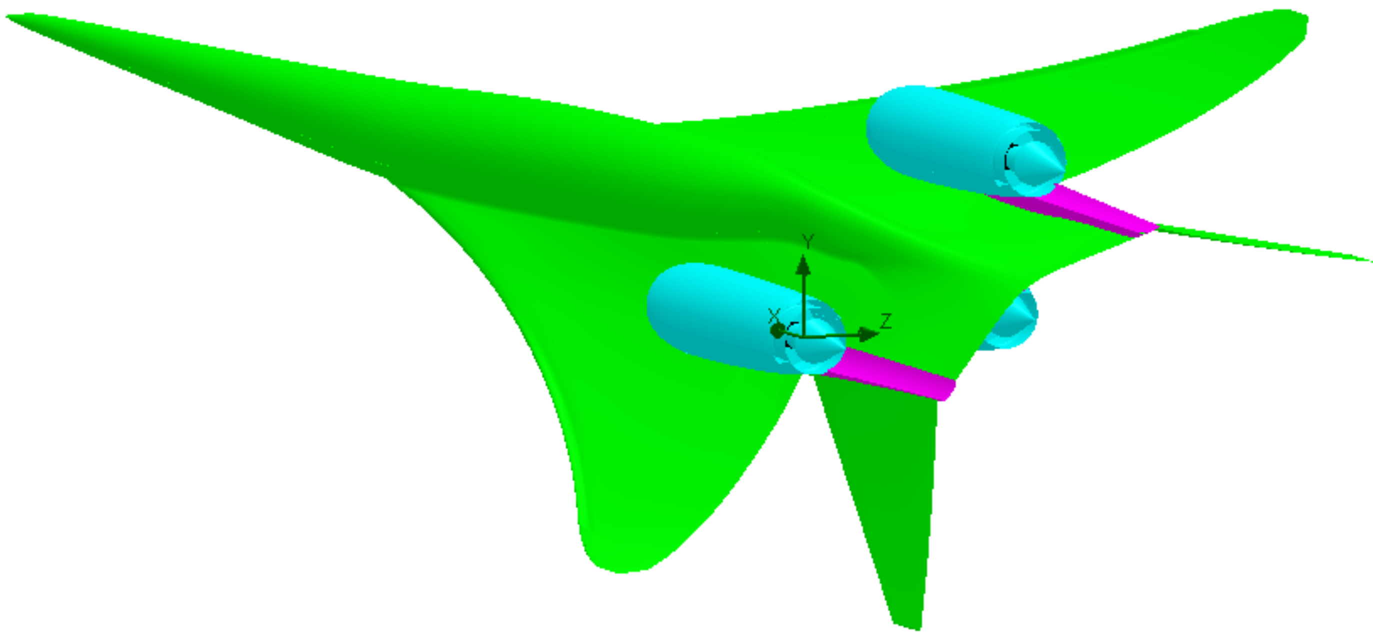
Demonstrated in Ground Test

- Model-scale testing in open freejet (NASA Glenn Nozzle Acoustic Test RIg) in anechoic chamber (Aero-Acoustic Propulsion Lab)
- 53” diameter freejet
- $M_{flight} < 0.35$
- Instrumentation
  - 45 ft radius far-field microphone arc
  - Phased arrays
  - Particle Image Velocimetry



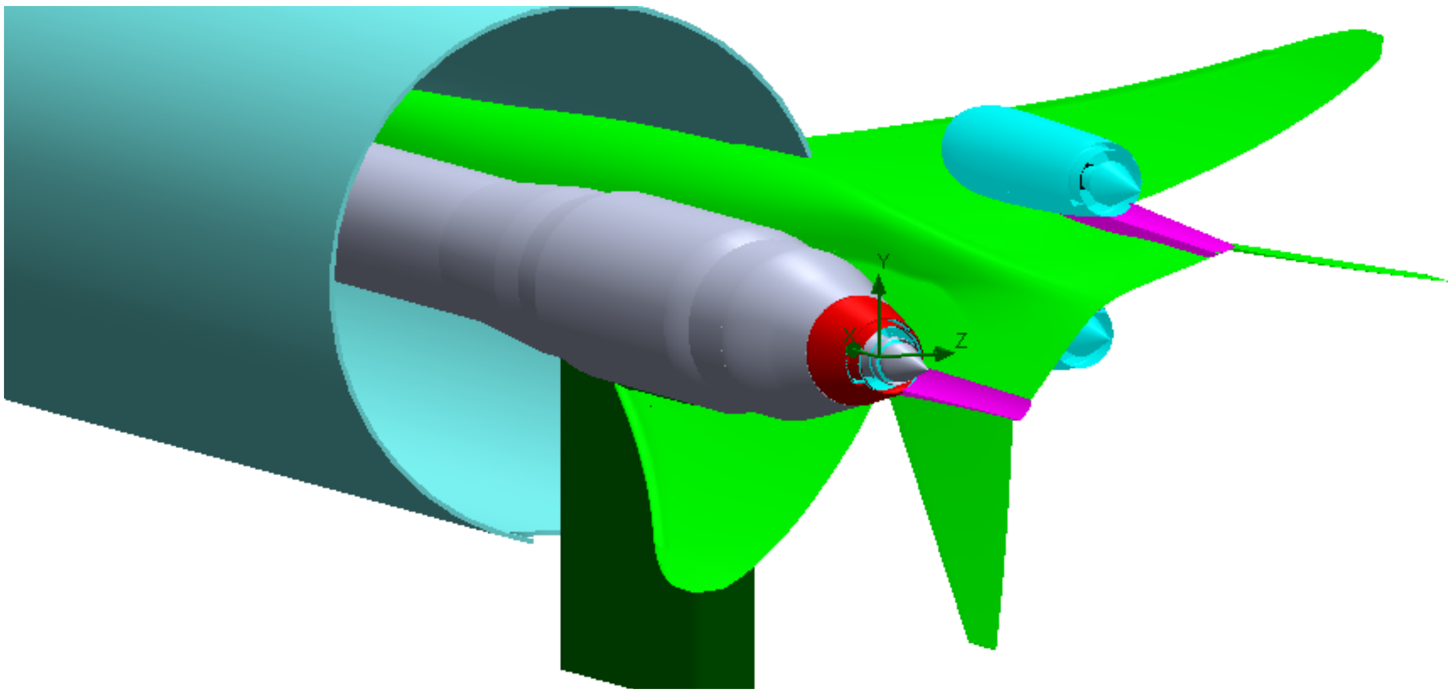
Demonstrated in Ground Test

- Aircraft positioned relative to microphones in ceiling



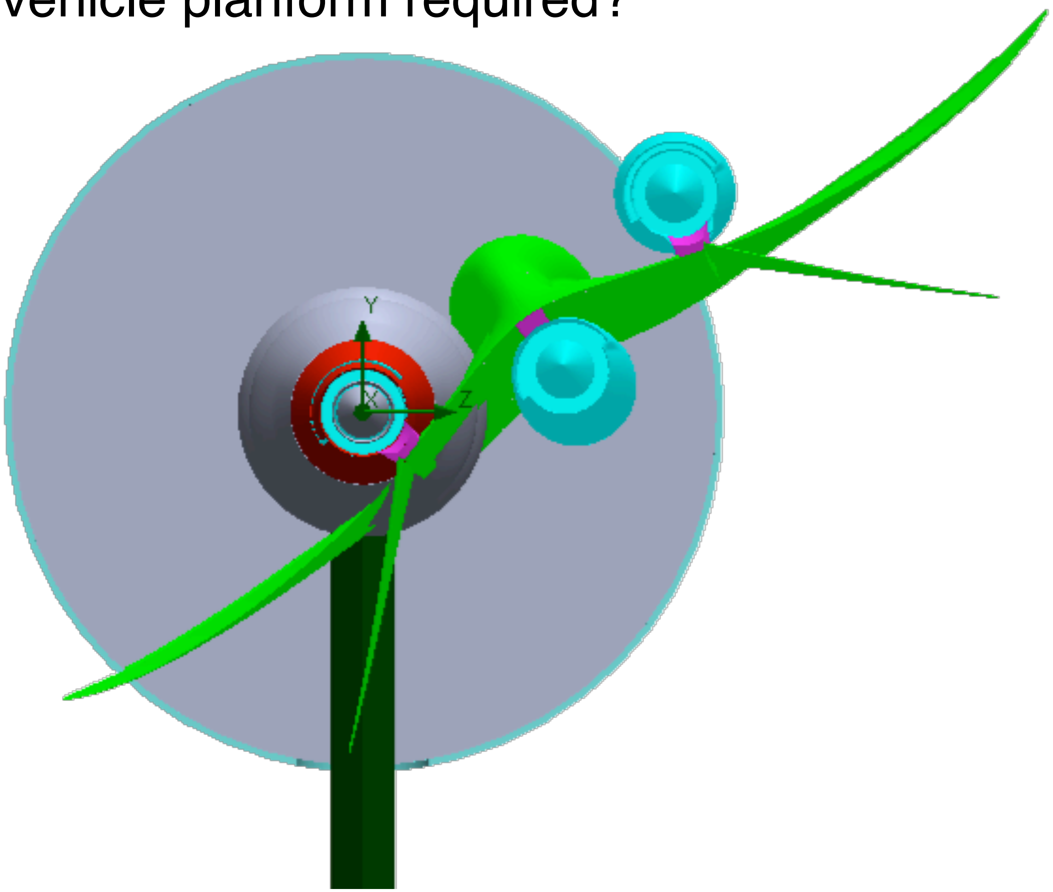
Demonstrated in Ground Test

- Aircraft superimposed on jet rig for outboard engine, matching nozzle size
- Note how much larger jet rig is than nacelle



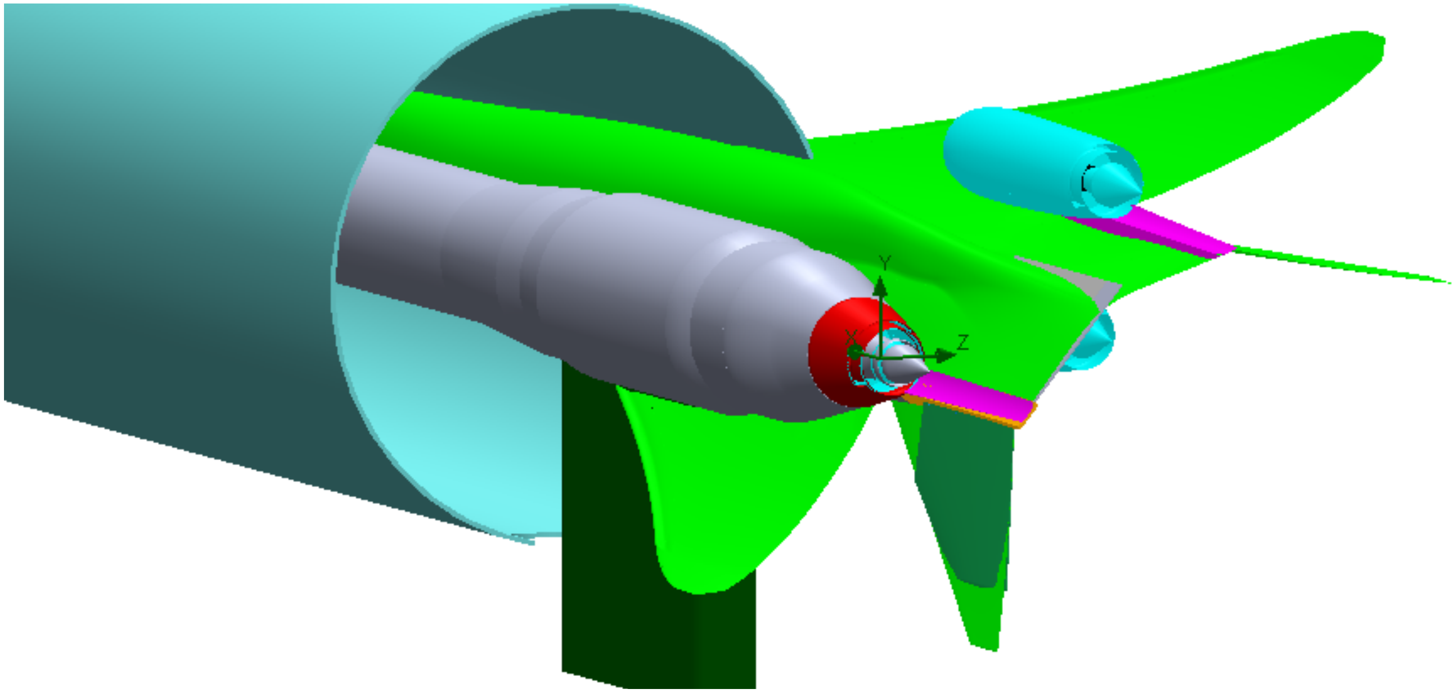
Fitting planform inside freejet flight stream

- Can’t put whole plane in!
- Avoid crossing freejet shear layer.
- How much vehicle planform required?



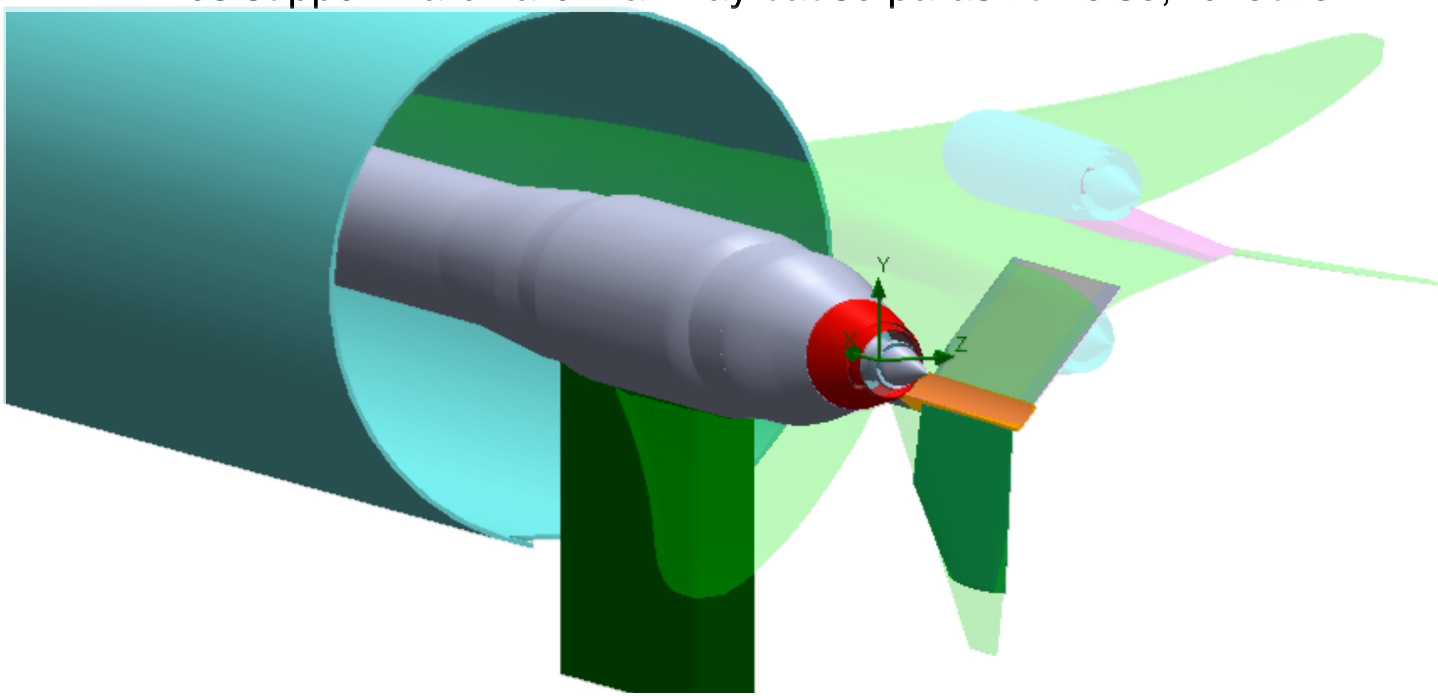
Fitting planform inside freejet flight stream

- Trim aircraft planform to fit within freejet.
- Neglect curvatures outside of pylon contours in immediate contact with flow.



Fitting planform inside freejet flight stream

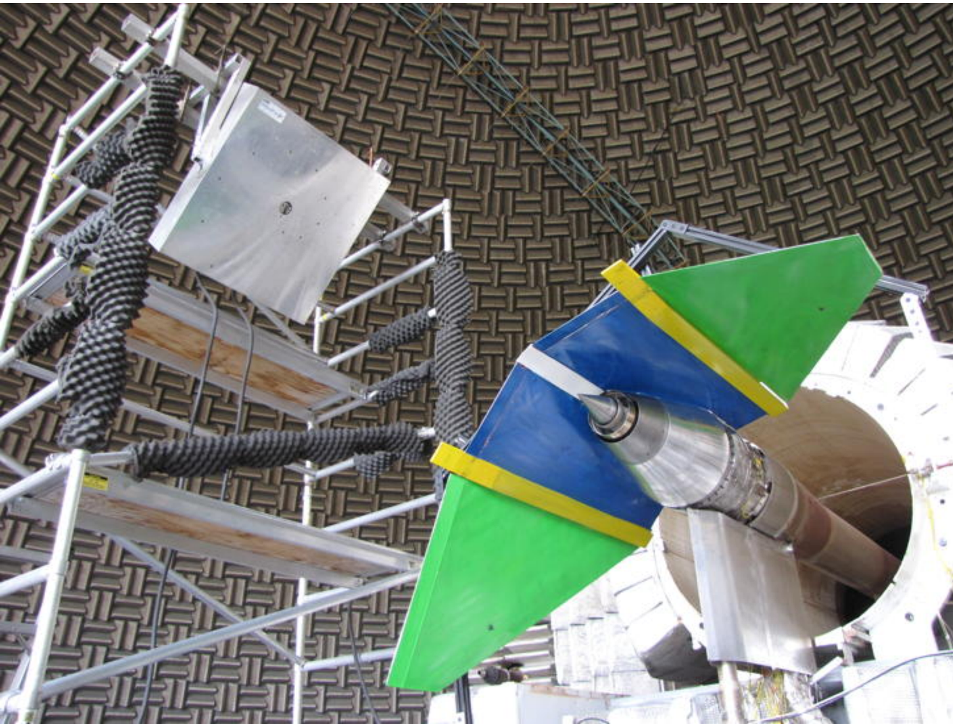
- Result: minimal aircraft planform
  - Captures reflection of jet plume noise sources.
  - Provides accurate trailing edge to interact with turbulent plume.
  - Minimizes support hardware that may cause parasitic noise, reflection.



Initial Tests of Installed Propulsion

- In 2015 a ‘static’ (no flight stream) test was conducted.
- Part of the test objective was to evaluate some critical aspects of the aircraft approximation.
  - How much of the vehicle planform has to be represented?
  - How many orientations must be measured?
- Determined minimal planform required for aircraft representation.

Center Engine Configuration, 0° orientation

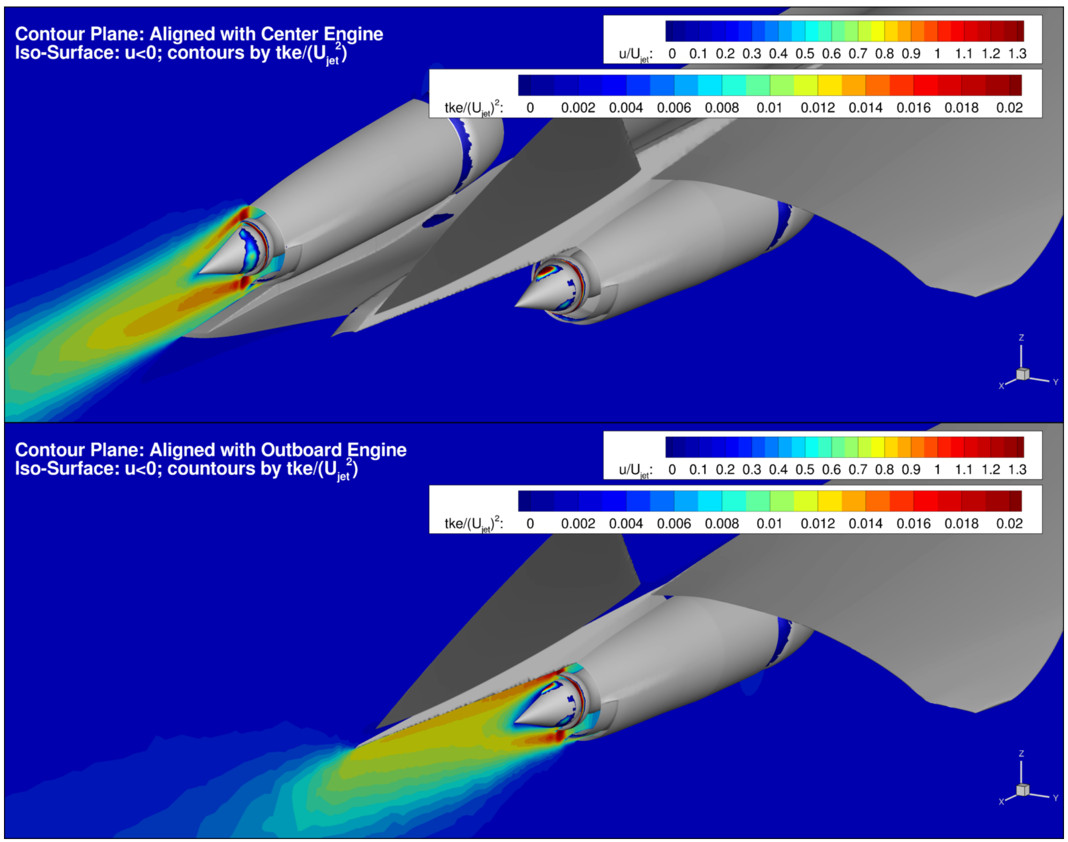


Outer Engine Configuration, 0° orientation

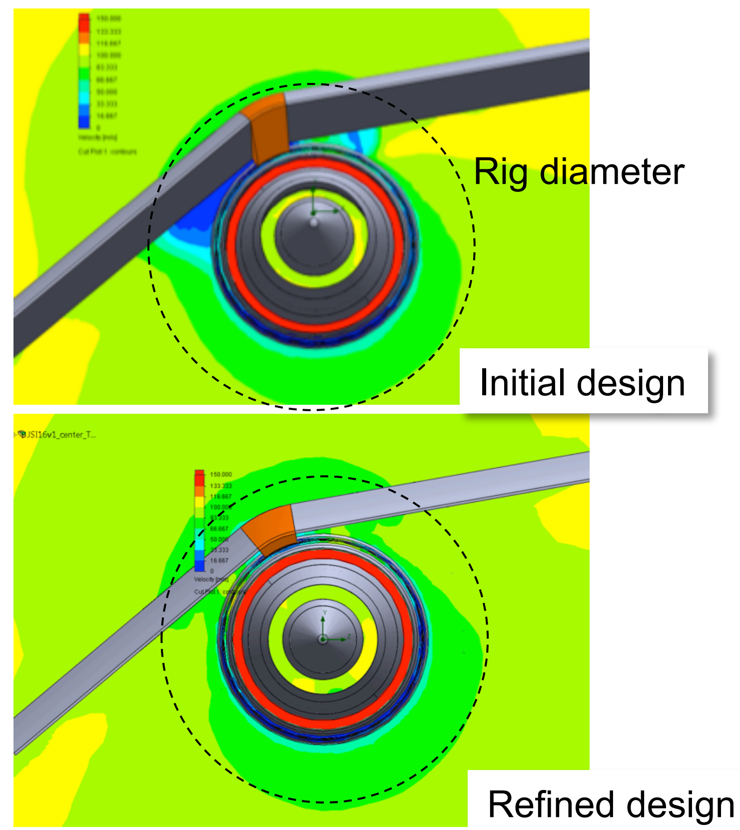
Match flight stream for integrated propulsion on LM1044 vehicle

- Looking for disparities in nozzle flows caused by
  - Differences in nacelle diameter and jet rig diameter
  - Cross-stream flows from lifting body

CFD of full vehicle to characterize flow around nozzles

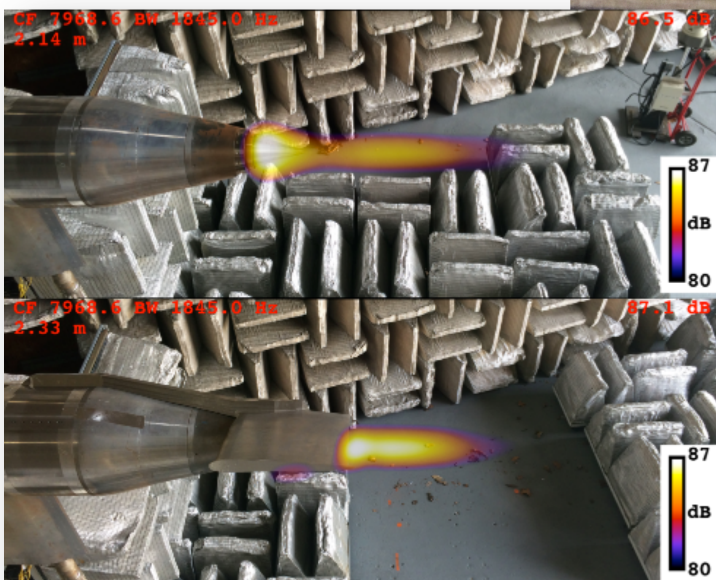


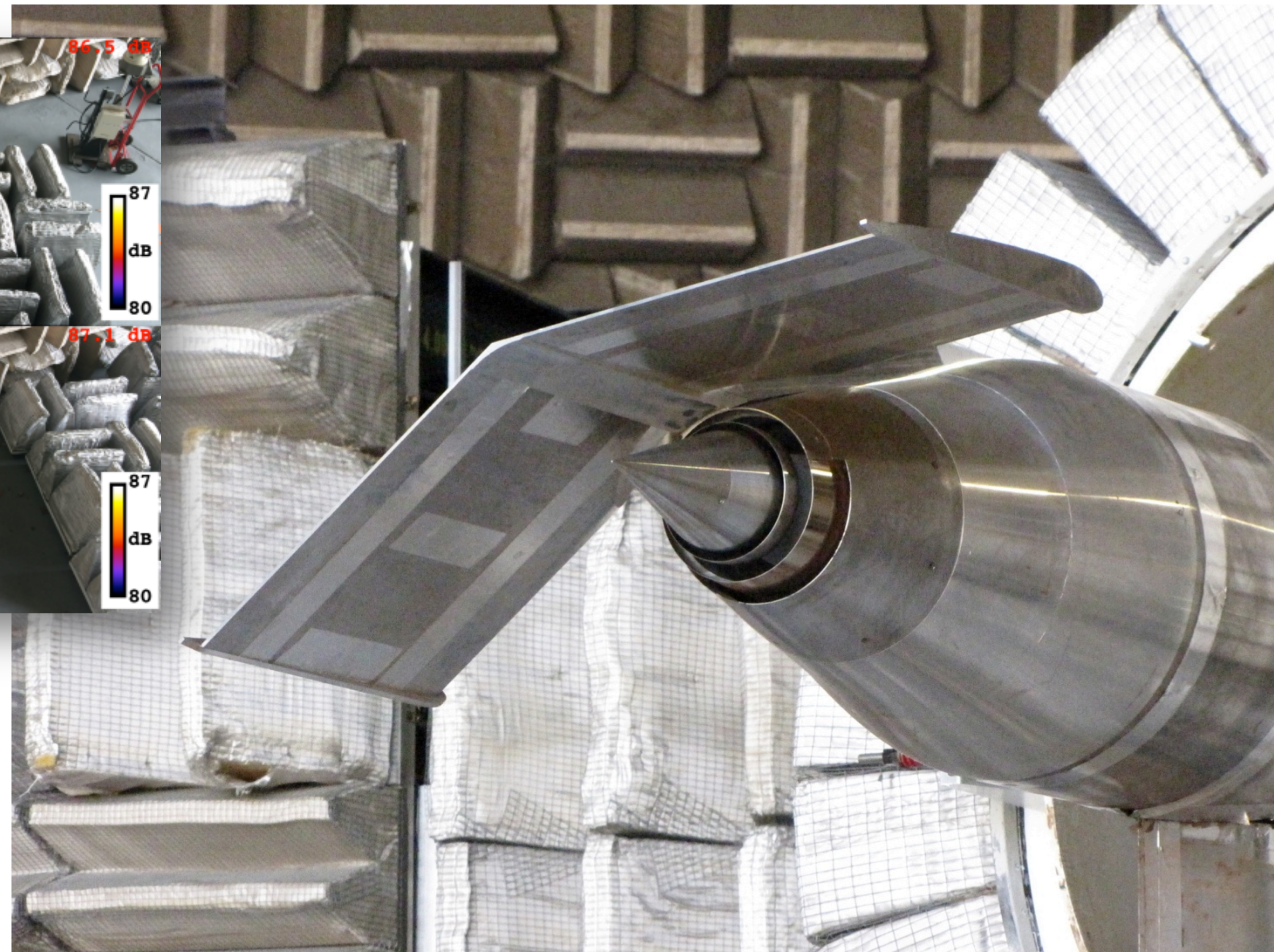
CFD of AAPL test article



2016 Integrated Propulsion Test

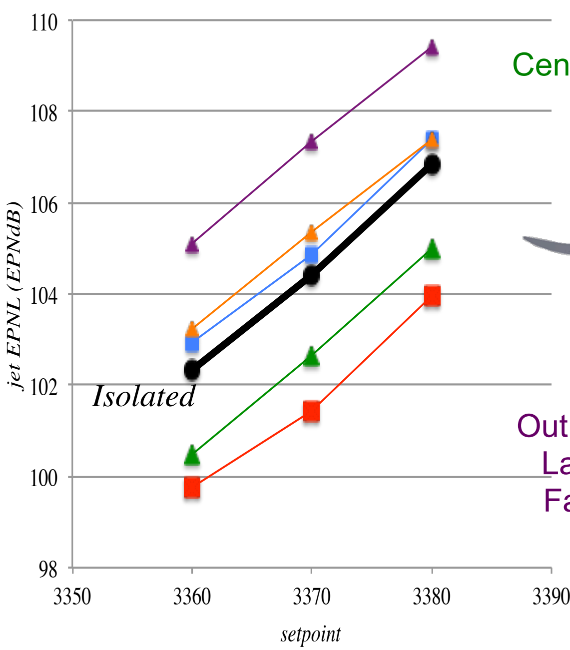
- Initial checkouts complete on center engine configuration
  - Confirm planform coverage
  - Satisfactory aero stability

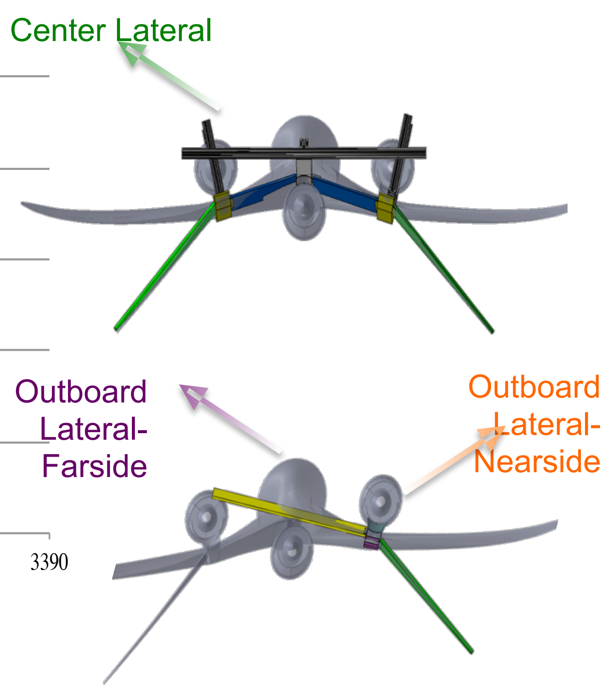


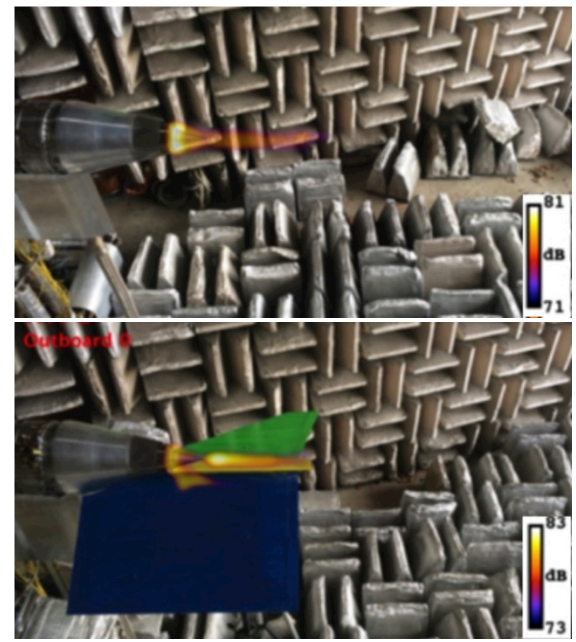


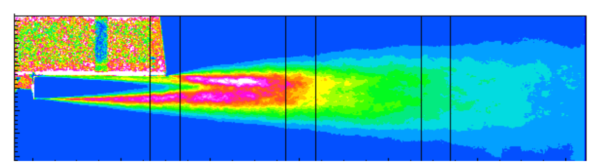
2016 Integrated Propulsion Test

- Test deliverables
  - EPNL of integrated multi-engine system for lateral observer to evaluate Goal achievement.
  - Measured vs predicted far-field noise directivities for multiple engine cycles/ nozzles to validate design predictions.
  - Phased array confirming shielding/reflection.
  - PIV of turbulent flow to validate design CFD.









Low Noise Propulsion for Low Boom Aircraft

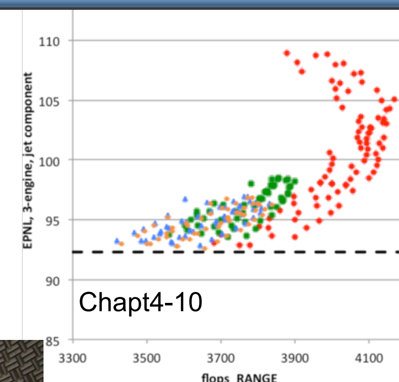
Technical Challenge To Be Completed Sep. 2016

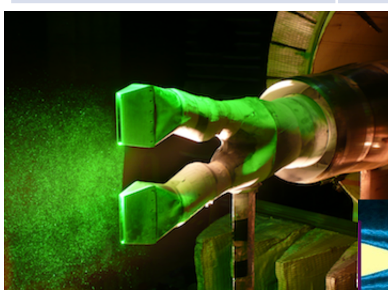
Design tools and innovative concepts for integrated supersonic propulsion systems with noise levels of 10 EPNdB less than FAR 36 Stage 4 demonstrated in ground test.

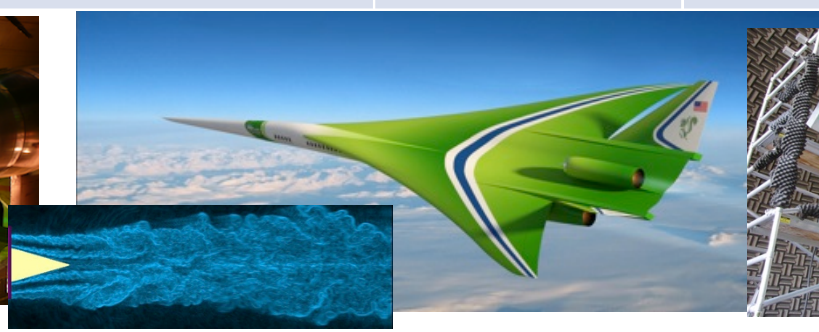
Deliverables:
1) Validate noise prediction and system modeling tools for prediction & optimization of N+2 supersonic airliner
2) Integrated aircraft solutions meeting airport noise requirements with viable range and low boom
3) Validation of acoustic performance and predicted design trades.

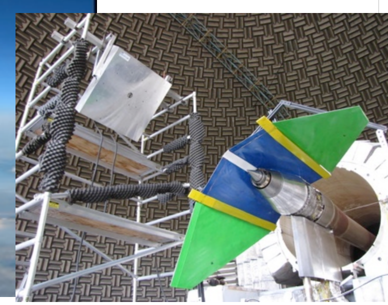
This space reserved

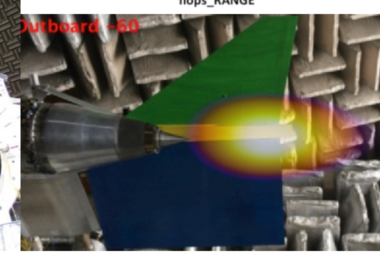
2013	2014	2015	2016
Multiple jet acoustic effect documented, modeled. Non-axisymmetric jet noise code created. IVPv2 design confirmed with LES.	Three-stream nozzle and IVPv2 tests completed. IVPv2 tests meet expectations First empirical models for three-stream and IVP nozzle systems	Aft-deck noise database 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.