NASA's Pursuit of Low-Noise Propulsion for Low-Boom Commercial Supersonic Vehicles

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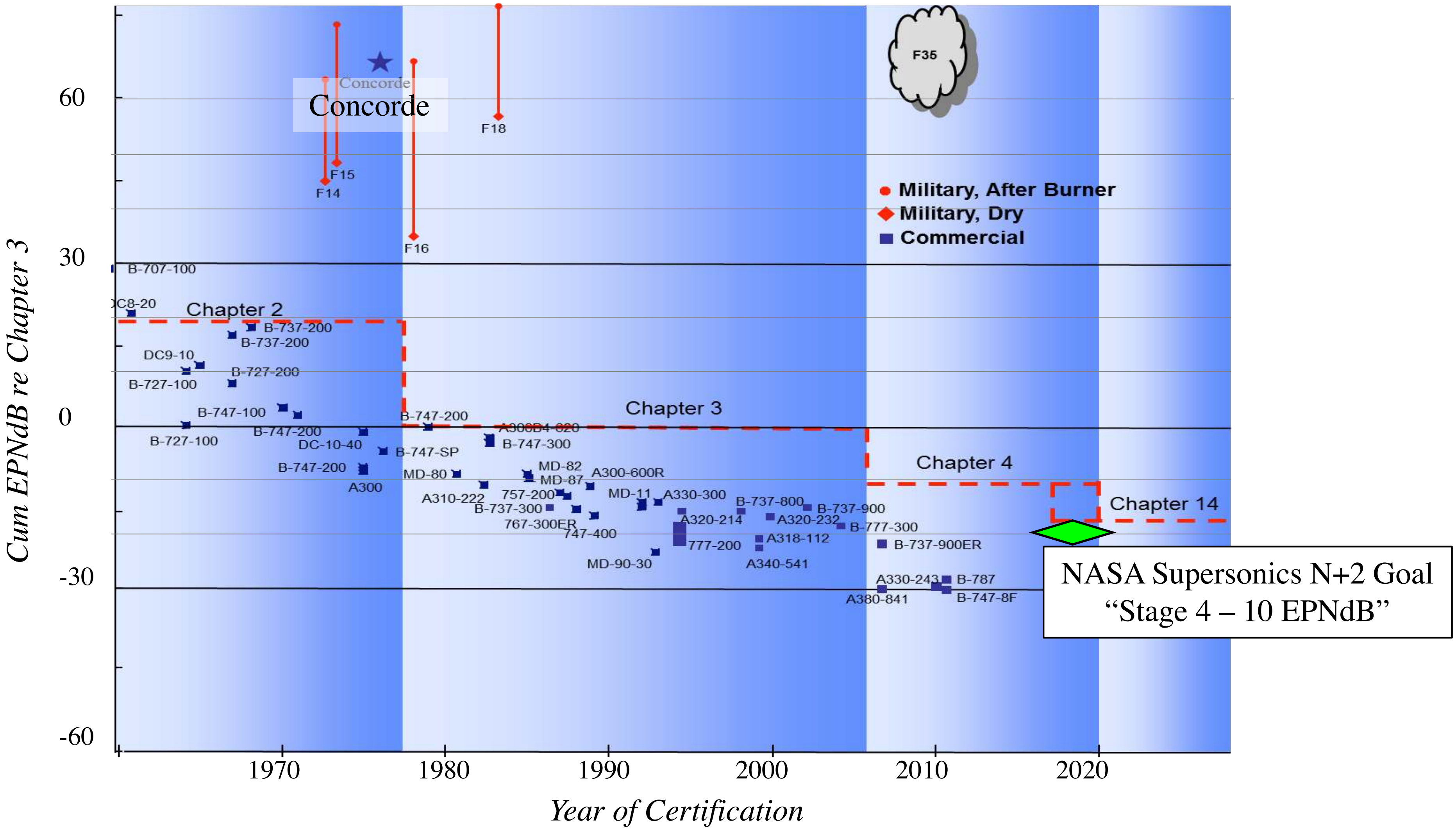
Supported by
NASA Advanced Air Vehicles Program/Commercial Supersonic Technology Project
And by many, many researchers working with NASA on supersonic aircraft noise.

Airport Noise—A Commercial Supersonics Challenge

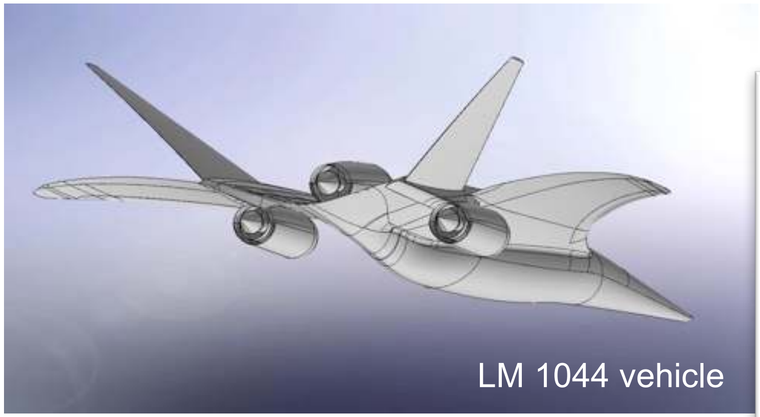


For Lockheed 1044 aircraft, Stage 4 – 10 EPNdB equates to **92.7 EPNdB** at Lateral observer. This is our **Noise Goal.**

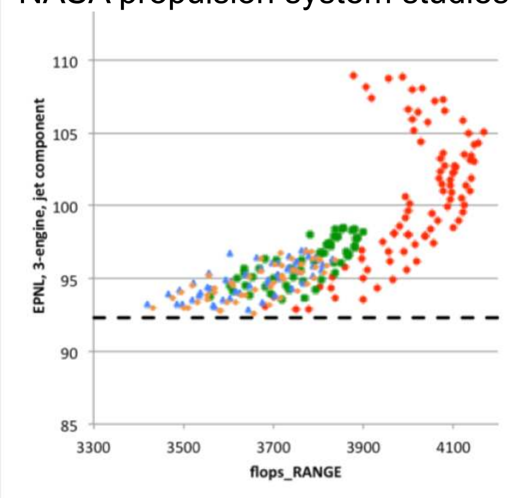
NASA's Supersonic Low Noise Propulsion Technical Challenge

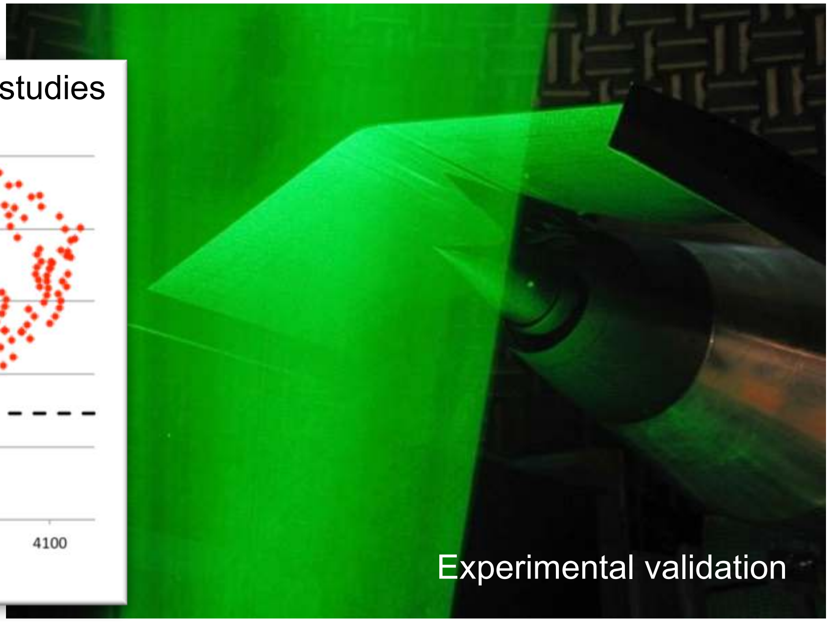
Exit Criteria: Creating **design tools** and **innovative concepts** for integrated supersonic propulsion systems with noise levels of **10 EPNdB less than FAR 36 Stage 4** demonstrated in **ground test**.

- Built on years of jet noise reduction exploration, prediction tool development
- Based on Lockheed-Martin 1044 airframe (aero performance, sonic boom)
    - 70 PAX, 145-tonne, low boom, 1.6 M_{cruise}
- Explored propulsion cycle/nozzles; focused on installed jet exhaust noise
- Validated designs in scaled model rig test with simulated planform


LM 1044 vehicle

NASA propulsion system studies




Experimental validation

Innovative Nozzle Concepts Explored

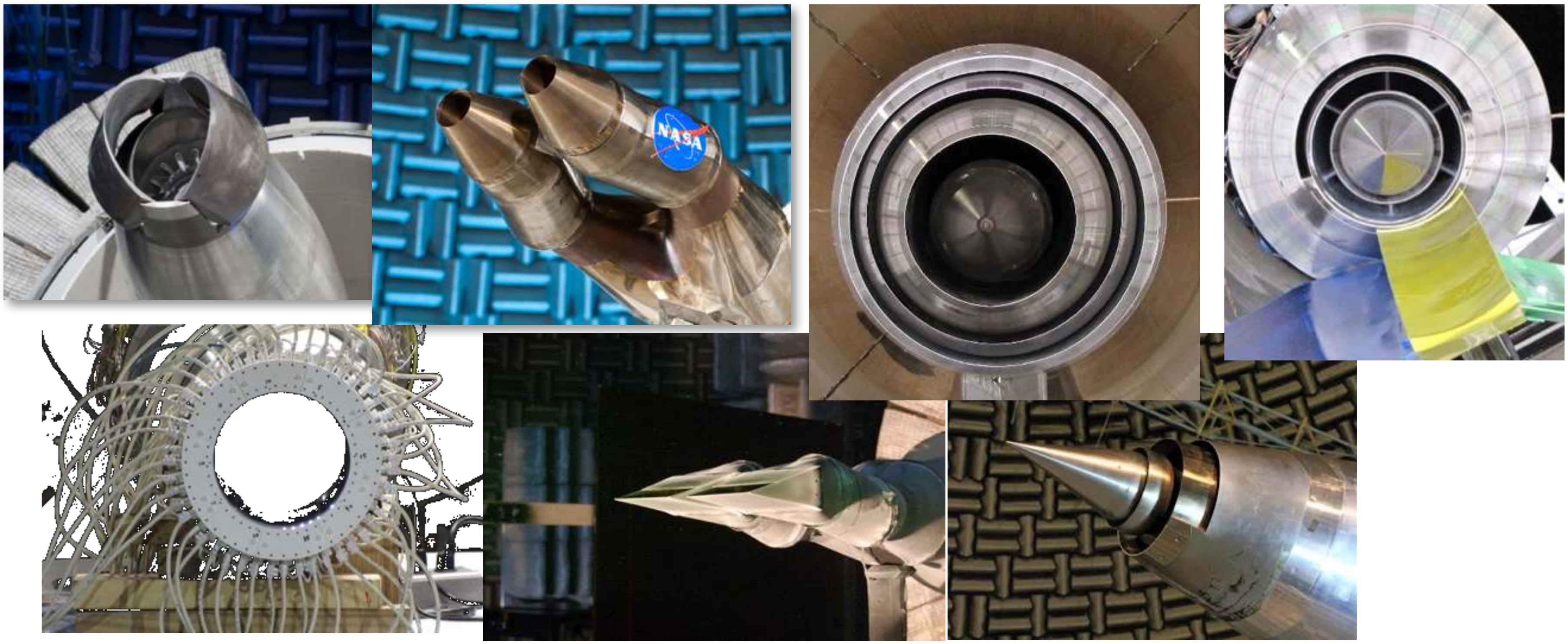
2011 2012 2013 2014 2015

Mixer-Ejector

Twin Jet Shielding

3-Stream Offset

Split Velocity Profile



Plasma Excitation

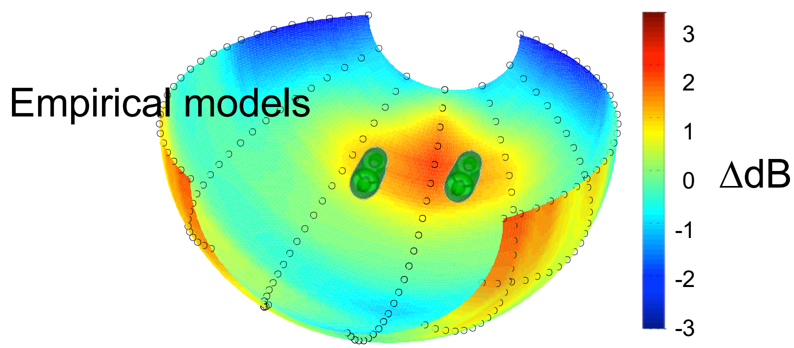
High Aspect Ratio

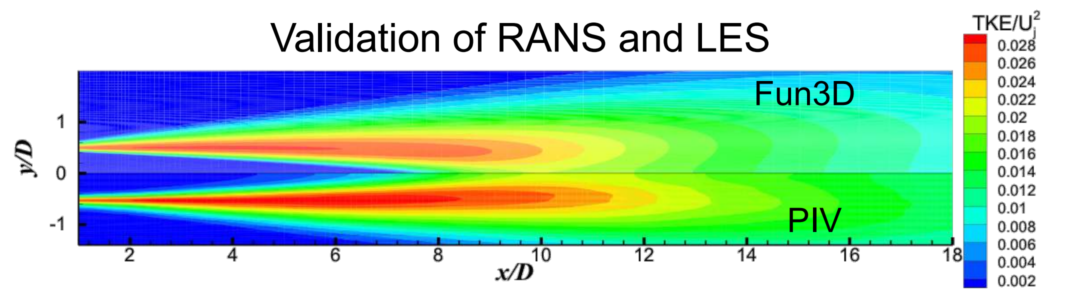
Inverted Velocity Profile

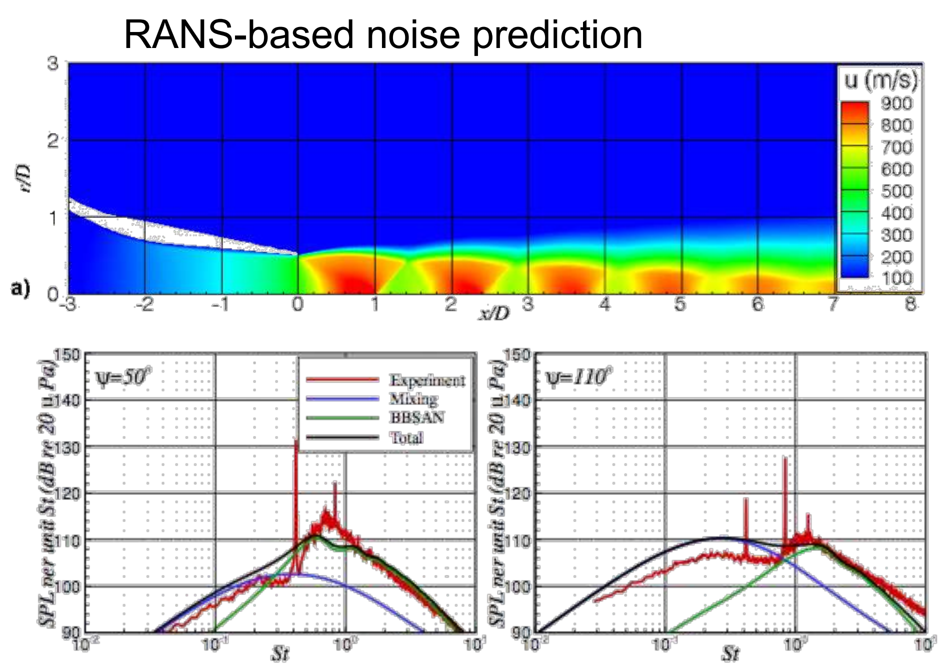
Acoustic benefits documented in databases for modeling used in design.

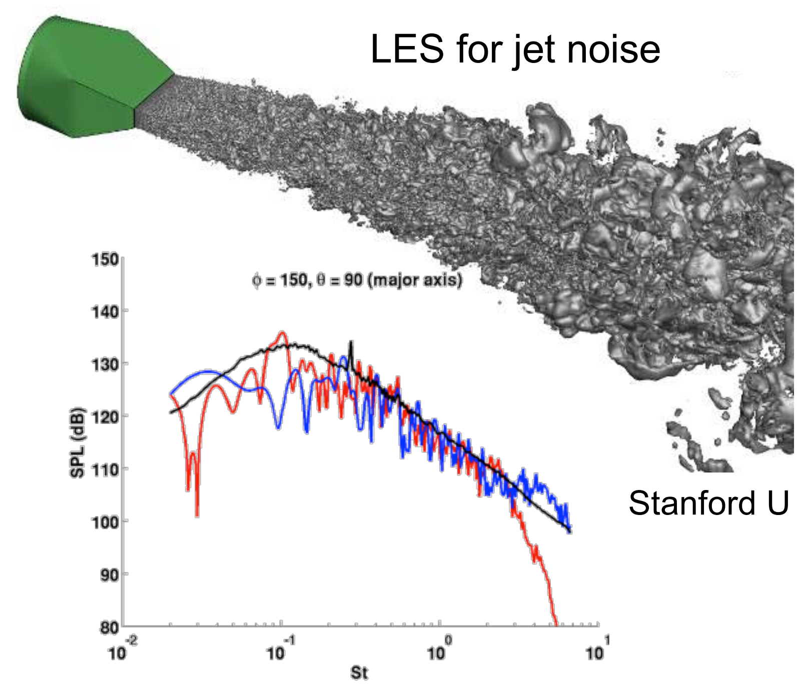
Broad Range of Noise Prediction Tools

- NASA supported development of cutting edge jet noise prediction tools, from empirical models for system-level predictions, to large eddy simulations.



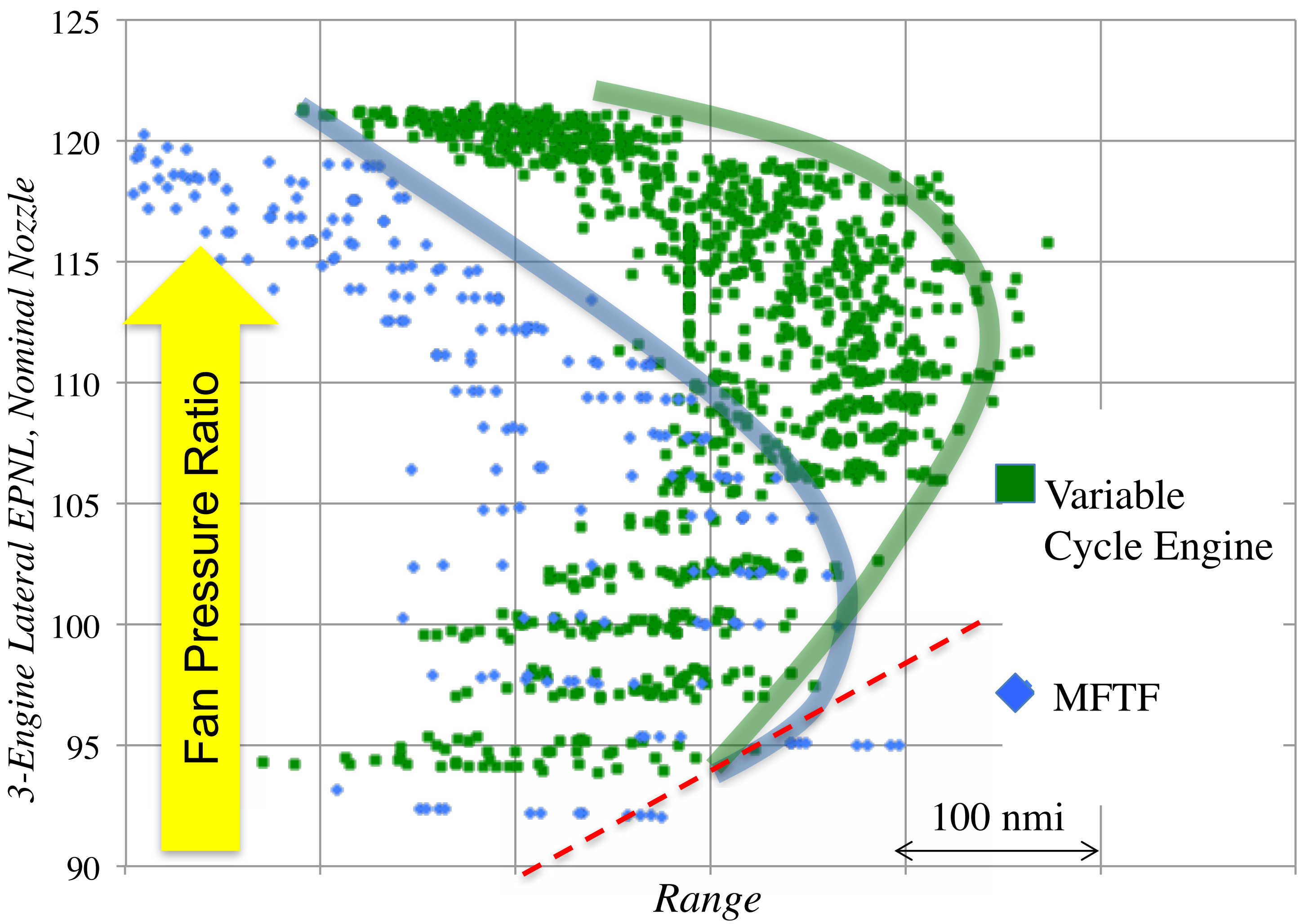






Early exploration of Variable Cycle Engines (VCE)
Noise vs range

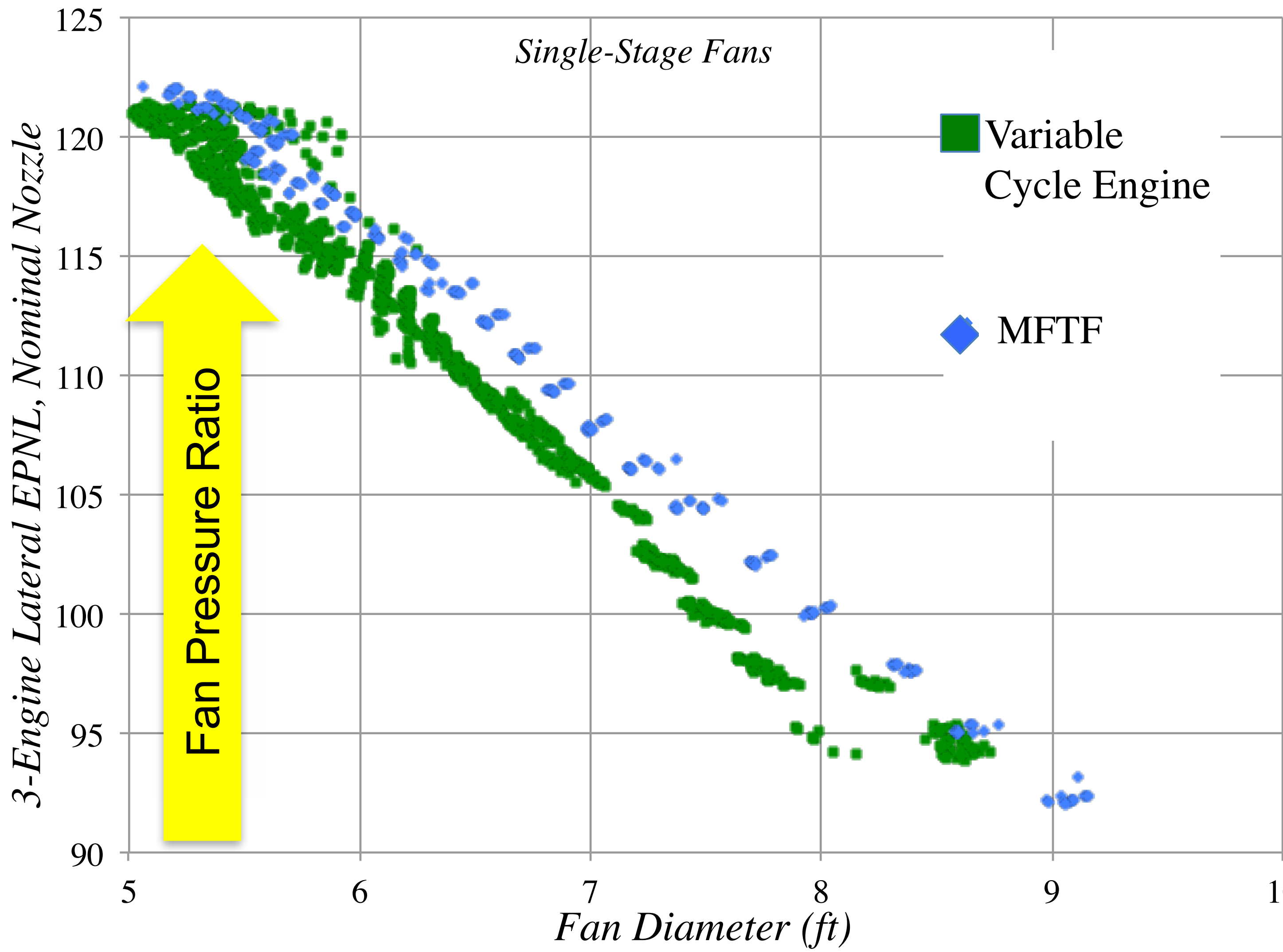
- Exercise NPSS numerical model for VCE and mixed flow turbofan (MFTF) designs.
- Dominant design parameter for noise is Fan Pressure Ratio (FPR).
- At low FPR, both engines have large losses in range for noise benefit.



Early exploration of Variable Cycle Engines (VCE)

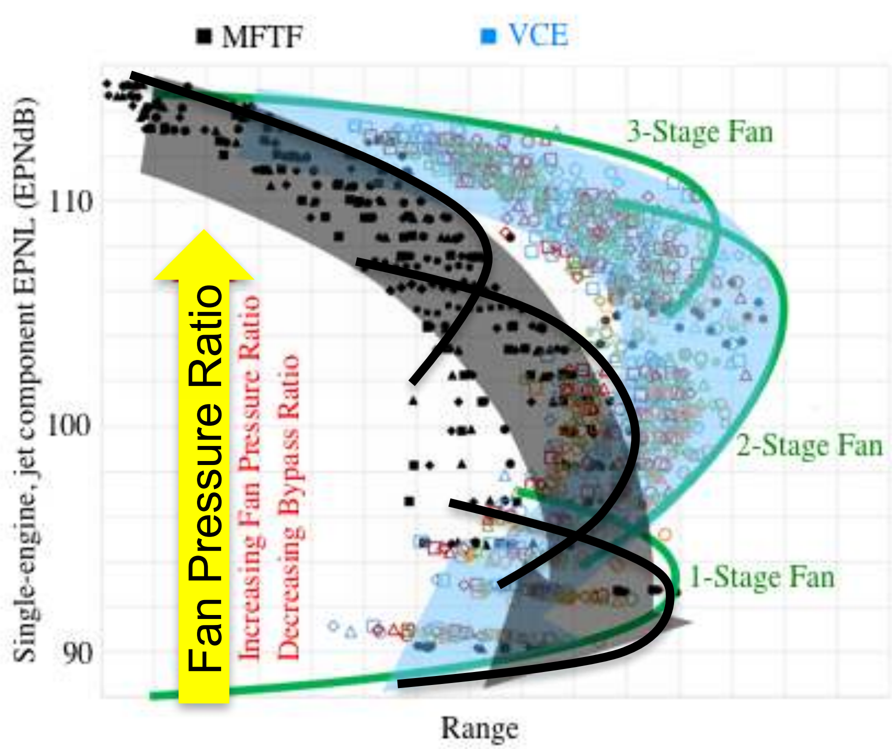
Noise vs Fan Diameter

- Fan diameter as surrogate for sonic boom.
- Lower FPR, larger engine diameter. Bad for boom, range.
- VCE engines have smaller diameter, more weight for given FPR.



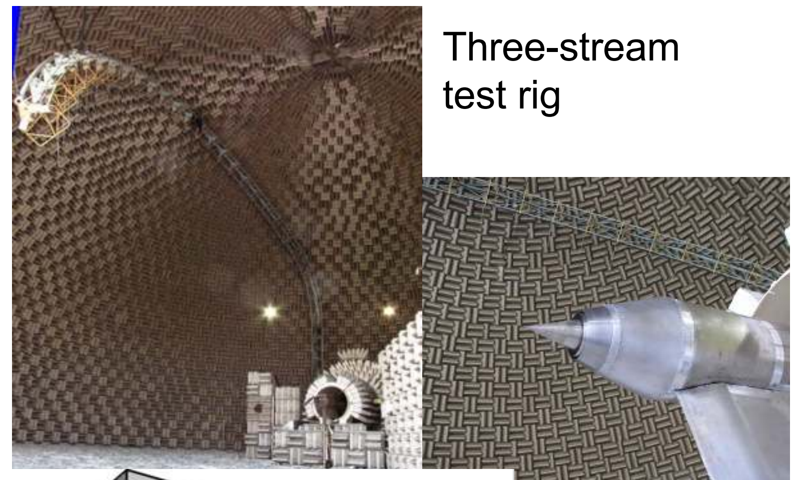
Early exploration of Variable Cycle Engines (VCE)
Fan stage count

- Increasing FPR produces smaller engines, more range.
- As FPR further increases, fan losses become prohibitive—add fan stages.
- As fan stages increase past 2, engine weight increases and max range suffers.
- Two-stage VCE significantly better range than two-stage MFTF.
- At FPRs where jet noise is tolerable, the mixed flow turbofan gives comparable or better range.



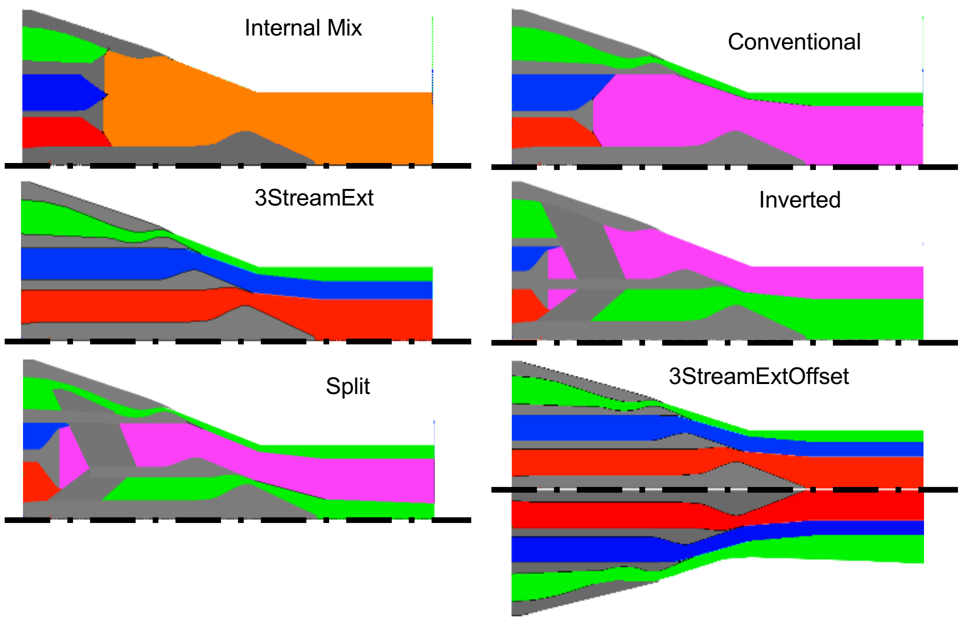
Acoustic Impact of Nozzle type
TSS models for noise of three-stream nozzles

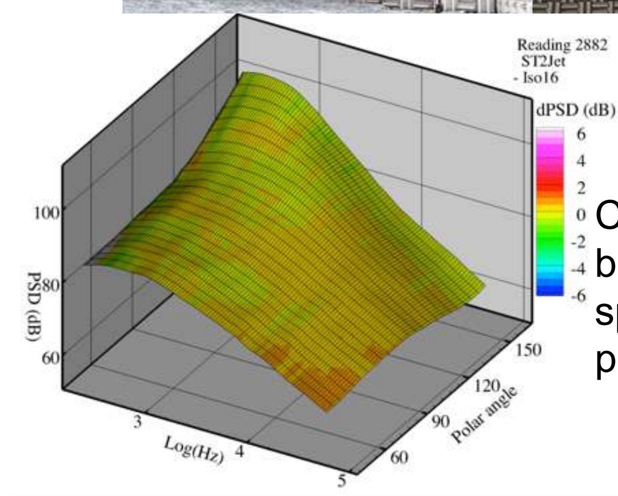
- Empirical noise models for various three-stream nozzles developed from model-scale aeroacoustic tests.
- Applied as 'corrections' to basic Stone jet noise model in NASA's Aircraft Noise Prediction Program (ANOPP).



Three-stream test rig

Three-stream nozzle types in TSS

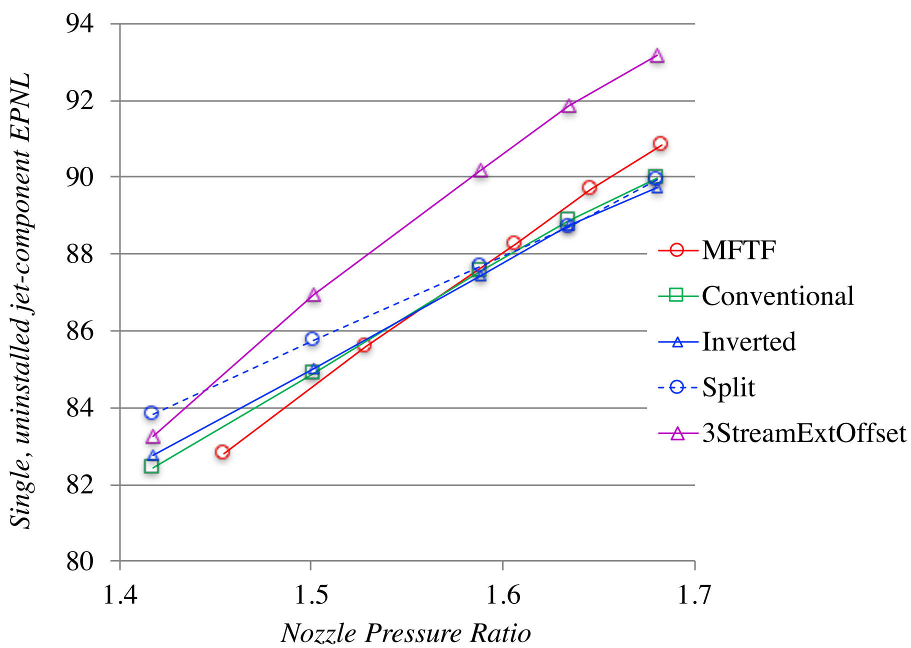


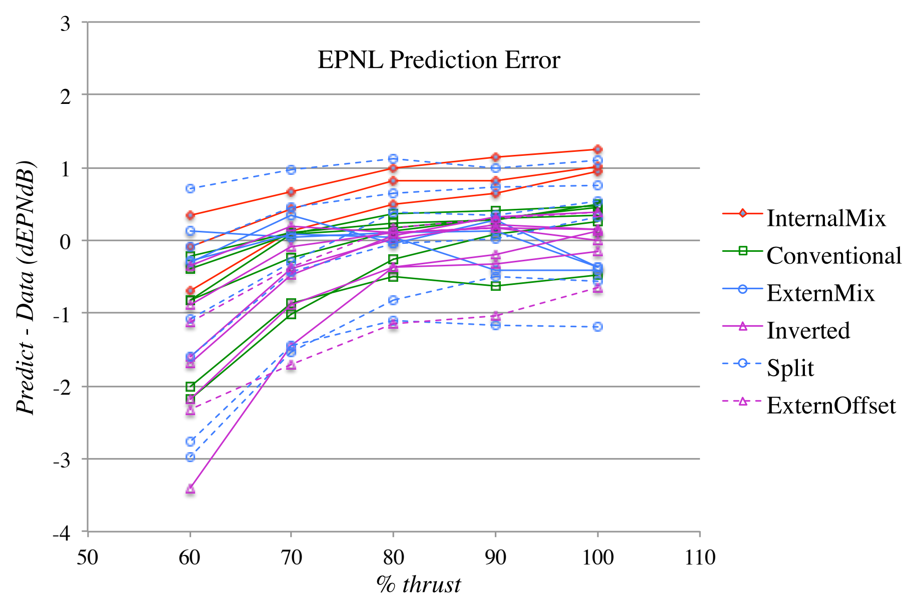


Correction to basic jet noise spectral directivity prediction

Iso16 Test: Nozzle Type Validation Results

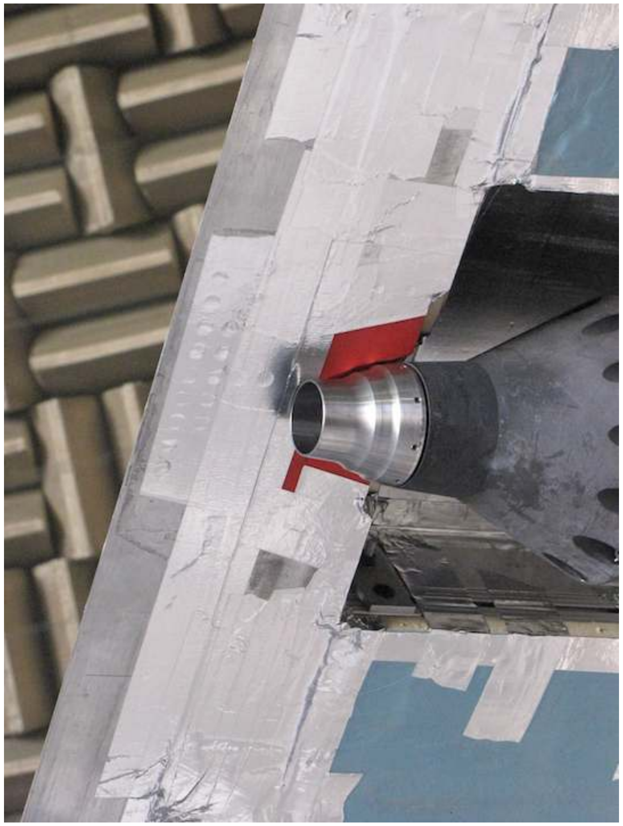
- Noise prediction codes applied to VCE designs, tested on six nozzle types in isolation.
- Direct comparison of nozzles on same engine cycle.
- Results compared at spectral directivity and EPNL levels.
- Only separate flow nozzle significantly different.
- Most cases predicted within expected uncertainty of ±1 EPNdB.

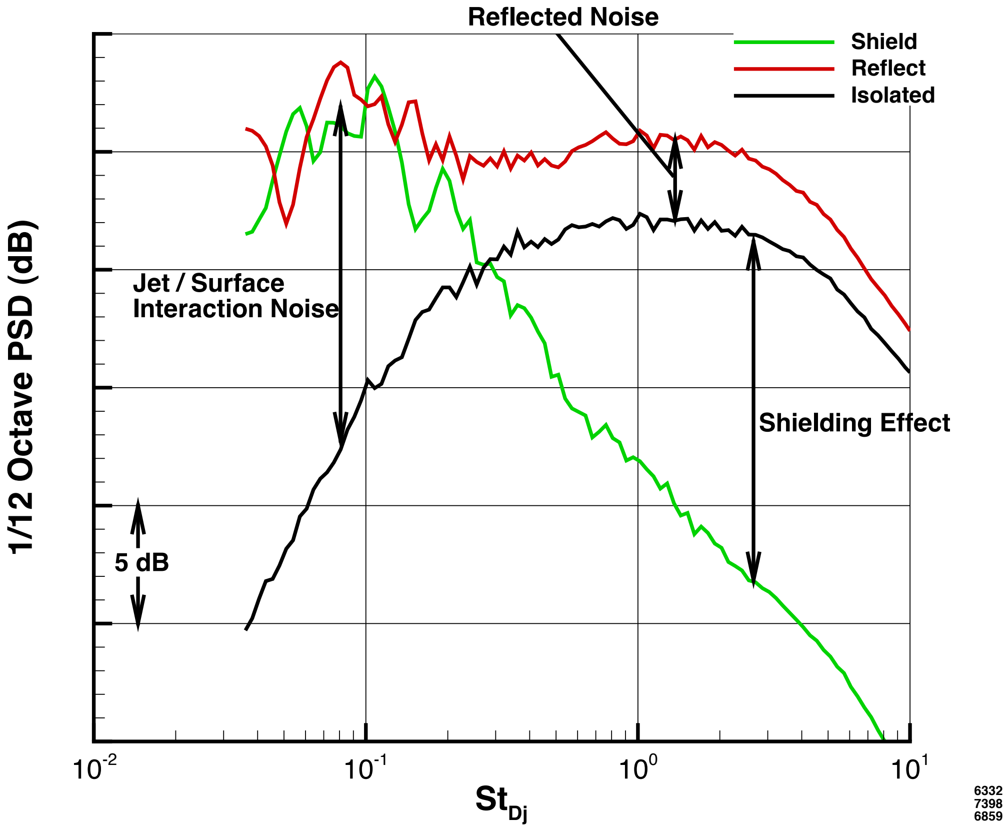




JSI Tests: Effect of Installation on Jet Noise

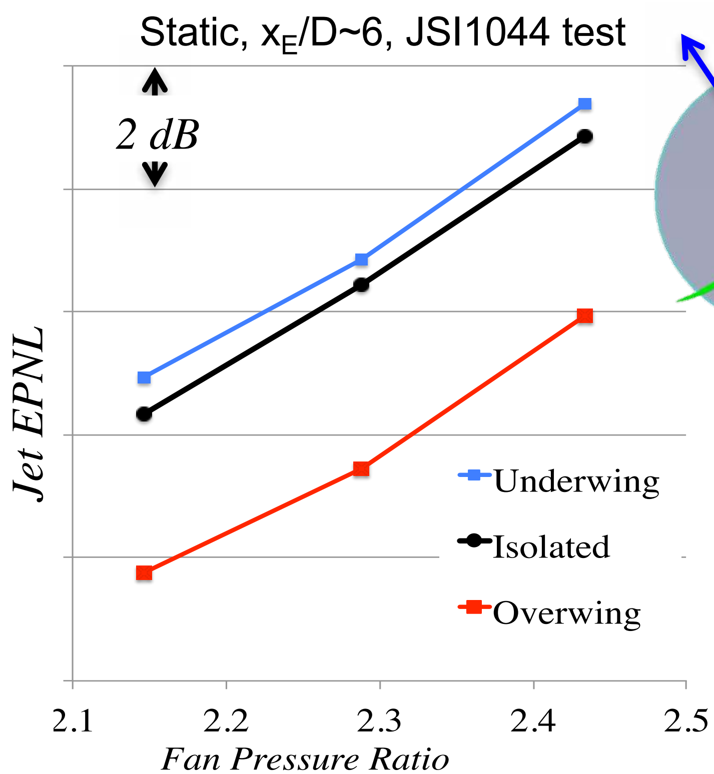
- Early simple experiments documented effect of shielding/reflection for simple round jet, and the addition of a trailing edge dipole source.
- Simple models developed for installation effect, but did not include impact of multiple stream nozzles, limited planform size, or flight.

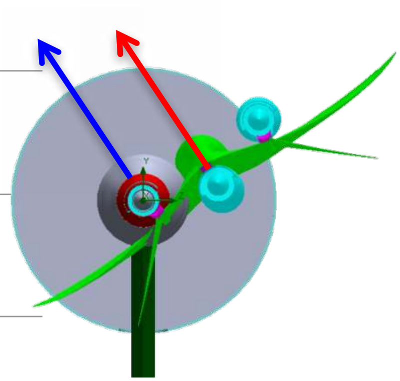


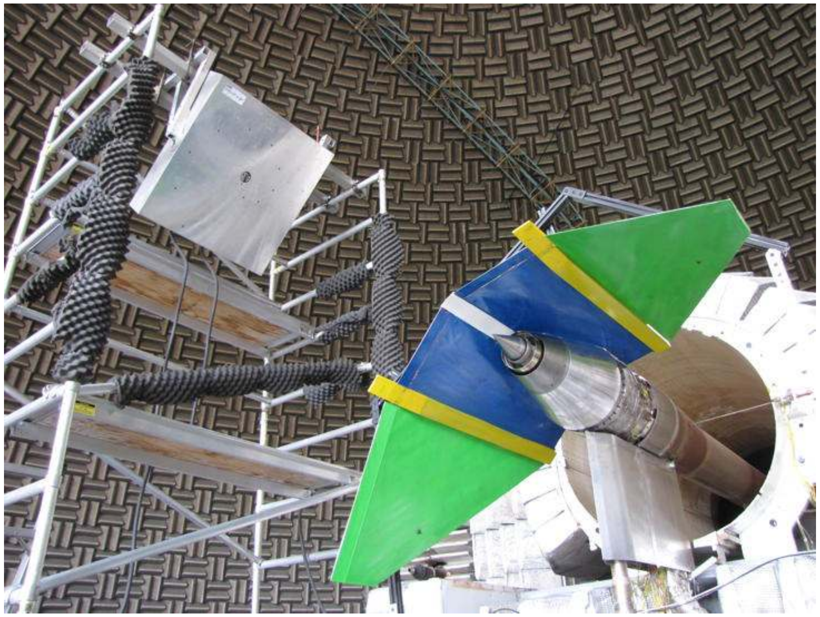


JSI1044 Test: Installation Impact

- Impact of installing engines underwing and overwing
- Static (no flight stream) test
- First jet-surface interaction test with multi-stream nozzles, realistic geometry



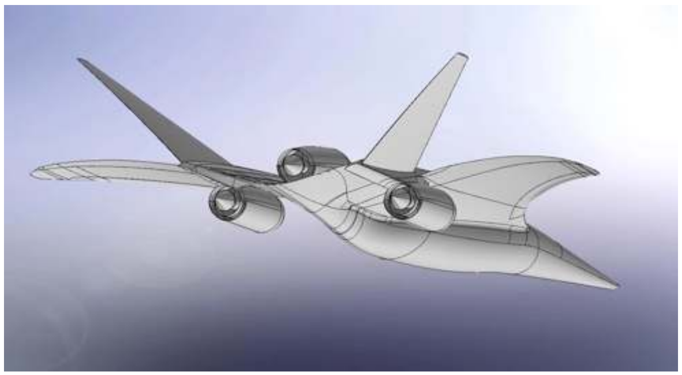


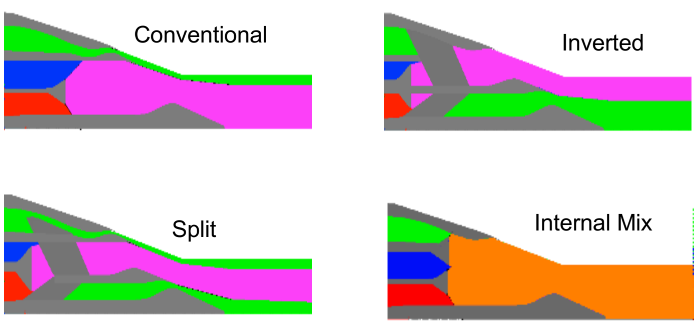


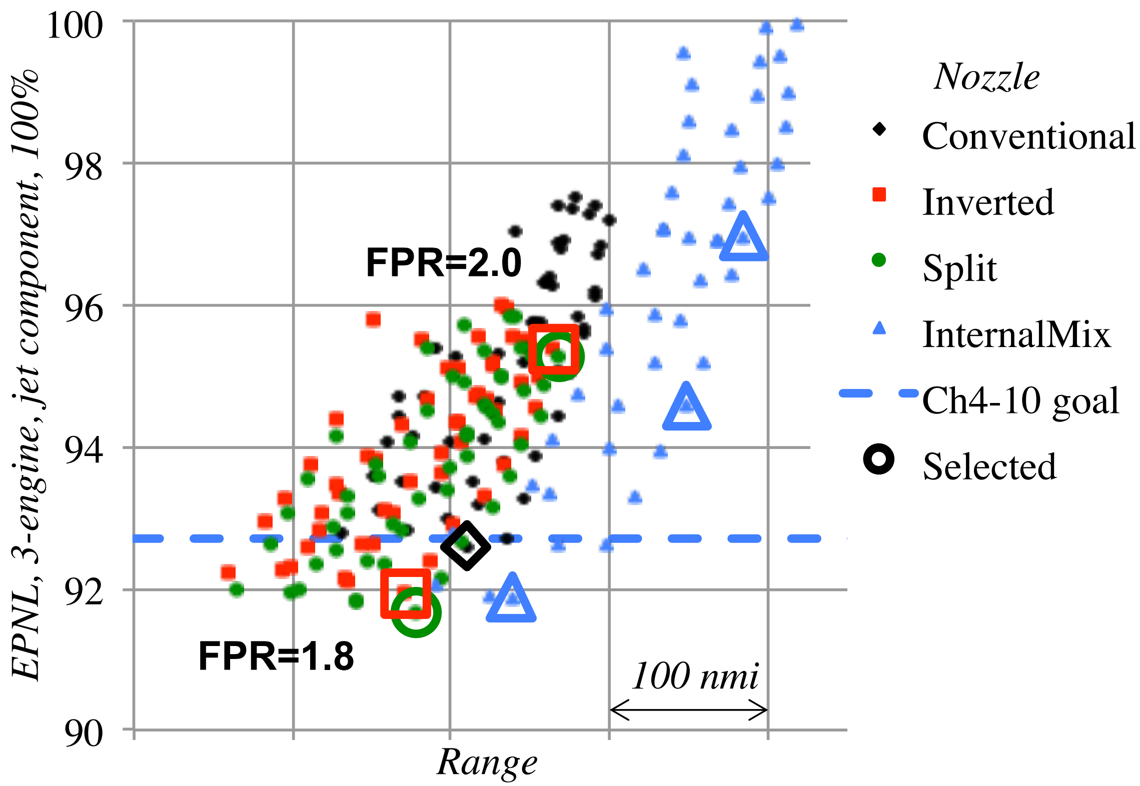
More shielding benefit possible from tailored nozzles—future tech development.

Engine/Nozzle Final Design for Validation

- VCE coupled with LM1044 aerodynamic model and new noise prediction codes to predict mission range and Lateral EPNL.
- Designs that maximize range while meeting noise goal selected for demonstration
- Also selected designs requiring Programmed Lapse Rate (PLR) to demonstrate design sensitivities.







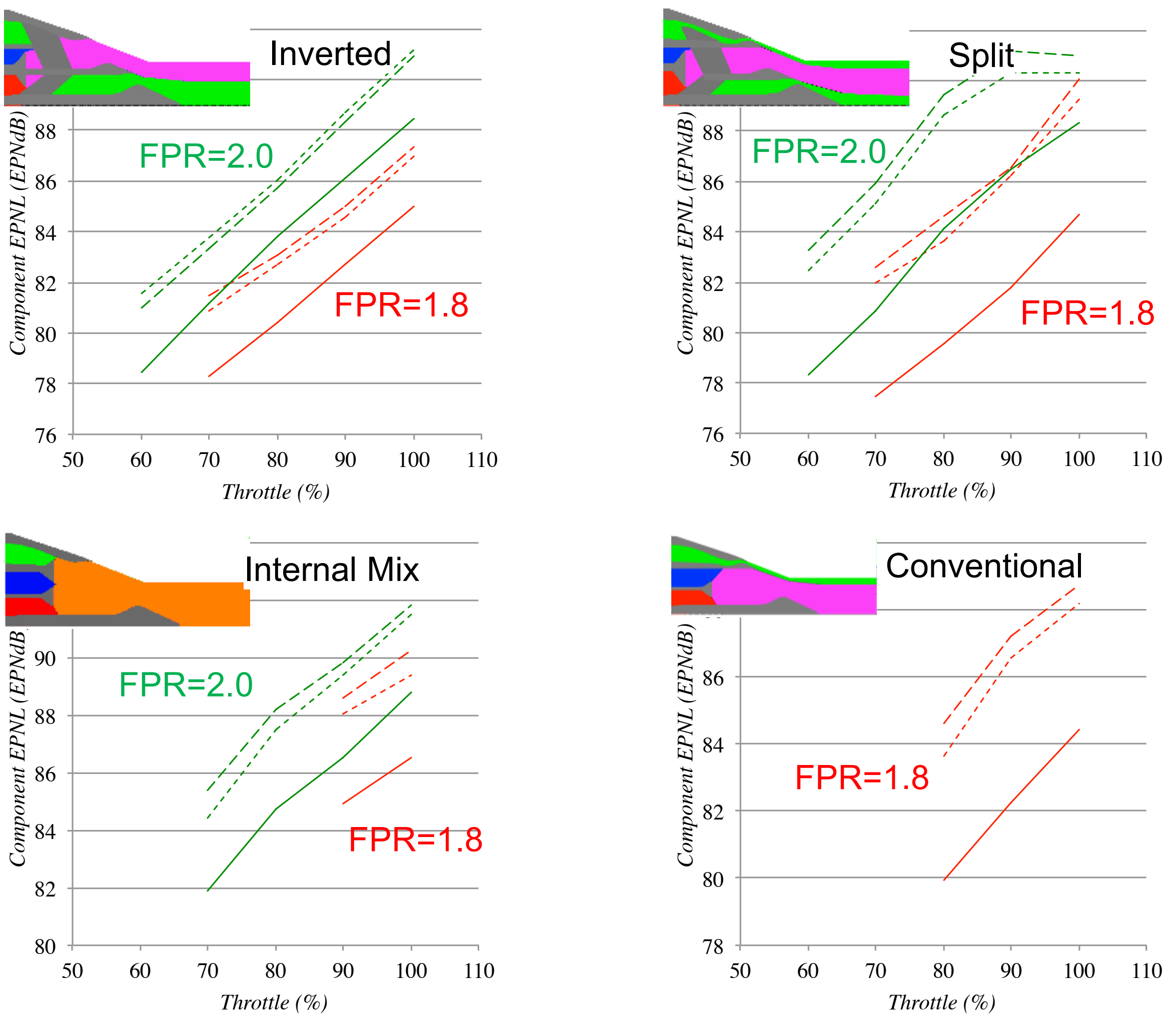
JSI16 Integrated Propulsion Test

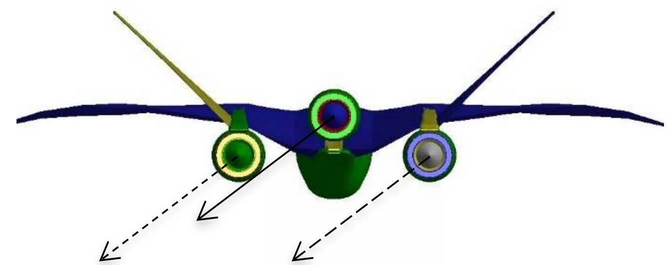
- Ground test conducted on selected engine/nozzles to demonstrate that noise goal was met with integrated propulsion system.
- Test conducted at GRC Aero-Acoustic Propulsion Lab, an anechoic wind tunnel with engine simulator.
- Four nozzle types, seven engines, three installation variations, center top-mounted and outboard underwing installations assessed at multiple flight speeds.

Bridges, J. “Aeroacoustic Validation of Installed Low Noise Propulsion for NASA’s N+2 Supersonic Airliner”, AIAA SciTech 2018 Monday AM

Installation Effect—Mount Location

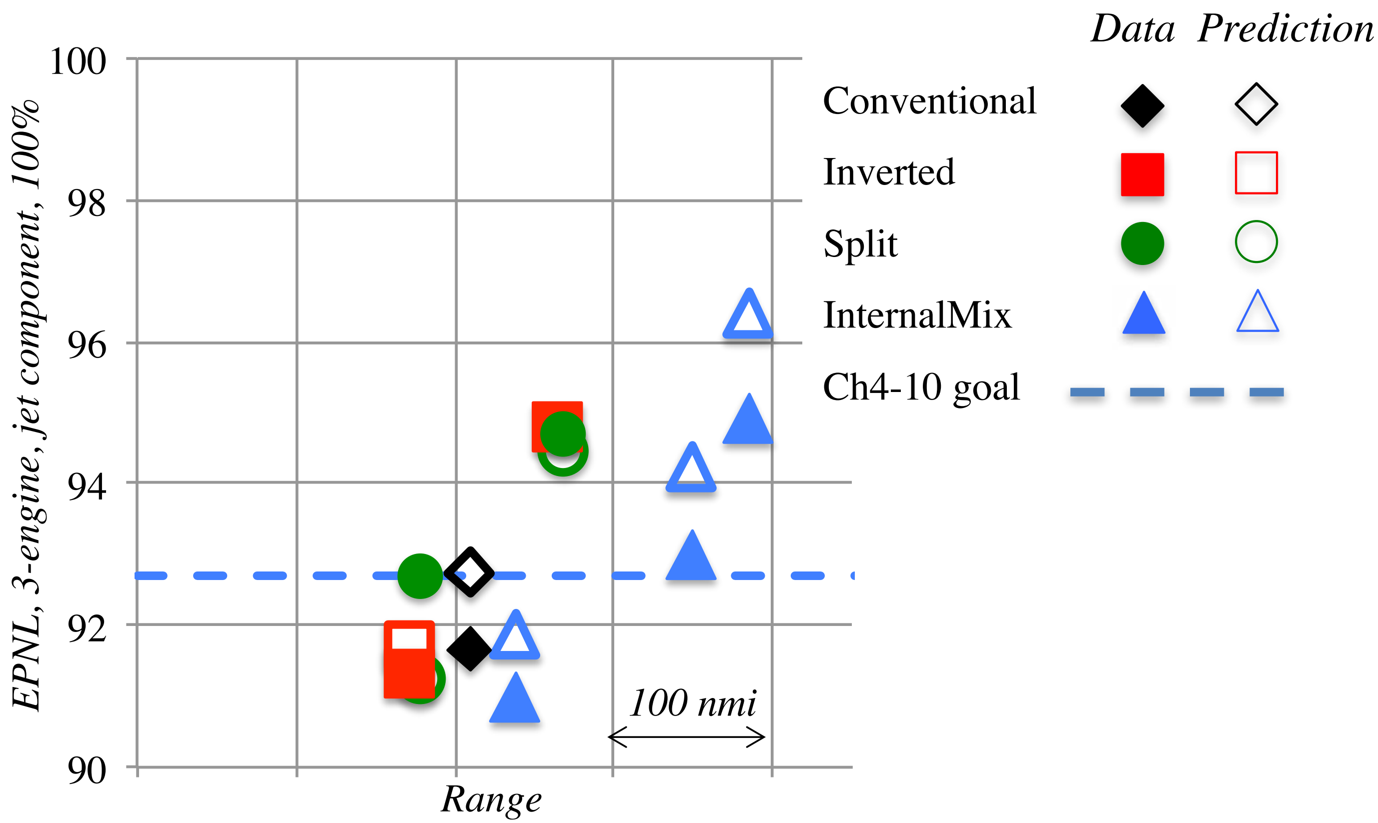
- EPNL for each engine as seen by Lateral observer
- Grouped by engine/nozzle (plot) and cycle (color)





Comparisons of Design Predictions and Data

- JSI16 test Data plotted against design Predictions.
- Predictions match Data within 1EPNdB, expected uncertainty of prediction method.



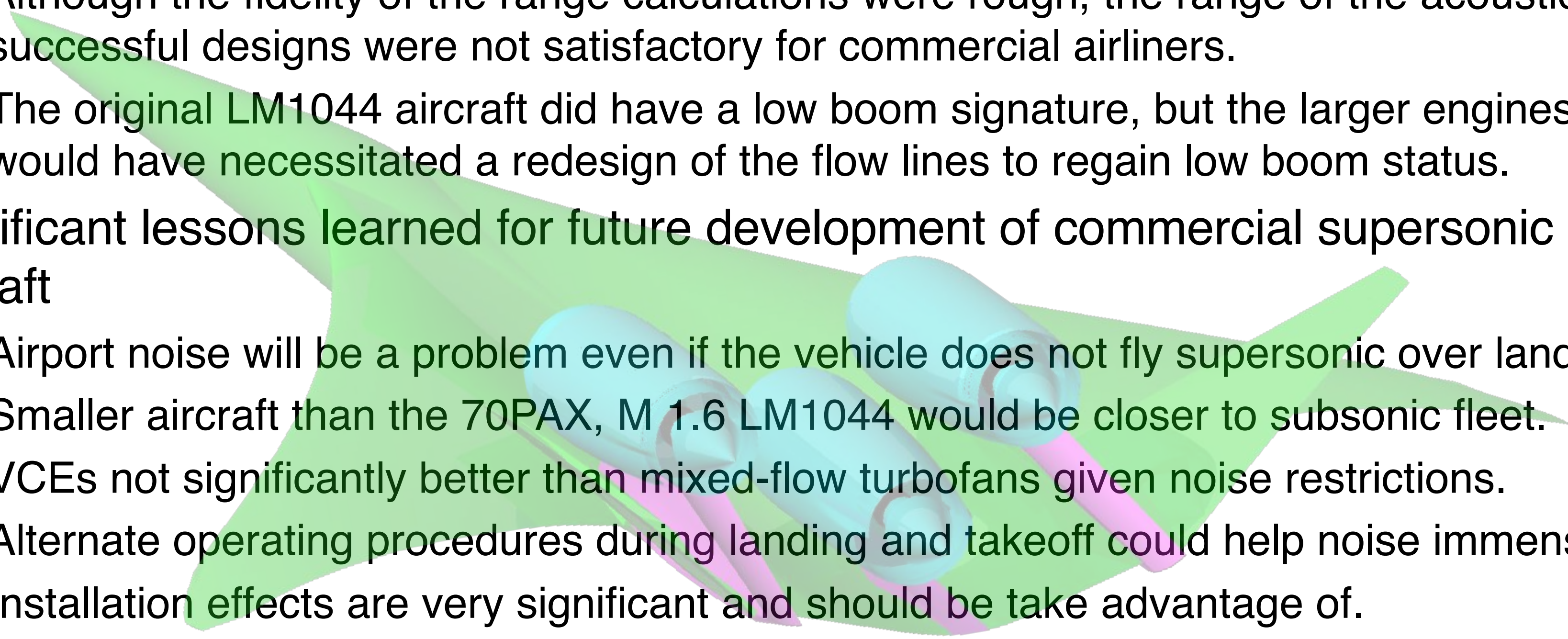
Significance: We have valid design tools for propulsion noise and know what must be done to meet airport noise regulations. This is not yet a closed design.

Summary

- NASA-supported research has helped develop significantly improved jet noise prediction methods.
- New tools allow strong insight into physics of jet noise generation, and design of exhaust systems for noise.
- NASA-supported research has explored many low-noise nozzle concepts brought forward by noise community.
- Acoustic performance of concepts shown to reliably reduce noise captured in system-level tools and used to validate physics-based methods.
- Installation effects on exhaust noise explored and modeled.
- System-level propulsion studies used new noise tools to explore variable cycle engine concepts and find best designs that meet LTO noise requirements for a low-boom, 70 pax, supersonic aircraft.
- Study results for noise validated in model-scale acoustic test.

But there's more work to be done…

- While formally the Low-Noise Propulsion Tech Challenge was successfully met, there were caveats.
  - Although the fidelity of the range calculations were rough, the range of the acoustically successful designs were not satisfactory for commercial airliners.
  - The original LM1044 aircraft did have a low boom signature, but the larger engines would have necessitated a redesign of the flow lines to regain low boom status.
- Significant lessons learned for future development of commercial supersonic aircraft
  - Airport noise will be a problem even if the vehicle does not fly supersonic over land.
  - Smaller aircraft than the 70PAX, M 1.6 LM1044 would be closer to subsonic fleet.
  - VCEs not significantly better than mixed-flow turbofans given noise restrictions.
  - Alternate operating procedures during landing and takeoff could help noise immensely.
  - Installation effects are very significant and should be take advantage of.
- LTO noise will have to be a major design requirement for successful design
  - Adequate noise levels cannot be obtained by nozzle design or engine cycle alone.
  - Acoustic benefits from propulsion installation will be required.



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