Commercial Supersonics Technology Project—Status of Airport Noise

Presented at Acoustics TWG, Langley Research Center
20 April 2016
James Bridges
Overview

• Project Maturation
  – Spinoff of QueSST

• Tech Development for LNP Tech Challenge
  – Evolution of VCE system studies
  – Exploration of low-noise nozzles for VCE
  – Modeling and prediction tool development
  – Validating current best solutions

• Looking Ahead
CST Project Maturation

- QueSST
  - The single-pilot X-plane to mimic sonic boom of commercial airliner
- Goals:
  - Demonstrate design prowess for low-boom design with real-world complications
  - Allow testing of community response to guide regulations for certification
Low-Noise Propulsion Tech Challenge 2016

- Supported by years of research:
  - S-Duct
  - 3-Stream, Externally Mixed, Offset Streams
  - Inverted Velocity Profile
  - Fun3D PIV
  - CFD validation
  - LES validation
  - RISN Acoustic Analogy
  - Jet-Surface Interaction Tests and Modeling (JSI)
  - Empirical Modeling (TSS)
  - Non-axisymmetric Green F’n
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 TSS code to predict noise of many VCE nozzles
  – Developed & validated JSI code to predict acoustic impact of installation
  – Integration of models with ModelCenter system optimizer ongoing
  – Used to design low-noise/low-boom vehicle, final Tech Challenge configs

• RANS-based Acoustic Analogies
  – Developed non-axisymmetric Green’s function
  – Developed hot jet source models
  – Qualified 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 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 cycle vs range vs sonic boom**
10dB below Stage 4

- Assume exhaust noise dominates at Lateral (sideline) certification point, not significant at Approach point.
- FAR Part 36 **Chapter 3** requires **99.3EPNdB** max at lateral for LM1044 airliner. Chapter 4 is 10dB (cumulative), with reduction at all points.
- Assuming that Approach is not dominated by exhaust noise, split remainder between Lateral and Flyover points.
  - Ch4 would require Lateral to be 95.3EPNdB.
  - Ch4 – 10 would require Lateral to be 92.3EPNdB
- **Ch4–10dB** equates to **92EPNdB** for the Lateral observer with an installed three-engine exhaust system.
Engine Design

- Engine model exercised using design variables: # fan stages, nozzle type, FPR, BPR, T4
- Output lateral noise EPNL, range, engine diameter, emissions index
- Pick off 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
  - At some point small adjustments cannot compensate
Validation of Empirical Models for VCE Nozzles

- Candidate nozzles from Isolated Nozzle Test (Iso16)
  - Externally mixed core, fan, tip flows
  - Internally mixed core & fan, conventional tipflow
  - Internally mixed core & fan, inverted tip flow
  - Optional; split tip flow to outer buffer
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 = 1.9 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

<table>
<thead>
<tr>
<th>Setpoint</th>
<th>At/Ab</th>
<th>Ab/At</th>
<th>(At+Ab)/At</th>
</tr>
</thead>
<tbody>
<tr>
<td>1196</td>
<td>0.53</td>
<td>1.78</td>
<td>3.30</td>
</tr>
<tr>
<td>1205</td>
<td>0.53</td>
<td>1.33</td>
<td>2.59</td>
</tr>
</tbody>
</table>
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

Final integrated test:
- IVP and IVPS on three VCE engines cycles
- MFTF on two engine cycles
Demonstrated in Ground Test

• In 2015 a ‘static’ (no flight stream) test was conducted (JSI1044).
• Part of the test objective was to evaluate some critical aspects of the aircraft approximation.
  – How much of the vehicle has to be represented?
  – How many orientations must be measured?

Center Engine Configuration, 0° orientation  Outer Engine Configuration, 0° orientation
Matching flight stream for integrated propulsion on LM1044 vehicle

• Looking for
  – Disparities between nacelle diameter and jet rig diameter
  – Cross-stream flow from lifting body

CFD of full vehicle to characterize flow around nozzles

CFD of AAPL test article

Initial design

Refined design
Integrated Propulsion Test

- Test deliverables
  - EPNL for all certification observers, multiple engine solutions, to confirm milestone deliverable
  - Phased array of noise source distributions, confirmation of shielding/reflection
  - PIV of turbulent flow to validate CFD
Looking Ahead

• Complete LNP Tech Challenge—Sept 2016
• New Tech Challenge for CST Airport Noise
  – New aircraft configurations
  – Consider all noise components in system studies
  – More computation, less experiment
• Continue system modeling to guide tech investment
• Possible technologies for focus
  – Inlet design for low noise fans with efficient cruise performance
  – Nozzle designs to complement topside engine mounting
  – Increased fidelity of predictions in system modeling
  – Improved test methods for integrated propulsion