Separate Flow Nozzle Test Status Meeting

December 2000
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Separate Flow Nozzle Test Status Meeting

Proceedings of a conference held at and sponsored by
NASA Glenn Research Center
Cleveland, Ohio
September 9–10, 1997

National Aeronautics and
Space Administration

Glenn Research Center

December 2000
Note that at the time of research, the NASA Lewis Research Center was undergoing a name change to the NASA John H. Glenn Research Center at Lewis Field. Both names may appear in this report.

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Available electronically at http://gltrs.grc.nasa.gov/GLTRS
In 1995, NASA GRC initiated efforts to meet the US industry’s rising need to develop jet noise technology for separate flow nozzle exhaust systems. Such technology would be applicable to long-range aircraft using medium to high by-pass ratio engines. With support from the Advanced Subsonic Technology Noise Reduction program, these efforts resulted in the formulation of an experimental study, the Separate Flow Nozzle Test (SFNT). SFNT’s objectives were to develop a data base on various by-pass ratio nozzles, screen quietest configurations and acquire pertinent data for predicting the plume behavior and ultimately its corresponding jet noise. The SFNT was a team effort between NASA GRC’s various divisions, NASA Langley, General Electric, Pratt&Whitney, United Technologies Research Corporation, Allison Engine Company, Boeing, ASE FluiDyne, MicroCraft, Eagle Aeronautics and Combustion Research and Flow Technology Incorporated.

SFNT found several exhaust systems providing over 2.5 EPNdB reduction at take-off with less than 0.5% thrust loss at cruise with simulated flight speed of 0.8 Mach. Please see the following SFNT related reports: Saiyed, et al. (NASA/TM—2000-209948), Saiyed, et al. (NASA/CP—2000-210524), Low, et al. (NASA/CR—2000-210040), Janardan et al. (NASA/CR—2000-210039), Bobbitt, et al. (NASA/CR—201-210706) and Kenzakowski et al. (NASA/CR—2001-210611.).

I wish to thank the entire SFNT team of nearly 50 scientists, engineers, technicians and programmers involved in this project. SFNT would have fallen well short of its goals without their untiring support, dedication to developing the jet noise technology.

Naseem Saiyed
SFNT Research Engineer
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<td>LeRC</td>
<td>Discussion of configurations, concepts tested, measurements, quality of data, schedule</td>
</tr>
<tr>
<td>LeRC</td>
<td>Results overview (EPNL Summary)</td>
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<td>LeRC</td>
<td>Break</td>
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<td>PW</td>
<td>PW noise reduction concept results</td>
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<td>PW</td>
<td>Phased array results</td>
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<tr>
<td>PW</td>
<td>Lunch</td>
</tr>
<tr>
<td>GE</td>
<td>GE noise reduction concept results</td>
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<tr>
<td>LeRC</td>
<td>Diagnostic Measurements</td>
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<td>Outstanding issues and schedule</td>
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<tr>
<td>All</td>
<td>Open Discussion</td>
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<tr>
<td>All</td>
<td>Adjourn</td>
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Advanced Subsonic Technology
Separate Flow Nozzle Tests for
Engine Noise Reduction sub-element
Presented to AST Participants

September 10, 1997

Naseem H. Saiyed
NASA Lewis Research Center
Cleveland, Ohio
Baseline Configurations for all models

2BB, 5 BPR

4BB, 8 BPR

1BB, 5BPR

3BB, 5 BPR

5BB, 8 BPR
Baseline Configurations for all models

1BB, 5 BPR

3BB, 5 BPR

5BB, 8 BPR

2BB, 5 BPR

4BB, 8 BPR

6BB, 5 BPR

For model 2
Advanced Subsonic Technology

Noise Reduction Element

Separate Flow Nozzle Tests for

Engine Noise Reduction sub-element

Presented to AST Participants

September 10, 1997

Naseem H. Saiyed
NASA Lewis Research Center
Cleveland, Ohio
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AST goals and general information
Nozzle nomenclature
Nozzle schematics
Photograph of all baselines
Configurations tests and types of data acquired
Engine cycle and plug geometry impact on EPNL

* Model 2
Model 5
Model 3
Results summary in text
Results summary in symbols
Conclusions

* Delta EPNLs at end of each model section.
Advanced Subsonic Technology (AST)

- Accelerate development of enabling technologies to maintain U.S. leadership in aeronautics

- Noise Reduction: One of 13 elements of AST
  
  Goal: Achieve 10 dB reduction relative to 1992 by 2000

- Engine Noise Reduction: One of five sub-elements of Noise Reduction
  
  Goal: Achieve 6 dB reduction relative to 1992 by 2000 for engine

  Intermediate jet noise goal:

  3 dB reduction by 1997
Separate Flow Nozzle Test (SFNT)

- Jet noise test in support of Engine Noise Reduction sub-element
- Cooperative effort between LeRC, PW, Boeing, GE and Allison

Test objectives:

a. Develop data base for separate flow nozzles (acoustics, flow-field, and source location)

b. Screen various noise reduction concepts for full scale engine tests

- Scale model testing completed
General Information

- Data acquired in LeRC's Aeroacoustic and Propulsion Lab
- Anechoic dome with 25 microphones at 50 foot nominal radius from 45° to 160° at 5° increment
- EPNL confidence of +/- 0.25 EPNdB
- Forward flight of 0.28 Mach simulated with an ejector tunnel
- Scale factor of 8 used for full scale simulation
- Data presented for level fly-over at 1500 foot sideline, 14.7 psia, 77°F and 70% r.h., One engine only
Test Matrix

- Bypass Ratio 5 and 8
- Bypass Ratio 5 cycle points were a compromise between GE and PW
- Fan temperature maintained at 600 R due to excessive time in gaining "on-point" status
- Static and forward flight at 0.2 and 0.28 Mach
- Test Hardware parameters varied:
  a. Core plug (internal and external)
  b. Fan nozzles (chevrons, tabs, scarf, off-set, doublets)
  c. Core nozzles (vortex generator doublets, tabs, mixers, chevrons)
Test Hardware

Hardware nomenclature:

- A 12 Alternating flipper chevrons
- B Baseline (clean nozzle without any enhancer device)
- C12 and C24 12 chevrons and 24 chevrons (for fan C24 = C)
- Di Interior doublet
- Dx Exterior doublet
- Fm Full mixer
- Hm Half mixer
- I 12 Inward flipper chevrons
- O Fan off-set nozzle
- S Scarfed nozzle
- T24 and T48 24 flipper tab and 48 flipper tabs
- Tm Tongue mixer

Hardware designation: [model #][core nozzle][fan nozzle]

Example: 3T24T48 = [model 3] with [24 tabs on core nozzle] and [48 tabs on fan nozzle]
Figure 6.
Figure 7.

Vortex Generator Doublet Description

Doublet Design and Installation Information

<table>
<thead>
<tr>
<th>Description</th>
<th># Doubles</th>
<th>H [in.]</th>
<th>a [in.]</th>
<th>L [in.]</th>
<th>W [in.] (arc length)</th>
</tr>
</thead>
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<td>internal placement on the BPR=5, external plug core nozzle</td>
<td>64</td>
<td>0.05</td>
<td>0.50</td>
<td>0.35</td>
<td>0.25</td>
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<tr>
<td>external placement on the BPR=5, external plug core nozzle</td>
<td>20</td>
<td>0.15</td>
<td>0.50</td>
<td>1.05</td>
<td>.75</td>
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<td>internal placement on the fan nozzle common to models 2-5</td>
<td>96</td>
<td>0.06</td>
<td>0.60</td>
<td>0.42</td>
<td>0.30</td>
</tr>
</tbody>
</table>
Figure 10. Fan Nozzle Flipper Tabs Example
Figure 11. Core Nozzle Flipper Tabs Example

Material: 304 S.S.
Figure 13. Half Mixer Concept
The offset centerline distance (z) will be a function of the axial distance (x) from the attachment flange of the fan nozzle. This offset distance is governed by the following equation:

\[ z = \frac{H}{2} \left[ \cos \left( \frac{\pi x}{L} \right) - 1 \right] \]

where \( H \) is the maximum offset distance, and \( L \) is the current baseline fan nozzle length.

Two sets of fan offset centerline nozzles are to be fabricated with the following maximum offset distances:

1. \( H = 0.25 \) " \( L = 10.216 \) "
2. \( H = 0.50 \) " \( L = 10.216 \) "

Figure 14. Offset Nozzle Concept
Baseline Configurations for all models

3BB, 5 BPR

2BB, 5 BPR

1BB, 5BPR

5BB, 8 BPR

4BB, 8 BPR
- **Model 1:** Co-Planar nozzle, 5 BPR (1BB)
- **Model 2:** Internal plug, shortened fan, 5 BPR

<table>
<thead>
<tr>
<th>Core Nozzle</th>
<th>Fan Nozzle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B (baseline)</td>
</tr>
<tr>
<td>B (baseline)</td>
<td>✓</td>
</tr>
<tr>
<td>C12 (12 chevrons)</td>
<td>1*</td>
</tr>
<tr>
<td>Tm (tongue mixer)</td>
<td>2</td>
</tr>
</tbody>
</table>

*Note:* These numbers refer to the photographs of hardware with pni directivity and epni vs vmix data superimposed.
Model 3: External plug, shortened fan, 5 BPR (work horse)

<table>
<thead>
<tr>
<th>Core Nozzle</th>
<th>B (baseline)</th>
<th>C24 (24 chevrons)</th>
<th>D (internal doublet)</th>
<th>S (scared)</th>
<th>O (offset)</th>
<th>T24 (24 flipper tabs)</th>
<th>T48 (48 flipper tabs)</th>
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<tr>
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<td>✓</td>
<td>17</td>
<td></td>
<td>26</td>
<td>28</td>
<td>30</td>
<td>32</td>
</tr>
<tr>
<td>T24 (24 flipper tabs)</td>
<td>7</td>
<td>18</td>
<td></td>
<td></td>
<td></td>
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<td>33</td>
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<td>T48 (48 flipper tabs)</td>
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<td>19</td>
<td></td>
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<td>34</td>
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<td>C8 (8 chevrons)</td>
<td>9</td>
<td>20</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>C12 (12 chevrons)</td>
<td>10</td>
<td>21</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>I (12 Inward flip. chevrons)</td>
<td>11</td>
<td>22</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A (12 alternating flip chev)</td>
<td>12</td>
<td>23</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DI (internal doublet)</td>
<td>13</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DX (external doublet)</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Hm (Half mixer)</td>
<td>15</td>
<td>24</td>
<td></td>
<td>27</td>
<td>29</td>
<td></td>
<td></td>
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<tr>
<td>Fm (Full mixer)</td>
<td>16</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</table>
- Model 4: Internal plug, shortened fan, 8 BPR
- Model 5: External plug, shortened fan, 8 BPR

<table>
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<tr>
<th>Core Nozzle</th>
<th>Fan Nozzle</th>
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</thead>
<tbody>
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<td></td>
<td>B (baseline)</td>
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<tr>
<td>B (baseline)</td>
<td>√</td>
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<tr>
<td>C12 (12 chevrons)</td>
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Table 1. Separate Flow Nozzle Acoustic Test Summary.

<table>
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<tr>
<th>Test Config.</th>
<th>Config. Code</th>
<th>Model No.</th>
<th>BPR</th>
<th>Plug</th>
<th>Core Mixing Enhancer</th>
<th>Fan Concept Enhancer</th>
<th>Mixing Concept Orig.</th>
<th>Clock Pos.</th>
<th>Mach Number</th>
<th>Total No. of Power Settings</th>
<th>Data Points</th>
<th>Date Tested</th>
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<td>1</td>
<td>100000</td>
<td>1</td>
<td>5</td>
<td>Int.</td>
<td>Base</td>
<td>Base</td>
<td>GEAE</td>
<td>0</td>
<td>0.20,0.28</td>
<td>Cyc. 1 &amp; 2</td>
<td>42</td>
<td>3/20/97</td>
</tr>
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<td>2BB</td>
<td>200000</td>
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<td>5</td>
<td>Int.</td>
<td>Base</td>
<td>Base</td>
<td>GEAE</td>
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<td>Cycle 2</td>
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<td>2000000</td>
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<td>5</td>
<td>Int.</td>
<td>Base</td>
<td>96 Int. Doub.</td>
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<td>200200</td>
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<td>Base</td>
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<td>P&amp;W</td>
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Notes: (blt) = boundary layer trip
(vg) = vortex generators
Total Number of Data Points includes background noise conditions
Table 1. – AAPL Separate Flow Nozzle Acoustic Test Summary (Concluded).  

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<th>Config. Code</th>
<th>Model No.</th>
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<th>Plug</th>
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<th>Concept Enhancer</th>
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<th>Clock Pos.</th>
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Notes:  
(blt) = boundary layer trip  
(vg) = vortex generators  
Total Number of Data Points includes background noise conditions.
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<th>Test Config.</th>
<th>Config. Code</th>
<th>Model No.</th>
<th>BPR</th>
<th>Plug</th>
<th>Mixing Enhancer</th>
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Note: Matrix does not include flexible wire (attached to centerbody plug trailing edge) configurations testing conducted on 6/18/97.
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Note: For all configurations, M=.28 & Cycle 2/Point 21 where test conditions.
Table 6. AAPL Separate Flow Nozzle IR Camera Test Summary.

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Table 6. AAPL Separate Flow Nozzle IR Camera Test Summary (Concluded).

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<td>4/23/97</td>
<td>0.28</td>
<td>2/20</td>
<td>1080</td>
<td>6</td>
</tr>
<tr>
<td>3T48T48</td>
<td>4/23/97</td>
<td>0.28</td>
<td>2/20</td>
<td>1085</td>
<td>7</td>
</tr>
<tr>
<td>6Tmb</td>
<td>5/12/97</td>
<td>0.28</td>
<td>2/21</td>
<td>1251</td>
<td>2</td>
</tr>
<tr>
<td>6Tmb</td>
<td>5/12/97</td>
<td>0.28</td>
<td>2/20</td>
<td>1252</td>
<td>3</td>
</tr>
<tr>
<td>6Tmc</td>
<td>5/12/97</td>
<td>0.28</td>
<td>2/21</td>
<td>1258</td>
<td>4</td>
</tr>
<tr>
<td>6Tmc</td>
<td>5/12/97</td>
<td>0.28</td>
<td>2/20</td>
<td>1259</td>
<td>5</td>
</tr>
<tr>
<td>3BB</td>
<td>5/13/97</td>
<td>0.28</td>
<td>2/21</td>
<td>1275</td>
<td>6</td>
</tr>
<tr>
<td>3FB</td>
<td>5/13/97</td>
<td>0.28</td>
<td>2/21</td>
<td>1283</td>
<td>7</td>
</tr>
<tr>
<td>3FB</td>
<td>5/13/97</td>
<td>?</td>
<td>Special</td>
<td>1286</td>
<td>8</td>
</tr>
<tr>
<td>3Hmb</td>
<td>5/13/97</td>
<td>0.28</td>
<td>2/21</td>
<td>1290</td>
<td>9</td>
</tr>
<tr>
<td>3FC</td>
<td>5/13/97</td>
<td>0.28</td>
<td>2/21</td>
<td>1296</td>
<td>10</td>
</tr>
<tr>
<td>3T24T48</td>
<td>5/13/97</td>
<td>0.28</td>
<td>2/21</td>
<td>1302</td>
<td>11</td>
</tr>
</tbody>
</table>
Internal and External Plug for 5 and 8 BPR engines

For BPR = 5:
- Internal Plug (2BB)
- External Plug (3BB)

For BPR = 8:
- Internal Plug (4BB)
- External Plug (5BB)

Y-axis: 3 EPNdB

X-axis: Ideally expanded velocity, ft/sec
Impact of Core 12 chevrons and Core Tongue Mixer with baseline fan

Note: All data shown at 125°, 0.28 Mach, 1500' sideline, one engine and growth takeoff (1200 ft/sec mixed jet).

12 Chevrons reduce jet noise and create mixing noise. Tongue mixer significantly reduces jet noise and creates intense mixing noise.
Impact of Core 12 chevrons with 24 Chevrons on Fan

Fan chevrons reduce jet noise but create mixing noise.

BPR 5, Internal Plug
Impact of Core Tongue mixer with 24 Chevrons on Fan

Fan chevrons reduce jet noise and slightly reduce mixing noise generated from Tongue mixer.

BPR 5, Internal Plug
Impact of Fan 96 Doublets and 24 Chevrons on baseline core

Fan doublets create broad-band noise slightly greater than baseline. Fan Chevrons reduce the jet noise and create mixing noise.
EPNL Benefits with Various Noise Suppressors
Internal Plug with 5 BPR engine

Growth Takeoff (Vmixed = 1200 ft/sec)

Current Takeoff (Vmixed = 1150 ft/sec)

EPNL benefit, EPNdB

2BD  2BC  2C12B  2C12C  6TmB  6TmC
MODEL 5

BPR 8, External Plug
Impact of 12 Chevrons on core with baseline fan

![Graph showing the impact of 12 chevrons on core with baseline fan. The graph illustrates the frequency in Hz and the impact on jet noise with 5 dB difference.](image)

**Note:** All data shown at 125°, 0.28 Mach, 1500' sideline, one engine, and 1150 ft/sec mixed jet velocity.

12 Chevrons on core reduce jet noise with little mixing noise increase.

BPR 8, External Plug
Impact of 24 Fan Chevrons with baseline core

24 Fan chevrons reduce jet noise without increase in mixing noise.
Impact of 24 Fan Chevrons with 12 Core Chevrons

24 Chevrons reduce jet noise but increase mixing noise.

BPR 8, External Plug
MODEL 3

BPR 5, External Plug
Impact of Core tab count, 24 and 48, with baseline fan

24 tabs on core create more mixing noise than baseline and 48 tabs. 48 tabs mixing noise is identical to the baseline.
Impact of Core chevrons, 8 and 12, with baseline fan

8 Chevrons reduce the low-frequency noise more than 12 chevrons. Neither device has a high-frequency component above the baseline.

BPR 5, External Plug
Impact of Core Inward and Alternating chevrons with baseline fan

Inward chevrons reduce the low-frequency noise WITHOUT appreciable high frequency noise.

BPR 5, External Plug
Impact of Core Internal and External Vortex Generating Doublets with baseline fan

Doublets do not provide significant variations from baseline.
Impact of Core Full and Half mixer with baseline fan (Half mixer at 0°)

Mixers reduce low frequency but create high frequency. Half-mixer is quieter than full mixer for nearly all frequencies.

BPR 5, External Plug
Impact of 24 Chevron Fan with Baseline Core

24 Chevron fan creates high frequency noise.

BPR 5, External Plug
Impact of 24 Chevron fan on 24-Tab core

Frequency, Hz

50 100 1000 10000

Fan chevrons reduce the broad-band noise including the high frequency mixing noise for 24-Tab core.

BPR 5, External Plug
Impact of 24 Chevron fan on 48 Tab core

Fan chevrons reduce the low-frequency but increase the high frequency.

BPR 5, External Plug
Impact of 24 Chevron fan on 8 Chevron Core

- 863 3BB
- 762 3C8B
- 843 3C8C

Fan chevrons significantly reduce low-frequency noise and slightly increase the high frequency noise.

BPR 5, External Plug
Impact of 24 Chevron fan on 12 Chevron Core

Fan chevrons significantly reduce broad-band noise.

5 dB
Fan chevrons significantly reduce low-frequency noise and slightly increase the high frequency noise.
Impact of 24 Chevron fan on 12-Alternating Chevron Core

Fan chevrons slightly increase the high frequency noise over the Alternating core chevrons.

BPR 5, External Plug
Impact of 24 Chevron fan on core Half-mixer

Fan chevrons reduce jet noise but do not change mixing noise.

BPR 5, External Plug
Impact of 24 Chevron fan on core Full-mixer

Fan chevrons increase the medium frequencies.

BPR 5, External Plug
Impact of Scarfing fan nozzle with baseline core

Scarfing creates significant transition noise
90° is the loudest.

BPR 5, External Plug
Impact of Off-set fan nozzle with baseline core

Off-set fan nozzle at 90 or 180 is very loud.

Frequency, Hz

50 100 1000 10000

5 dB

683 3BO
704 3BO
690 3BO(90)
697 3BO(180)

BPR 5, External Plug
Impact of Fan tabs (24 and 48) with baseline core

Fan 24 and 48 Tabs have same jet noise reduction, but 24 tabs create more mixing noise than 48 tabs.

BPR 5, External Plug
Impact of Fan tabs (24 and 48) with 24 Tab core

48 Tab fan reduces low-frequency more than 24 tab.

BPR 5, External Plug
EPNL Benefits with Various Noise Suppressors
External Plug with 5 BPR engine

Growth Takeoff (Vmixed = 1200 ft/sec)
EPNL Benefits with Various Noise Suppressors
External Plug with 5 BPR engine (continued)

Growth Takeoff (Vmixed = 1200 ft/sec)
EPNL Benefits with Various Noise Suppressors
External Plug with 5 BPR engine (completed)

Growth Takeoff (Vmixed = 1200 ft/sec)
EPNL Benefits with Various Noise Suppressors
External Plug with 5 BPR engine (static and flight)

Current Takeoff (Vmixed = 1150 ft/sec)
EPNL Benefits with Various Noise Suppressors
External Plug with 5 BPR engine (static and flight)

Current Takeoff (Vmixed = 1150 ft/sec)
EPNL Benefits with Various Noise Suppressors
External Plug with 5 BPR engine (static and flight)

Current Takeoff (Vmixed = 1150 ft/sec)
# BPR 5, External Plug Summary (Model 3)

<table>
<thead>
<tr>
<th>Core Nozzle</th>
<th>Fan Nozzle</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>B (baseline)</td>
<td>BB</td>
<td>wrt BB: No change in jet noise. Creates mixing noise.</td>
</tr>
<tr>
<td>T24 (24 flipper tabs)</td>
<td>$^1$Significantly reduces jet noise but creates mixing noise</td>
<td>$^2$Reduces jet noise, transition noise and mixing noise</td>
</tr>
<tr>
<td>T48 (48 flipper tabs)</td>
<td>Reduces jet noise, but less than T24. Minute mixing noise</td>
<td>Reduces jet noise but creates mixing noise</td>
</tr>
<tr>
<td>C8 (8 chevrons)</td>
<td>Reduces jet noise. No mixing noise.</td>
<td>Reduces jet noise and slightly increases mixing noise</td>
</tr>
<tr>
<td>C12 (12 chevrons)</td>
<td>Reduces jet noise, but less than C8. No mixing noise.</td>
<td>Reduces jet noise, transition noise and mixing noise.</td>
</tr>
<tr>
<td>I (12 inward flip chevrons)</td>
<td>Moderately reduces jet noise. Creates small amount of mixing noise.</td>
<td>Significantly reduces jet noise with slight increase in mixing noise.</td>
</tr>
<tr>
<td>Di (internal doublet)</td>
<td>Not much difference.</td>
<td>Not done</td>
</tr>
<tr>
<td>Dx (external doublet)</td>
<td>Not much difference.</td>
<td>Not done</td>
</tr>
<tr>
<td>Fm (Full mixer)</td>
<td>Less reduction than Hm for jet noise. Creates intense mixing noise (even more than Hm).</td>
<td>No change in jet noise or mixing noise. Creates transition noise.</td>
</tr>
</tbody>
</table>

$^1$ Note: Fan baseline column comparisons are made against the baseline core and baseline fan nozzles.

$^2$ Note: Fan chevron column comparisons are made against the core device with baseline fan nozzles.
## BPR 5, External Plug Summary (Model 3) concluded

<table>
<thead>
<tr>
<th>Core Nozzle</th>
<th>Fan Nozzle</th>
</tr>
</thead>
<tbody>
<tr>
<td>B (baseline)</td>
<td>T24</td>
</tr>
<tr>
<td>BB</td>
<td>wrt BB: Reduces jet noise but creates significantly high transition and mixing noise</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Core Nozzle</th>
<th>Fan Nozzle</th>
</tr>
</thead>
<tbody>
<tr>
<td>B (baseline)</td>
<td>Scarfed</td>
</tr>
<tr>
<td>BB</td>
<td>wrt BB: Creates high transition frequencies at all rotations. 90° rotation is noisest.</td>
</tr>
</tbody>
</table>
**BPR 5, Internal Plug Summary (Model 2)**

<table>
<thead>
<tr>
<th>Core Nozzle</th>
<th>Fan Nozzle</th>
<th>C24 (24 chevrons)</th>
<th>D (96 doublets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B (baseline)</td>
<td>BB</td>
<td>wrt BB: Reduce jet noise and increase mixing noise.</td>
<td>wrt BB: Broad-band small increase.</td>
</tr>
<tr>
<td>C12 (12 chevrons)</td>
<td>4Slightly reduce jet noise. Minimal increase in mixing noise</td>
<td>Jet noise is reduced and mixing noise is enhanced.</td>
<td></td>
</tr>
<tr>
<td>Tm (tongue mixer)</td>
<td>Significantly reduce jet noise and increase mixing noise.</td>
<td>Jet noise is reduced. Mixing noise is unchanged.</td>
<td></td>
</tr>
</tbody>
</table>

**BPR 8, External Plug Summary (Model 5)**

<table>
<thead>
<tr>
<th>Core Nozzle</th>
<th>Fan Nozzle</th>
<th>C24 (24 chevrons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B (baseline)</td>
<td>BB</td>
<td>wrt BB:</td>
</tr>
<tr>
<td>C12 (12 chevrons)</td>
<td>5Slightly reduce jet noise with no change in mixing noise</td>
<td></td>
</tr>
</tbody>
</table>

---

4 Note: See notes 1 and 2.

5 Note: See notes 1 and 2.
# BPR 5, External Plug Summary (Model 3)

<table>
<thead>
<tr>
<th>Core Nozzle</th>
<th>Fan Nozzle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(wrt 3BB) Baseline Fan</td>
</tr>
<tr>
<td></td>
<td>Jet Noise</td>
</tr>
<tr>
<td>B (baseline)</td>
<td>0</td>
</tr>
<tr>
<td>T24 (24 flipper tabs)</td>
<td>- - - -</td>
</tr>
<tr>
<td>T48 (48 flipper tabs)</td>
<td>- - -</td>
</tr>
<tr>
<td>C8 (8 chevrons)</td>
<td>- -</td>
</tr>
<tr>
<td>C12 (12 chevrons)</td>
<td>-</td>
</tr>
<tr>
<td>I (12 Inward flip. chevrons)</td>
<td>- - -</td>
</tr>
<tr>
<td>A (12 alternating flip chev)</td>
<td>- - -</td>
</tr>
<tr>
<td>D1 (internal doublet)</td>
<td>0</td>
</tr>
<tr>
<td>D2 (external doublet)</td>
<td>0</td>
</tr>
<tr>
<td>Hm (Half mixer)</td>
<td>- - - -</td>
</tr>
<tr>
<td>Fm (Full mixer)</td>
<td>- - -</td>
</tr>
</tbody>
</table>
### BPR 5, External Plug Summary (Model 3) concluded

#### Table 1: Core Nozzle and Fan Nozzle Interaction

<table>
<thead>
<tr>
<th>Core Nozzle</th>
<th>Fan Nozzle</th>
<th>Scarfed (wrt 3BB)</th>
<th>Off-set</th>
</tr>
</thead>
<tbody>
<tr>
<td>B (baseline)</td>
<td>0°</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>B (baseline)</td>
<td>90°</td>
<td>++</td>
<td>+++</td>
</tr>
<tr>
<td>B (baseline)</td>
<td>180°</td>
<td>+</td>
<td>+++</td>
</tr>
</tbody>
</table>

#### Table 2: Core Nozzle and Fan Nozzle Interaction

<table>
<thead>
<tr>
<th>Core Nozzle</th>
<th>Fan Nozzle</th>
<th>T24 (24 flip. tabs)</th>
<th>T48 (48 flip. tabs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B (baseline)</td>
<td>- -</td>
<td>++</td>
<td>- -</td>
</tr>
<tr>
<td>T24 (24 flipper tabs)</td>
<td>- -</td>
<td>++</td>
<td>- -</td>
</tr>
</tbody>
</table>
### BPR 5, Internal Plug Summary (Model 2)

<table>
<thead>
<tr>
<th>Core Nozzle</th>
<th>Fan Nozzle</th>
<th>Baseline</th>
<th>C24 (24 chevrons)</th>
<th>D (96 doublets)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Jet noise</td>
<td>Transition</td>
<td>Mixing</td>
<td>Jet noise</td>
</tr>
<tr>
<td>B (baseline)</td>
<td>-</td>
<td>0</td>
<td>+</td>
<td>- -</td>
</tr>
<tr>
<td>C12 (12 chevrons)</td>
<td>- -</td>
<td>0</td>
<td>+</td>
<td>- -</td>
</tr>
<tr>
<td>Tm (tongue mixer)</td>
<td>- - -</td>
<td>0</td>
<td>++ +</td>
<td>- -</td>
</tr>
</tbody>
</table>

### BPR 8, External Plug Summary (Model 5)

<table>
<thead>
<tr>
<th>Core Nozzle</th>
<th>Fan Nozzle</th>
<th>Baseline</th>
<th>C24 (24 chevrons)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Jet noise</td>
<td>Transition</td>
<td>Mixing</td>
</tr>
<tr>
<td>B (baseline)</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>C12 (12 chevrons)</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>
Conclusions

- High quality and quantity data (acoustics, plume flow field and source location)
- Jet noise reduction goal of 3 EPNdB in model scale accomplished using 3IC configuration (3.2 EPNdB reduction)
- Several concepts provided 2.5 - 2.7 EPNdB reduction
- Test clearly demonstrated need for balancing jet noise reduction with increased transition and mixing noise
- 24 Fan chevrons reduced jet noise in some cases, but increased mixing noise reduced its benefits
- Core tabs and chevrons reduced jet noise with little or no gain in mixing noise (T24 on core is an exception)
- Doublelets did not provide any significant EPNL reductions
Half mixer and Full mixer reduced jet noise and increased mixing noise.

Half mixer reduced jet noise more than full mixer and increased mixing noise less than full mixer. (Half is better than full).

Core tabs and chevrons reduced jet noise with little or no gain in mixing noise (T24 on core is an exception)

Scarfed fan created transition and mixing noise at all rotations without decreasing jet noise. (90° was loudest)

Offset fan nozzle created jet, transition and mixing noises at 90° and 180°. 0° did not create or reduce any form of noise.

24 Tab fan reduced the jet noise but increased the transition and mixing noise

48 Tab fan reduced the jet and the transition noise and increased the mixing noise
- Tongue mixer reduced jet noise and increased mixing noise.
- Data base in place to explore full-scale verification candidates
SEPARATE FLOW NOZZLE JET NOISE TEST STATUS
MEETING at NASA Lewis Research Center

Presentation Outline

0 Test Objective

0 PW’s Jet Noise Reduction Nozzle Concepts
   0 Descriptions of PW’s Nozzles “Acoustic” Features
   0 CFD Analyses for Selected Nozzles

0 Review of Test Results
   0 Noise Data Repeatability / Normalization Factors Applied
   0 Noise Comparisons for Selected Concepts, EPNL, PNL Directivities, Spectra
   0 Summary of EPNL Reductions for PW’s Nozzle Concepts Tested
   0 Plume Survey Temperature Profiles
   0 Boeing’s Phased–Array Microphone System Source Noise Location Results

0 Discussion of Measured Acoustics and Related Aero Data

J.Low / T. Barber / S. Bhat
September 10, 1997
AST TASK 14.2 JET NOISE TEST OBJECTIVE

Conduct model jet noise tests, demonstrating a 3 dB reduction in jet noise (relative to 1992 technology) for nonmixed, separate flow high bypass ratio (BPR) engine/nacelle installations with minimal changes in engine and nacelle geometry.
Baseline Nozzle System with Separate Flow, External Plug and BPR of 5

Model # 3
Nomenclature For Naming Nozzle Configurations

Nozzle Configuration

Model # (W)
1 = Coplanar (BPR=5)
2 = Internal Plug (BPR=5)
3 = External Plug (BPR=5)
4 = Internal Plug (BPR=8)
5 = External Plug (BPR=8)

Core Nozzle Mixing Enhancer (XX)
B = Baseline Axisymmetric Nozzle
C12 = 12 Chevrons
C8 = 8 Chevrons
I = 12 Inward Flipper Chevrons
A = 12 Alternating Flipper Chevrons
Di = 64 Internal Doublet Vortex Generators
Do = 20 External Doublet Vortex Generators
T24 = 24 Flipper Tabs (P&W)
T48 = 48 Flipper Tabs (P&W)
Hm = 10–mini-lobed Half Mixer (P&W)
Tu = Tongue Mixer (Allison)
Fm = 20–mini-lobed Full Mixer (P&W)

Fan Nozzle Mixing Enhancer (YY)
B = Baseline Axisymmetric Nozzle
C = 24 Chevrons
Di = 96 Internal Doublet Vortex Generators
T24 = 24 Flipper Tabs (P&W)
T48 = 48 Flipper Tabs (P&W)
Omax = Maximum Offset Centerline Nozzle (P&W)
S = Scarfed Nozzle (P&W)
Ct = 24 Chevrons with B.L. trip
Cv = 24 Chevrons with external VGs
PW's JET NOISE REDUCTION NOZZLE CONCEPTS

Core Jet Noise Reduction Concepts

- 24 Flipper Tabs
- 48 Flipper Tabs
- 10 mini-lobed Half Mixer
- 20 mini-lobed Full Mixer

Fan Jet Noise Reduction Concepts

- 24 Flipper Tabs
- 48 Flipper Tabs
- Scarfed / “Sugar Scoop”
- Offset Centerline

* Combinations of PW’s “best” core nozzle concepts and GE’s “best” fan nozzle concepts were also tested.
PW's 24 Flipper Tabs Core Nozzle
Sketch of the Tab Arrangement for the 24 Flipper Tabbed Core Nozzle
(6 up, 6 neutral, 6 down, 6 neutral)
PW's 48 Flipper Tabs Core Nozzle
PW's 10 mini-lobed Core Half Mixer
PW's 10 mini-lobed Core Half Mixer
PW's 24 Flipper Tabs Fan Nozzle
PW's 48 Flipper Tabs Fan Nozzle
SKETCH SHOWING OFFSETTING OF THE CENTERLINE OF FAN NOZZLE AS FUNCTION OF NOZZLE AXIAL LENGTH

Material: 416 S.S.

Offset Fan Nozzle
Not. to Scale
PW's Offset Centerline Fan Nozzle
CFD Analysis for Selected Nozzles

Thomas J. Barber
United Technologies Research Center
CFD Analysis Parametrics

- NASTAR Navier-Stokes Analyses Performed for HBPR Separate Flow Nozzles
  - $k-\varepsilon$ Model Used With Wall Functions
- Take-Off Condition Only Simulated
  - $M = 0.3$, $P_{tp} = 3184$ psf, $T_{tp} = 1491R$
- Grid Independence Studies Have Been Performed
  - Axisymmetric (3BB): 35K Points
  - Scarfed (3BS): 300K Points
  - Offset (3BOmax): 400K Points
  - Blended Mixer (3HB): 1200K Points
- Results Referenced to Fan Nozzle Diameter (D)
Computational Domain

- All Coordinates Normalized by Fan Nozzle T.E. Diameter
- Axial Coordinate Origin at Centerbody T.E.
Axial Velocity 3BB-Axisymmetric
Axial Velocity 3BOMax

$x/D = 6.0$

$x/D = 0.0$
Axial Velocity 3HB-Mixer

x/D = 6.0

x/D = 0.0
Temperature profiles at 10.5° from fan exit (tip of plug)
Power condition 21.

Temperature profiles at 30° from fan exit
Power condition 21.
Total Temperature Contours

Axisymmetric & Offset Nozzles
REVIEW OF TEST RESULTS

- Noise Data Variability Due to:
  - variations in test day ambient temperatures (29 deg. F – 74 deg. F)
  - variations in jet velocities and idealized net thrusts from differences in nozzles pressure ratios and temperatures settings for test conditions.
MODEL #3 BASELINE NOZZLE EPNL VARIATIONS FOR REPEAT RUNS TAKEN UNDER A RANGE OF TEST DAY AMBIENT TEMPERATURES (29 deg. F – 74 deg. F)
MODEL #3 BASELINE NOZZLE NOISE CURVE REPLOTTED AS EPNL vs VMIX/C0

(NORMALIZED FOR AMBIENT TEMPERATURE DIFFERENCES)

1500-ft Sideline Flyover

EPNL = 10 log10 (En/1000)

NASA/CP—2000-210524 143
REVIEW OF TEST RESULTS

- Noise Comparisons For Baseline and Selected Nozzle Concepts (PW’s and GE’s “best” Core Nozzle Concepts) – 3BB vs 3T24B vs 3IB
  - EPNL vs VMIX/C0
  - PNL Directivities
  - SPL and NOY Spectra

- Summary of EPNL Reductions for PW’s Nozzle Concepts Tested.
COMPARISON OF BASELINE AND SELECTED CORE NOZZLE CONCEPTS

PNL DIRECTIVITIES

1500-ft Sideline Flyover

Baseline Nozzle (3BB)

GE's Best Core Nozzle Concept (3I12B)

PW's Best Core Nozzle Concept (3T24B)
COMPARISON OF BASELINE AND SELECTED CORE NOZZLE CONCEPTS

SPL SPECTRA at Baseline Nozzle Inlet Angle of 80 degrees.

1500-ft Sideline Flyover

Baseline Nozzle (3BB)

PW's Best Core Nozzle Concept (3T24B)

GE's Best Core Nozzle Concept (3I12B)
COMPARISON OF BASELINE AND SELECTED CORE NOZZLE CONCEPTS

NOY SPECTRA at Baseline Nozzle Peak PNLT Angle (130 deg)

Baseline Nozzle (3BB)
GE's Best Core Nozzle Concept (312B)
PW's Best Core Nozzle Concept (3T24B)

1500-ft Sideline Flyover
EPNL REDUCTIONS for PW's FAN NOZZLE CONCEPTS

1590-ft Sideline Flyover NASA/CP—2000-210524 151
EPNL REDUCTIONS for PW's COMBINED CORE & FAN NOZZLE CONCEPTS

1500-ft Sideline Flyover

NASA/CP—2000-210524
SUMMARY / CONCLUSION

- CONCEPTS THAT PROMOTE MIXING OF THE CORE STREAM ARE MORE EFFECTIVE THAN THOSE THAT WORK ON THE FAN STREAM.
PLUME SURVEY TEMPERATURE PROFILES for Selected Nozzles
Phased array measurements for the Separate Flow Jet Noise test at LeRC

Srini Bhat/ John Premo
Boeing Commercial Airplane Group
September 10, 1997
Overview

Phased array measurements for the SFJN test at LeRC

- Introduction
- Description of phased arrays
- Setup for the SFJN test
  - Boeing supplied resources
  - LeRC provided resources
- Phased array acquisition and processing
- Review of selected results
  - Selected 1/3 octave band contours
  - Selected integrated spectra
- Conclusions
Description of phased arrays

Phased array measurements for the SFJN test at LeRC

phased arrays – system of microphones which allows the sound from a particular location or direction to be selectively measured through coherent addition of the microphone signals

Source Region

Microphone Array
Setup for the SFJN test

Phased array measurements for the SFJN test at LeRC

Three arrays were used during testing.

- **Each array has its own advantages**

  Array A: Large 7 arm logarithmic spiral
  - **Determines source density in two dimensions**
  - Located below the jet at 90 and 120 degrees
  - Works well from 1000 to 8000 Hertz

  Array B: Small 7 arm logarithmic spiral (contained within array A)
  - **Determines source density in two dimensions**
  - Located below the jet at 90 and 120 degrees
  - Works well from 8000 to 50000+ Hertz

  Array C: Sideline linear array
  - **Image in one direction along axis of jet**
  - Works well from 1000 to 50000 Hertz
Phased Array Acquisition and Processing

Phased array measurements for the SFJN test at LeRC

Boeing supplied resources
- Microphones, amplifiers, cables, and arrays
- Data acquisition hardware

LeRC supplied resources
- Access to the LACE cluster parallel computer for processing
- SGI computer with the FAST program for viewing the processed data
Separate Flow Jet Noise Reduction Test

Model 3BB viewed with array B

Run: 1115  Point: 21  Mach: 0.28

dB re Peak SPL

-8.0

-6.0

-4.0

-2.0

0.0

fc = 10000 Hz  fc = 12500 Hz  fc = 16000 Hz
x = 31.0; y = -1.0  x = 29.5; y = -1.0  x = 28.0; y = -1.0
Peak SPL = 92.0 dB  Peak SPL = 91.2 dB  Peak SPL = 89.5 dB

fc = 20000 Hz  fc = 25000 Hz  fc = 31500 Hz
x = 27.0; y = -1.0  x = 25.5; y = -0.5  x = 25.5; y = -0.5
Peak SPL = 87.4 dB  Peak SPL = 86.0 dB  Peak SPL = 85.3 dB
Review of Selected Results

Phased array measurements for the SFJN test at LeRC

General Results:
- **Looks like there are two separate source regions**
  - Region 1: Near the the nozzle exit
  - Region 2: Several nozzle diameters downstream of the nozzle exit

Possible Explanation:
- **Two regions correspond to different source mechanisms**
  - Region 1 is primarily due to secondary/ambient mixing and any nozzle trailing edge and duct noise
  - Region 2 is more the classical jet noise region
Review of Selected Results

Phased array measurements for the SFJN test at LeRC

General Results:

- The relative importance of the two regions change with frequency
  - Region 1: dominates at higher frequencies
  - Region 2: dominates at low frequencies

Note that the peak levels as a function of frequency remain relatively constant within each region. However, the center of mass of the source density moves progressively closer to the nozzle as the frequency is increased and Region 1 starts to dominate Region 2.
Separate Flow Jet Noise Reduction Test
Model 3BB viewed with array A
Run: 1113 Point: 23 Mach: 0.28

$dB$ re Peak SPL

-8.0
-6.0
-4.0
-2.0
0.0

$fc = 1000$ Hz
$x = 83.0; y = 0.0$
Peak SPL = 91.5 dB

$fc = 1250$ Hz
$x = 84.4; y = -1.0$
Peak SPL = 90.2 dB

$fc = 1600$ Hz
$x = 29.8; y = 0.0$
Peak SPL = 89.0 dB

$fc = 2000$ Hz
$x = 31.2; y = 0.0$
Peak SPL = 88.2 dB

$fc = 2500$ Hz
$x = 32.6; y = 0.0$
Peak SPL = 86.0 dB

$fc = 3150$ Hz
$x = 32.6; y = 0.0$
Peak SPL = 85.4 dB
Separate Flow Jet Noise Reduction Test

Model 3BB viewed with array A

Run: 1119  Point: 23  Mach: 0.00

dB re Peak SPL

fc = 1000 Hz
x = 71.8; y = 0.0
Peak SPL = 102.5 dB

fc = 1250 Hz
x = 73.2; y = 0.0
Peak SPL = 101.7 dB

fc = 1600 Hz
x = 69.0; y = 0.0
Peak SPL = 100.4 dB

fc = 2000 Hz
x = 69.0; y = 0.0
Peak SPL = 98.3 dB

fc = 2500 Hz
x = 66.2; y = 0.0
Peak SPL = 96.3 dB

fc = 3150 Hz
x = 50.8; y = 0.0
Peak SPL = 94.3 dB
Review of Selected Results

Phased array measurements for the SFJN test at LeRC

Comparison of sources versus power settings:

• The upstream region is less affected by increases in power than the downstream

Possible Explanation:

• Two regions correspond to different source mechanisms
  • Region 1 likely scales as $M^6$ or $M^7$
  • Region 2 likely scales as $M^8$

Comparison of sources versus tunnel Mach number:

• The upstream region is less affected by increases in tunnel Mach number than the downstream

Possible Explanation:

• Same as above
Separate Flow Jet Noise Reduction Test

Model 31C viewed with array A

Run: 1109  Point: 21  Mach: 0.28

\[ dB \text{ re Peak SPL} \]

-2.0
-4.0
-6.0
-8.0

\[ fc = 1000 \text{ Hz} \]
\[ x = 92.8; y = 0.0 \]
Peak SPL = 94.2 dB

\[ fc = 1250 \text{ Hz} \]
\[ x = 94.2; y = -1.0 \]
Peak SPL = 93.4 dB

\[ fc = 1600 \text{ Hz} \]
\[ x = 34.0; y = 0.0 \]
Peak SPL = 93.2 dB

\[ fc = 2000 \text{ Hz} \]
\[ x = 34.0; y = 0.0 \]
Peak SPL = 94.5 dB

\[ fc = 2500 \text{ Hz} \]
\[ x = 35.4; y = 0.0 \]
Peak SPL = 93.9 dB

\[ fc = 3150 \text{ Hz} \]
\[ x = 35.4; y = 0.0 \]
Peak SPL = 93.5 dB
Review of Selected Results

Phased array measurements for the SFJN test at LeRC

Comparison of baseline to enhanced mixing nozzles:

- The upstream region has increased levels
- The downstream region has decreased levels

Possible Explanation:

- Increased mixing from the devices
  - Increases the turbulence intensities/mixing upstream
  - Decreases the relative velocities downstream
Conclusions

Phased array measurements for the SFJN test at LeRC

- Phased arrays can be used to qualitatively image jet noise sources
- Two separate source regions:
  - upstream near nozzle exit (Region 1)
  - downstream several nozzle diameters (Region 2)
- The upstream region is less affected by increases in power than the downstream
- The upstream region is less affected by increases in tunnel Mach number than the downstream
- Jet Mixing devices:
  - increase upstream sources (Region 1)
  - decrease downstream sources (Region 2)
- Preliminary results of using phased array measurements to determine far-field spectra are promising
Discussion of Measured Acoustic & Related Aero Data

Thomas J. Barber
United Technologies Research Center
NOY Spectra, dB

3BB

3IB

3T24B

3BOmax-0

Band No
Critical Propulsion and Noise Reduction Technologies for Future Commercial Subsonic Engines
NASA Contract NAS3-27720

Area of Interest 14.3: Separate Flow Exhaust System Noise

NASA/AST Separate Flow Test Status Meeting
Cleveland, September 10, 1997

B A Janardan, G E Hoff, J W Barter, J F Brausch, P R Gliebe, R S Coffin, S Martens, B R Delaney
GE Aircraft Engines, Cincinnati
W N Dalton, V G Mengle, B R Vittal, V D Baker, F Smith
Allison Engine Company, Indianapolis
Outline

1. Objectives, Approach & Goal
2. Baseline Nozzles & Test Cycle Definition
3. Repeatability & Baseline Nozzle Results
4. Noise Reduction Concepts
5. Noise Reduction Test Configurations of BPR=5 Internal Plug Nozzle & Acoustic Results
6. Noise Reduction Test Configurations of BPR=5 External Plug Nozzle & Acoustic Results
7. Noise Reduction Test Configurations of BPR=8 External Plug Nozzle & Acoustic Results
8. Summary
Area of Interest 14.3: Separate Flow Exhaust System Noise


Approach: Model Design & Fabrication
5 Baseline Separate Flow Configurations (BPR = 5, 8)
Baseline Nozzles Representative of Langley/MD Designs
11 Jet Mixing Enhancement Concepts (both Core & Fan)
Mixing Concepts Screening Selection
Hardware Adapted to NASA Lewis Jet Rig System
Assistance in Test Planning & Test Coverage at Lewis AAPL Data Analyses & Report

Goal: 1.5+ dB Jet Noise Reduction Relative to Separate Flow Designs
AAPL Jet Exit Rig Configuration for Separate Flow Nozzle Test

- NASA Lewis responsible for hardware upstream of break planes and adaptive spool
- GEAE/AEC responsible for baseline model test hardware design downstream of adaptive spool and their fabrication
- GEAE/AEC responsible for design and fabrication of selected noise reduction concept hardware (P&W also designed and fabricated different noise reduction concept hardware under a separate NASA contract)
Baseline Nozzles: BPR = 5

Model 1
BPR=5; Coplanar Nozzle

Model 2
BPR=5; Internal Plug

Model 3
BPR=5; External Plug
Baseline Nozzles: BPR = 8

BPR=8; Internal Plug
Model 4

BPR=8; External Plug
Model 5
BPR = 5 & 8; Power Setting Parameters of Test Points

Fan or Core Nozzle Pressure Ratio

Core Nozzle Pressure Ratio
Repeatability
Baseline Models 2 & 3 (BPR=5)

Results of Baseline Nozzles
Baseline Models 1, 2, 3 (BPR=5) & 4, 5 (BPR=8)

Coplanar Nozzles Vs Internal Plug Vs External Plug
Baseline Models 1 vs 2 vs 3 (BPR=5)
Internal Plug Vs External Plug
Baseline Models 4 vs 5 (BPR=8)
GENERAL ELECTRIC Aircraft Engines

- PNL Directivity
- One-Third Octave Spectrum at 130.0 deg.
- One-Third Octave Spectrum at 90.0 deg.
- One-Third Octave Spectrum at 155.0 deg.

**LEGEND**

- 265, 46 deg
- 548, 74 deg
- 594, 40 deg
- 642, 33 deg
- 682, 38 deg
- 734, 44 deg
- 788, 57 deg
- 836, 48 deg
- 862, 39 deg
- 917, 45 deg
- 1072, 51 deg
- 1275, 60 deg

**Baseline (3BB)**
- Repeatability
- BPR = 5
- TP 21
- M = 0.28
- Scale Factor = 8
- Altitude = 1500 ft

PNL Directivity & SPL Spectra

Separate Flow Test Status Meeting

NASA Lewis, Cleveland, Ohio

September 10, 1997
Baseline (3BB) Repeatability
BPR = 5
TP 21
M = 0.28
Scale Factor = 8
Altitude = 1500 ft

PNL Directivity & Noy Spectra
Separate Flow Nozzle with External Plug (3BB); BPR=5
Normalized EPNL vs Normalized Vmix

- 3BB - April 1
- 3BB - April 4
- 3BB - April 8
- 3BB - April 9
- 3BB - April 10
- 3BB - April 11
- 3BB - April 15
- 3BB - April 16
- 3BB - April 17
- 3BB - April 18
- 3BB - April 23
- 3BB - May 13

Scale Factor = 8, Altitude = 1500 ft, M = 0.28

EPNL = 10log(10^100), dB
Normalized Vmix (Vmix/camb)

GE Aircraft Engines
ba46/AAPL03 XL6/Chart2
Co-Planar (1BB) vs External Plug (3BB)
BPR=5
M=0.28
TP 21
Scale Factor =8
Altitude=1500 ft

PNL Directivity & SPL Spectra
General Electric Aircraft Engines

Legend

<table>
<thead>
<tr>
<th>Internal (2BB) VS External Plug (3BB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BPR = 5</td>
</tr>
<tr>
<td>M = 0.28</td>
</tr>
<tr>
<td>TP 21</td>
</tr>
<tr>
<td>Scale Factor = 8</td>
</tr>
<tr>
<td>Altitude = 1500 ft</td>
</tr>
<tr>
<td>PNL Directivity &amp; SPL Spectra</td>
</tr>
</tbody>
</table>
Separate Flow Nozzle with Int Plug (4BB) & Ext Plug (5BB); BPR = 8

Scale Factor = 8, Altitude = 1500 ft, M = 0.28

- 4BB
- 5BB

---

GE Aircraft Engines
baj46/AAPL03A.XLS/Chan19
Internal (4BB) vs External Plug (5BB)
BPR = 8
M = 0.28
TP 41
Scale Factor = 8
Altitude = 1500 ft

PNL Directivity & SPL Spectra
Summary - Repeatability & Baseline Nozzle Results

- Baseline 3BB Was Repeated 12 Times (Probably a Record For Number of Repeats of A Baseline)
- For a Given Test Point Setting, Noise Level Was Dependent Upon Ambient Temperature
- Repeatability Was Established With Normalization
- No Significant Acoustic Differences Were Noted Between Coplanar (1BB), Internal Plug (2BB) & External Plug (3BB) Baseline BPR=5 Nozzles
- No Significant Acoustic Differences Were Noted Between Internal Plug (4BB) & External Plug (5BB) Baseline BPR=8 Nozzles
- Normalized & Correlated Baseline Nozzle EPNL Database Will Be Used To Compare & Evaluate Tested Noise Reduction Concepts
# Noise Reduction Concepts Selected for Evaluation

<table>
<thead>
<tr>
<th>Core Nozzle</th>
<th>Model</th>
<th>Fan Nozzle*</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 2 3</td>
<td>x</td>
<td>x x x</td>
</tr>
<tr>
<td><strong>Chevron (8)</strong></td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Chevron (12)</strong></td>
<td>x x x</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Flipper Chevron (12)</strong></td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Inward Flip)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Flipper Chevron (12)</strong></td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Alternately Flip)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Vortex Generating Doublet (64)</strong></td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Core Flow Side)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Vortex Generating Doublet (20)</strong></td>
<td>x</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Fan Flow Side)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Tongue Mixer</strong></td>
<td>x</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Fan Nozzle Hardware Is Common For Models 2 Through 5
Noise Reduction Test Configurations of Model 2

With Fan Nozzle Noise Reduction Concepts
2BC, 2BD

With Core Nozzle Noise Reduction Concepts
2C12B, 2TmB, 6TmB

With Core & Fan Nozzle Noise Reduction Concepts
2C12C, 2TmC, 6TmC
Noise Reduction Test Configurations with Model 2
BPR = 5, Internal Plug
With Different Fan Nozzles

2BC

2BD
Separate Flow Nozzle with Internal Plug (2BB); BPR=5
with Chevron and Doublets Fan Nozzle (2BC, 2BD)

Scale Factor = 8, Altitude = 1500 ft, M = 0.28
Separate Flow Nozzle with Internal Plug (2BB); BPR=5 with Chevron and Doublets Fan Nozzle (2BC, 2BD)

Scale Factor = 8, Altitude = 1500 ft, M = 0.28

EPNL, dB

Net Thrust, lb

GE Aircraft Engines
bj46/AAPL03B.XLS/Chart14A
Comparison of fan nozzle mixing enhancers - Sound power

Model 2 150' polar Scale factor=8 Mij=.28 Cycle point 21

Baseline core Baseline fan 26B
Baseline core 24 chevrons fan 26C
Baseline core 96 internal doublets - fan 26D

1/3 octave center frequency

Sound power - dp.
Baseline (2BB) vs Features on Fan only
BPR = 5
TP 21
M=0.28
Scale Factor =8
Altitude=1500 ft

PNL Directivity
& SPL Spectra
Noise Reduction Test Configurations with Model 2
BPR = 5, Internal Plug

With Different Core Nozzles
Separate Flow Nozzle with Internal Plug (2BB); BPR=5
with Chevron & Tongue Mixer on Core Nozzle (2C12B, 2TmB, 6TmB)

Scale Factor = 8, Altitude = 1500 ft, M = 0.28

- 2C12B
- 2TmB
- 6TmB
- Poly. (2BB)

Normalized Vmix (Vmix/camb)
Comparison of Core nozzle mixing enhancers - Sound power

Model 2  5 BPR  Scale factor=8  Mfj=.28  Cycle point 21

- Baseline core  Baseline fan
- 12 core chevrons baseline fan
+ Core tongue mixer - extended core plug base fan
* Core tongue mixer - original core plug base fan
Baseline (2BB) vs Features on Core only
BPR = 5
TP 21
M = 0.28
Scale Factor = 8
Altitude = 1500 ft

PNL Directivity & SPL Spectra
General Electric Aircraft Engines

Legend:
- 2BB, 66 deg-1236
- 2TMB, 43 deg-265
- 2C128, 65 deg-316
- 6TMB, 59 deg-1261

Baseline (2BB)
vs Features on
Core only
BPR = 5
TP 21
M = 0.28
Scale Factor = 8
Altitude = 1500 ft

PNL Directivity
&
Noy Spectra

Separate Flow Test Status Meeting
NASA Lewis, Cleveland, Ohio
September 10, 1997
Noise Reduction Test Configurations with Model 2
BPR = 5, Internal Plug

With Different Core & Fan Nozzles

2C12C

2TMC

6TMC
Separate Flow Nozzle with Internal Plug (2BB); BPR=5
with Chevron & Tong-Mix on Core and Chevron on Fan Nozzle (2TmC, 2CC)

Scale Factor = 8, Altitude = 1500 ft, M = 0.28

Normalized Vmix (Vmix/camb)

EPNL - 10LOG(F/1000), dB
Comparison of combined nozzle mixing enhancers - Sound power

Model 2  150' polar  Scale factor=8  Mfj=.28  Cycle point 21

Sound power - db.

1/3 octave center frequency

- Baseline core  Baseline fan
- 12 core chevron  24 chevrons fan
+ Core tongue mixer-extended plug  24 fan chevrons
* Core tongue mixer- original plug  24 chevron fan
Baseline (2BB) vs Features on Fan and Core
BPR = 5
TP 21
M = 0.28
Scale Factor = 8
Altitude = 1500 ft
PNL Directivity & SPL Spectra
GENERAL ELECTRIC Aircraft Engines

Baseline (2BB) vs Features on Fan and Core
BPR = 5
TP 21
M = 0.28
Scale Factor = 8
Altitude = 1500 ft
PNL Directivity & Noy Spectra
Noise Benefits Relative to Baseline Model 2

\[ \text{Tamb} = 50^\circ\text{F}; \text{Scale Factor} = 8; \text{Altitude} = 1500 \text{ ft}; M = 0.28 \]
Summary - Noise Reduction Test Concepts of BPR=5 Internal Plug Nozzle (Model 2)

- Some Mixing Concepts Change Slope of EPNL vs $V_{\text{mix}}$
- There is Tradeoff Between Low Frequency Jet Noise Reduction Due to Improved Mixing & High Frequency Noise Increase From Vortex Generation
- Test Noise Reduction Concepts Used Separately on Core Or Fan Provide $\cong 1$ EPNdB Benefit At Typical Sideline Condition
- Test Noise Reduction Concepts Used Combined on Core And Fan Provide $\cong 1.5$ to $2$ EPNdB Benefit At Typical Sideline Condition
- Test Noise Reduction Concepts Provide Little Benefit Or Noise Increase At Typical Cutback Condition
Noise Reduction Test Configurations of Model 3

With Fan Nozzle Noise Reduction Concept
3BC

With Core Nozzle Noise Reduction Concepts
3DiB, 3DxB
3C8B, 3C12B, 3IB, 3AB

With Core & Fan Nozzle Noise Reduction Concepts
3C8C, 3C12C, 3IC, 3AC
Noise Reduction Test Configurations with Model 3
BPR = 5, External Plug
With Different Fan Nozzle
Separate Flow Nozzle with External Plug; BPR=5
With 24 Chevron Fan Nozzle (3BC)

Scale Factor = 8, Altitude = 1500 ft, M = 0.28

Poly. (3BB Test Data)

× 3BC

Normalized Vmix (Vmix/camb)
Baseline (3BB) vs 24 Chevrons on Fan (3BC)
BPR=5
M=0.28
TP 21
Scale Factor = 8
Altitude = 1500 ft

PNL Directivity & SPL Spectra
Baseline (3BB) vs 24 Chevrons on Fan (3BC)
BPR=5
M=0.28
TP 21
Scale Factor =8
Altitude=1500 ft

PNL Directivity & Noy Spectra
Noise Reduction Test Configurations with Model 3

BPR = 5, External Plug

With Doublets on Core Nozzle

3DIB

3DXB
Separate Flow Nozzle with External Plug; BPR=5
With Doublet Noise Reduction Features on Core Nozzle (Di, Dx)

Scale Factor = 8, Altitude = 1500 ft, M = 0.28

+ 3DiB
× 3DxB
Poly. (3BB Test Data)
Baseline (3BB) vs 64 Internal Doublets on Core (3DiB)
BPR=5
M=0.28
TP 21
Scale Factor = 8
Altitude = 1500 ft

PNL Directivity & SPL Spectra
Baseline (3BB) vs 20 External Doublets on Core (3DxB)
BPR=5
M=0.28
TP 21
Scale Factor = 8
Altitude = 1500 ft

PNL Directivity & SPL Spectra
Noise Reduction Test Configurations with Model 3

BPR = 5, External Plug

With Different Core Nozzles

3C12B

3C8B

3AB

3IB
Separate Flow Nozzle with External Plug; BPR=5
With Four Different Chevron Core Nozzles (C8, C12, I, A)

Scale Factor = 6, Altitude = 1500 ft, M = 0.28

Normalized Vmix (Vmiox/camb)

ENL (10LOG(E1000)) dB

- 3C8B
- 3C12B
- 3I
- 3AB

Poly. (3BB Test Data)
Baseline (3BB) vs Features on Core only
BPR = 5
TP 21
M = 0.28
Scale Factor = 8
Altitude = 1500 ft

PNL Directivity

Angle re: Inlet, Deg.
One-Third Octave Spectrum at 130.0 deg.

Baseline (3BB) vs Features on
Core only
BPR = 5
TP 21
M = 0.28
Scale Factor = 8
Altitude = 1500 ft

SPL Spectrum at 130 deg
One-Third Octave Noisiness at 130.0 deg.

Baseline (3BB) vs Features on Core only
BPR = 5
TP 21
M=0.28
Scale Factor =8
Altitude=1500 ft
Noy Spectrum at 130 deg
Comparison of core mixing enhancers - Sound power

Model 3 BPR Scale factor=8 Mj=28 Cycle point 21

Sound Power - dB

1/3 octave center frequency

NASA/CP-2000-210524
Noise Reduction Test Configurations with Model 3
BPR = 5, External Plug
With Different Core & Fan Nozzles

3C12C

3C8C

3IC

3AC
With Four Different Core & Fan Chevron Nozzle (3C8C, 3C12C, 3IC, 3AC)

Separate Flow Nozzle with External Plug; BPR=5

Scale Factor = 8, Altitude = 1500 ft, M = 0.28

Normalized Vmix (Vmix/camb)
GENERAL ELECTRIC Aircraft Engines

PNG Directivity

Baseline (3BB)
vs Features on
Core and Fan
BPR = 5
TP 21
M=0.28
Scale Factor =8
Altitude=1500 ft

PNL Directivity

Angle re: Inlet, Deg.

Separate Flow Test Status Meeting
NASA Lewis, Cleveland, Ohio
September 10, 1997
One-Third Octave Spectrum at 130.0 deg.

Baseline (3BB) vs Features on Core and Fan
BPR = 5
TP 21
M = 0.28
Scale Factor = 8
Altitude = 1500 ft

SPL Spectrum at 130 deg
One-Third Octave Noisiness at 130.0 deg.

Baseline (3BB) vs Features on
Core and Fan
BPR = 5
TP 21
M = 0.28
Scale Factor = 8
Altitude = 1500 ft

Noy Spectrum at 130 deg
Comparison of combined mixing enhancers - Sound power

Model 3 5 BPR Scale factor=8 Mfj=.28 Cycle point 21

Sound Power-db.

1/3 octave center frequency
SPL values of 3BB minus SPL values of 3IC
BPR = 5
TP 21
M = 0.28
Scale Factor = 8
Altitude = 1500 ft
Noy values of 3BB minus Noy values of 3IC

BPR = 5
TP 21
M = 0.28
Scale Factor = 8
Altitude = 1500 ft

General Electric Aircraft Engines

Separate Flow Test Status Meeting
SPL values of 3BB minus SPL values of 3AC
BPR = 5
TP 21
M = 0.28
Scale Factor = 8
Altitude = 1500 ft
Summary - Noise Reduction Test Concepts of BPR=5 External Plug Nozzle (Model 3)

- Core Nozzle Doublets (Both Internal & External of Core Nozzle) Provide No Significant Noise Benefit
- At Typical Sideline Condition Following Benefits Were Noted:
  1) Both 8 Chevron & 12 Chevron Core Nozzles \(\cong 1\) to \(1.5\) EPNdB
  2) Inward & Alternate Flip Core Chevron Nozzles \(\cong 2.5\) EPNdB
  3) Addition of Fan Chevron Increases Core Chevron Nozzle Benefits upto An Additional Maximum Benefit of \(1.0\) EPNdB
  4) 3IC & 3AC \(\cong 3.0\) & \(3.4\) EPNdB
- Chevron Core Nozzles Gave Significant Low Frequency Jet Noise SPL Reduction. Except for Alternate Flip Core Chevron Nozzle, Chevron Nozzles Did Not Increase High Frequency SPL
- Test Concepts Provide 0.5 to 1 EPNdB Benefit at Typical Cutback Condition
Noise Reduction Test Configurations of Model 5

With Fan Nozzle Noise Reduction Concept

5BC

With Core Nozzle Noise Reduction Concept

5C12B

With Core & Fan Nozzle Noise Reduction Concepts

5C12C
Noise Reduction Test Configurations with Model 5

BPR = 8, External Plug
With Chevron Core and Fan Nozzles
Separate Flow Nozzle with Int Plug (4BB) & Ext Plug (5BB); BPR = 8

- 5C12B
- 5BC
- 5C12C
- Poly. (5BB)

Scale Factor = 8, Altitude = 1500 ft, M = 0.28

Normalized Vmix (Vmix/camb) vs. EPNL (10LOG(F/1000), dB)
Baseline (3BB) Repeatability
BPR = 5
TP 21
M=0.28
Scale Factor =8
Altitude=1500 ft

PNL. Directivity & SPL Spectra
Baseline (5BB) vs Features on Core and/or Fan
BPR = 8
TP 41
M = 0.28
Scale Factor = 8
Altitude = 1500 ft
PNL Directivity & SPL Spectra
Baseline (5BB) vs Features on Core and/or Fan
BPR = 8
TP 41
M = 0.28
Scale Factor = 8
Altitude = 1500 ft

PNL Directivity & Noy Spectra
Summary - Noise Reduction Test Concepts of BPR=8 External Plug Nozzle (Model 5)

- Chevron Noise Reduction Concepts Used Separately on Core Or Fan Provide \( \approx 1 \) EPNdB Benefit At Typical Sideline Condition

- Chevron Noise Reduction Concepts Used Combined on Core And Fan Provide \( \approx 1.5 \) EPNdB Benefit At Typical Sideline Condition
Summary

• Successful Separate Flow Acoustic Test Program Completed

• Concepts Identified That Give Significant Jet Noise Reduction

• Some Concepts Meet NASA Stretch Goal of 3.0 EPNdB Jet Noise Reduction At Typical Takeoff Condition

• Good Cooperation Between NASA & Industry Participants During Planning & Execution of Test Program

• Need to Assess Performance Impact of Significant Noise Reduction Concepts
SFNT97 Flow Field Measurements

Nozzle geometry → Flow → Sound

- IR for online diagnostics with acoustics
- Ptot, Ttot, Pstat rake surveys for mean flow measurements
- Focused Schleiren for density and some turbulence structure
- Laser sheet visualization for near-nozzle diagnostics
- Two-point hotwire measurements for turbulence models
IR Camera On-line
Non-intrusive flow diagnostic with acoustic testing

Total temperature rake data

3BO
Plume Survey Rake Instrumentation

- Four vertical rakes (Z)
  - 10” total span
  - 1/4” $\Delta z$ $p_{tot}$
  - 1/4” $\Delta z$ $t_{tot}$
  - 1/2” $\Delta z$ $p_{stat}$ x 2 rakes
- Traverse actuation in horizontal plane (X,Y)
- pstat only measured in first two cross-sections (10.5” and 13.5”)
- Velocity obtained using $p_{stat} = p_{amb}$ is denoted by “velocity*”
Comparison of velocity calculated with and without measured pressure — x=10.5"
# Model 3 Configurations Tested

**Fan mixers**

<table>
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<th>C24</th>
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**Core mixers**

**Other Configurations Tested**

- 1BB
- 2BB
- 4BB
- 6TmB
- 7BB
Mean velocity field
3T24T48
Cycle point 21, M=0.28

velocity* (ft/sec)

400 1600
Mean velocity field
3BB
Cycle point 21, M=0.28
Mean velocity field
3C8B
Cycle point 21, M=0.28

velocity* (ft/sec)

400 1600
Mean velocity field
3BC24
Cycle point 21, M=0.28
Mean velocity field
3T24C24
Cycle point 21, M=0.28
Mean velocity field

3C12B

Cycle point 21, M=0.28

SFNT97: Plume survey

velocity* (ft/sec)

10.5"

30"

NASA/CP—2000-210524
Mean velocity field
3C12C24
Cycle point 21, M=0.28
Mean velocity field
3T48B
Cycle point 21, M=0.28

velocity* (ft/sec)

10.5"
30"

400 1600
Mean velocity field
3T24B
Cycle point 21, M=0.28
Mean velocity field

3AB

Cycle point 21, M=0.28

10.5''

30''

velocity* (ft/sec)

400

1600

SFNT97: Plume survey

NASA/CP—2000-210524
Mean velocity field
3T24T24
Cycle point 21, M=0.28
Mean velocity field
3BO
Cycle point 21, M=0.28
Mean velocity field
Cycle point 21, M=0.28; y = 0

SFNT97: Plume survey

Fan exit Plug

3BB

3AB

3C8B

3C12B

3C12C24

velocity* (ft/sec)
400 1600
Mean velocity field

Cycle point 21, M=0.28; y = 0

velocity* (ft/sec)
Mean velocity field
Cycle point 21, M=0.28; y = 0

velocity* (ft/sec)

400 1600
Mean velocity field

Cycle point 21, M=0.28; x=10.5"

3C8B

3AB

3BB

SFNT97: Plume survey

velocity (ft/sec)

1600

400
Mean velocity field
Cycle point 21, M=0.28; x=10.5"
Mean velocity field
Cycle point 21, M=0.28; x=10.5"
Mean velocity field
Cycle point 21, M=0.28; x=10.5"
Mean velocity field
Cycle point 21, M=0.28; x=10.5"

3T24C24  3T24T24  3T24T48

velocity (ft/sec)

400 1600
Mean velocity field
Cycle point 21, M=0.28; x=10.5”
Mean velocity field
Cycle point 21, $M=0.28; x=10.5''$

- 3FB
- 3HB
- 3BO

Velocity (ft/sec)

400 1600
Mean velocity field

Cycle point 21, M=0.28; x=13.5”

SFNT97: Plume survey
Mean velocity field
Cycle point 21, M=0.28; x=13.5''

3C12B

3C12C24

velocity (ft/sec)

400 1600
Mean velocity field
Cycle point 21, M=0.28; x=13.5''

velocity (ft/sec)

400 1600
Mean velocity field
Cycle point 21, M=0.28; x=13.5"

3T24B

3T48B

velocity (ft/sec)

400 1600
Mean velocity field
Cycle point 21, $M = 0.28; x = 13.5''$

3T24C24

3T24T24

3T24T48

velocity (ft/sec)

400

1600
Mean velocity field
Cycle point 21, M=0.28; x=13.5"

3BB

3BC24

3BT24

velocity (ft/sec)

400

1600
Mean velocity field
Cycle point 21, \( M=0.28; \ x=13.5'' \)

3FB

3HB

3BO

velocity (ft/sec)

400 1600
Mean velocity field
Cycle point 21, M=0.28; x=18"

velocity* (ft/sec)

400 1600
Mean velocity field

Cycle point 21, M=0.28; x=18''

SFNT97: Plume survey
Mean velocity field
Cycle point 21, M=0.28; x=18"

SFNT97: Plume survey

NASA/CP—2000-210524 298
Mean velocity field
Cycle point 21, M=0.28; x=18”
Mean velocity field
Cycle point 21, $M=0.28; x=18''$

3T24C24  3T24T24  3T24T48

velocity* (ft/sec)

400  1600
Mean velocity field
Cycle point 21, M=0.28, x=18"
Mean velocity field

Cycle point 21, M=0.28; x=18"
Mean velocity field
Cycle point 21, M=0.28; x=30°
Mean velocity field
Cycle point 21, M=0.28; x=30"
Mean velocity field
Cycle point 21, M=0.28; x=30''

SFNT97: Plume survey
Mean velocity field
Cycle point 21, $M=0.28; x=30''$

3T24C24  3T24T24  3T24T48

velocity* (ft/sec)

400  1600
Mean velocity field
Cycle point 21, M=0.28; x = 30"

velocity* (ft/sec)

3FB

3HB

3BO

400 1600
Mean velocity field

Cycle point 21, M=0.28; x=60”

3C12C24

3C12B

SFTF97: Plume survey

velocity* (ft/sec)

1600

400
Mean velocity field

Cycle point 21, M=0.28; x = 60°

SFNT97: Plume survey
Mean velocity field
Cycle point 21, M=0.28; x=60"

3BB

3AB

3C8B

velocity* (ft/sec)

400 1600
Mean velocity field
Cycle point 21, M=0.28; x= 60"

3T24B

3T48B

velocity* (ft/sec)

400

1600
Mean velocity field
Cycle point 21, M=0.28; x=60"

SFNT97: Plume survey

3T24T48
3T24T24
3T24C24

velocity* (ft/sec)
1600
400
Mean velocity field
Cycle point 21, M=0.28; x= 60°
Mean velocity field

Cycle point 21, M=0.28; x=60°

3BO

3HB

3FB

SFN97: Plume survey
Mean velocity field
Cycle point 21, M=0.28; x= 100"

velocity* (ft/sec)

400 1600
Mean velocity field
Cycle point 21, M=0.28; x= 100"

velocity* (ft/sec)

400 1600
Mean velocity field
Cycle point 21, M=0.28; x= 100"

3T24C24

3T24T24

3T24T48

velocity* (ft/sec)

400 1600
Mean velocity field
Cycle point 21, M=0.28; x= 100"

3BB

3BC24

3BT24

velocity* (ft/sec)

400

1600

NASA/CP 2000-210524 322
Velocity profiles

Core mixer comparisons

SFNT97: Plume survey

Y = 0.0''
Z = -0.5''

Centerline velocity

Velocity (fl/see)

X (inches)

NASA/CP—2000-210524 324
Velocity profiles
Fan mixer: Effect of chevron

\[ y = 0.0'' \]
\[ z = -0.5'' \]
Velocity profiles
Fan: Offset Nozzle

\[ Y = 0.0'' \]
\[ Z = -0.5'' \]

SFNT97: Plume survey
**Focused Schleiren**

**Model 3 Configurations**

<table>
<thead>
<tr>
<th>Model 3</th>
<th>B</th>
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<td>T48</td>
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- 10" diameter view taken every 6" along x for 16" < x < 46"
- All data taken at Cycle Point 21, M = 0.28

**Model 2 configurations**

<p>| |</p>
<table>
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<tbody>
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<td>2BB</td>
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</table>
Near Nozzle Schleiren
Initial divergence and longitudinal distortion

3BB

3T24B
Downstream Schlieren

Unsteady turbulent structure

3BT24

cycle point 21, x=46''
shutter speed 1/2000 sec
Measurements of two-point space-time correlations using hotwires

- MGB prediction method assumes isotropic, homogeneous turbulence
- Shear layers are not isotropic, nor homogeneous.
- Q: How far from these assumptions is reality and what are some actual valid turbulence models?
- Q: By how much have previous measurements been incorrect in neglecting probe interference?
- Q: What is the frequency dependence of the space-time correlation matrix? (Space-time separation assumption)
Measurements/Statistics

- Attempt to answer these by taking data in simple round jet (core of model 1).
- Used two x-wires separated by $\xi$ on independent traverses.
- Used combination of probes to take space-time correlations for several radii at 3 axial locations
  - $uu(\xi,\tau;x)$, $uv(\xi,\tau;x)$, $uw(\xi,\tau;x)$, $vv(\xi,\tau;x)$, $ww(\xi,\tau;x)$
  - $uuuu(\xi,\tau;x)$, $uuvv(\xi,\tau;x)$, $uvuv(\xi,\tau;x)$, $vvvv(\xi,\tau;x)$, $wwww(\xi,\tau;x)$, $uwuw(\xi,\tau;x)$
- Will calculate $L_{11}/L_{22}$ and $A_{1111}$, $A_{1212}$, $A_{2222}$ as a function of radius, axial location, and frequency.
Expected Turbulence Results

Contours of uu

Region of $\xi$ accessible to two probes

$\xi_1$

$\xi_2$

$L_{11}/L_{22} > 1$

$\beta = 4$

$\beta = 8$

$\beta = 20$
Preliminary Flow Field Insights

- Complicated flow fields defy simple analysis
  - Centerline decay
  - Spread rate
- Fan mixer:
  - C24 'thickens' fan/ambient shear layer; no deformation of core flow
  - C24 decreases core decay re baseline!
  - T24 distorts fan/ambient shear layer and deforms the core flow
  - T24 increases core decay re baseline.
  - Offset nozzle caused 'vectored' flow, with fan flow splitting the core flow downstream.
Preliminary Flow Field Insights, Cont.

- Core mixer:
  - ‘l’ chevron has more impact on core/fan shear layer than ‘C’ chevron.
  - C8 gave stronger initial deformation than C12. Little effect by 60°.
  - Tabs were doubly effective because they alternated in/out and gave strong deformation (destruction!) of core/fan shear layer.
  - Half mixer better mixed than full by 60°.
  - T24 better mixed than T48.
  - Alternating Tab (‘A’) performed similarly to T24, especially downstream.
LaRC SEPARATE FLOW TESTING STATUS

JACK SEINER
JET NOISE LABORATORY
NASA LANGLEY RESEARCH CENTER

SEPTEMBER 10, 1997
PROGRAM OBJECTIVES

• DEVELOP JET NOISE DATA BASE FOR SEPARATE FLOW NOZZLES WITH BYPASS RATIO'S 5 TO 14.

• EVALUATE EFFECT OF PYLON ON NOISE.

• DEVELOP LOW PERFORMANCE IMPACT NOISE SUPPRESSION CONCEPTS.

• EVALUATE POTENTIAL FOR ACTIVE CONTROL OF JET NOISE.
PROGRESS TO DATE

- COMPLETED ACOUSTIC DATA BASE FOR RC AND SEPARATE FLOW NOZZLES WITH INTERNAL AND EXTERNAL PLUGS FOR BPR=5.

- ACQUIRED PERFORMANCE & ACOUSTIC DATA FOR BLUEBELL PRIMARY AND SECONDARY RAMPS.
JNL SIDELINE AST PNL COMPARISONS

- INTERNAL PLUG
- EXTERNAL PLUG
- BLUEBELL NOZZLE WITH INTERNAL PLUG

Mach 0.2

TAKEOFF CONDITION

CUTBACK CONDITION

PNL, dB vs. inlet angle (deg)

NASA Langley Jet Noise Laboratory
FUTURE STUDIES

- COMPLETE DATA BASE STUDY
- VALIDATE NUMERICAL SIMULATION STUDIES
- OBTAIN RELIABLE PERFORMANCE DATA FOR SUPPRESSOR NOZZLES.
- EVALUATE POTENTIAL OF GLOW DISCHARGE AND SYNTHETIC JET ACTUATORS.
Installed Jet Noise

Thonse R. S. (Srini) Bhat

September 10, 1997
NASA Lewis Research Center
NASA AST Jet Noise Meeting

Outline:

- Test facility
- Hardware & instrumentation layout
- Test configurations
- Results
  - Spectral plots
  - Phased array data
  - Velocity profiles
- Concluding remarks
NASA AST Jet Noise Meeting

Hardware & Instrumentation Layout
Test Configurations:

- Installed jet (inboard)
  - different power settings
  - various flap settings
  - different angle-of-attacks
  - different installation locations
  - changes in bifurcation

- Isolated jet
LSAF 1043 – Installed Jet Noise

Run: 2194  Mach: 0.0

dB from Peak SPL

<table>
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<tr>
<th>Frequency</th>
<th>Peak SPL</th>
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<td>20000 Hz</td>
<td>85.3 dB</td>
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<td>40000 Hz</td>
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<td>50000 Hz</td>
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<td>50000 Hz</td>
<td>87.0 dB</td>
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<tr>
<td>100000 Hz</td>
<td>90.8 dB</td>
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```plaintext
f_c = 20000 Hz  x = 66.2; y = 7.4
Peak SPL = 85.3 dB

f_c = 40000 Hz  x = 64.4; y = 6.0
Peak SPL = 79.9 dB

f_c = 50000 Hz  x = 63.8; y = 6.0
Peak SPL = 78.4 dB

f_c = 25000 Hz  x = 86.6; y = 8.8
Peak SPL = 91.8 dB

f_c = 50000 Hz  x = 84.2; y = 8.8
Peak SPL = 87.0 dB

f_c = 100000 Hz x = 80.0; y = 8.5
Peak SPL = 90.8 dB
```
LSAF 1043 – Installed Jet Noise

Run: 2131                  Mach: 0.0

dB from Peak SPL

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<th>Frequency (Hz)</th>
<th>Location (x, y)</th>
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<tr>
<td>40000</td>
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<td>50000</td>
<td>64.4; 5.7</td>
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<td>83.6; 6.2</td>
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<td>10000</td>
<td>82.4; 6.8</td>
<td>94.7 dB</td>
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LSAF 1043 – Installed Jet Noise

Run: 2195
Mach: 0.28

dB from Peak SPL

-8.0
-6.0
-4.0
-2.0
0.0

fc = 20000 Hz
x = 65.0; y = 6.0
Peak SPL = 73.4 dB

fc = 40000 Hz
x = 62.6; y = 5.7
Peak SPL = 64.1 dB

fc = 50000 Hz
x = 63.2; y = 4.8
Peak SPL = 61.0 dB

fc = 2500 Hz
x = 86.6; y = 8.5
Peak SPL = 83.3 dB

fc = 5000 Hz
x = 84.8; y = 8.5
Peak SPL = 77.5 dB

fc = 10000 Hz
x = 82.4; y = 7.9
Peak SPL = 80.2 dB
LSAF 1043 – Installed Jet Noise

Run: 2132
Mach: 0.28

dB from Peak SPL

-8.0
-6.0
-4.0
-2.0
0.0

fc = 20000 Hz
x = 80.6; y = 5.7
Peak SPL = 75.9 dB

fc = 40000 Hz
x = 65.0; y = 4.8
Peak SPL = 64.8 dB

fc = 50000 Hz
x = 63.8; y = 5.4
Peak SPL = 61.5 dB

fc = 2500 Hz
x = 81.8; y = 5.1
Peak SPL = 88.2 dB

fc = 5000 Hz
x = 81.8; y = 4.6
Peak SPL = 85.2 dB

fc = 10000 Hz
x = 66.2; y = 4.8
Peak SPL = 88.0 dB
Schematic of Jet Noise Source Model
Schematic of Jet Noise Component Spectra
Concluding remarks:

- Installation increases noise
- Noise increases with increasing flap deflection
- Secondary—ambient & mixed—ambient components are dominant
- Noise for installed jet is not axi—symmetric
- Modeling of installation effects is in progress
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<th>LastName</th>
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# Jet Noise Analysis and Separate Flow Nozzle Test Workshops

**Sept. 9-10, 1997**

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<td>NASA Glenn, in partnership with US industry, completed an exhaustive experimental study on jet noise reduction from separate flow nozzle exhaust systems. The study developed a data base on various bypass ratio nozzles, screened quietest configurations and acquired pertinent data for predicting the plume behavior and ultimately its corresponding jet noise. Several exhaust system configurations provided over 2.5 EPNdB jet noise reduction at take-off power. These data were disseminated to US aerospace industry in a conference hosted by NASA GRC whose proceedings are shown in this report.</td>
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