Jet Noise Prediction Comparisons with Scale Model Tests and Learjet Flyover Data

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Motivation for Study

- Renewed interest in commercial supersonic flight
- Near-term entry into service aircraft
  - Business type jet
  - 2 – 3 engines
  - Fully mixed exhausts
  - Jet noise dominant at takeoff
- NASA systems studies supporting ICAO Working Group1/LTO subgroup
- Need to quantify our ability to predict absolute jet-noise levels
- Results of this study assist with error bars placed on our ICAO system results
- Comparisons are made between prediction models in ANOPP, scale-model data, and flight data
Comparisons

• Interest is in EPNL but spectra contributing to EPNL are also compared

• Three different datasets explored
  – Flight test data
    • Did not use a noise certification flight procedure
    • Intent is to determine general jet-noise prediction capability
  – Spectra obtained from jet-noise models within NASA’s ANOPP
    • Stone 1 (1980)
    • Stone 2 (2009)
    • SAE 876
    • Modified SAE 876
      – Scale model data acquired in NASA Glenn’s AAPL

• Angles between 70° and 150° can be used to compute EPNL that is within 0.5 EPNdB of that computed from all microphones
Flight and Scale-Model Tests

• Learjet 25 flight test conducted in 2001
  – Believed to be jet-noise dominated
  – Exhaust conditions for lower power settings of interest for supersonic business jet

• Scale model tests conducted in 2018 in NASA Glenn’s AAPL facility
**Flight Tests**

- Used a Learjet 25 with a CJ610 engine
  - CJ610 is a variant of the J85
  - EGT read from cockpit gauge during pretest conducted in Ohio but not during flight test
  - EPR recorded during flight test
- Performed with a constant 500 ft flyover
- Right engine at idle
- Conducted at Estrella Sailport (Phoenix)
- Measurements made with three linear arrays
  - Left - 6 microphones
  - Center (under flight path) - 8 microphones
  - Right – 6 microphones

### Approximate Jet Temperature (°R)

<table>
<thead>
<tr>
<th>EPR</th>
<th>J85 Engine Stand °R</th>
<th>J85 Flight Test (M~0.38) °R</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.6</td>
<td>1180</td>
<td>1306*</td>
</tr>
<tr>
<td>1.8</td>
<td>1257</td>
<td>1402*</td>
</tr>
<tr>
<td>2.0</td>
<td>1374</td>
<td>1505*</td>
</tr>
</tbody>
</table>

Scale-Model Tests

• Conducted in the Aero-Acoustic Propulsion Laboratory
• Used 0.31 scale model of Learjet nozzle system
• Secondary stream was used to mimic secondary flow through NACA scoop and vents
• Slight offset in nozzle was replicated
• Measurements made at two azimuthal angles
  – For centerline flyover array
  – For sideline flyover array
• NPR was matched to flyover EPR
• NTR was matched to temperature ratio in flyover tests
• Secondary stream NTR = 1.25
• Secondary stream set to low NPR_s

Learjet 25 Nozzle

AAPL Facility

Scale-Model Nozzle System

Microphone Array

HFJER

NATR

Scoop

Vents
Scale-Model Data
• No shock associated noise – study only focused on mixing noise
• Data repeatability good
• Small tones in one installation did not impact EPNLs
• No azimuthal dependency – data from multiple runs and two clocking angles averaged
Impact of Secondary Stream

- Spectra for NPRs = 1.05 and 1.10 are similar
- Slight increased levels for NPR = 1.20
Impact of Shear Layer Correction

- Investigated impact of source distribution assumption in shear layer correction
- Source at exit peak at ~150°
- Distributed source peaks at ~140°
- Peak jet-noise level is roughly the same for all source distributions
- Source distribution assumption was found to have little impact on EPNL

\[
\theta = 70°, \quad \theta = 110°_{\text{NPR 1.8}}, \quad \theta = 150°
\]
Predictions and Scale Model

- **NPR 1.6**
- **NPR 1.8**
- **NPR 2.0**

<table>
<thead>
<tr>
<th>SPL (dB)</th>
<th>Frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>110</td>
<td>10^2</td>
</tr>
<tr>
<td>115</td>
<td>10^3</td>
</tr>
<tr>
<td>120</td>
<td>10^4</td>
</tr>
<tr>
<td>125</td>
<td>10^5</td>
</tr>
<tr>
<td>130</td>
<td>10^6</td>
</tr>
</tbody>
</table>

- **θ = 70°**
- **θ = 110°**
- **θ = 150°**
Flight Data
Spectral Comparisons

- No aircraft GPS information from flight test
- Needed aircraft position information to compare flight data to scale-model data and predictions
- Aircraft position determined from tones assuming changes in frequency only associated with Doppler shift
- Spectra obtained from data at different microphones were averaged with time shift accounting for aircraft flight
**Data Repeatability**

NPR = 1.8
Centerline Array

1/3 Octave

<table>
<thead>
<tr>
<th></th>
<th>Run 135</th>
<th>Run 134</th>
<th>Run 133</th>
<th>Run 123</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><img src="image" alt="Graph" /></td>
<td><img src="image" alt="Graph" /></td>
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</tbody>
</table>

- Hump at ~500 Hz matches predicted frequency for tire noise from Fink
- Tones around 200 Hz are likely cavity tones
- Flight Mach number range 0.231 – 0.252
- Differences between runs likely associated with throttle setting
- Tone removal did not eliminate impact of tones

\[ \theta = 158^\circ \]
Predictions and Flight Data Comparisons

NPR = 1.8
Centerline Array

1/3 Octave

\[ \text{SPL (dB)} \]

\[ 95 \]
\[ 90 \]
\[ 85 \]
\[ 80 \]
\[ 75 \]
\[ 70 \]
\[ 65 \]
\[ 60 \]
\[ 55 \]

\[ 1 \]
\[ 2 \]
\[ 3 \]

\[ \theta = 140^\circ \]
\[ \theta = 158^\circ \]

\[ \text{Frequency (Hz)} \]
\[ 10^1 \]
\[ 10^2 \]
\[ 10^3 \]
\[ 10^4 \]

\[ \text{Time (seconds)} \]
\[ 10 \]
\[ 15 \]
\[ 20 \]
\[ 25 \]
\[ 30 \]
\[ 35 \]
\[ 40 \]

PNL

\[ \text{NATR @ Exit} \]
\[ \text{Run 134} \]
\[ \text{Stone 2} \]
\[ \text{SAE} \]

Run 134 Tone Removed
SAE
SAE +100
Predictions and Flight Data Comparisons

NPR = 1.6
Centerline Array

1/3 Octave

Narrowband

Run 139

1

θ = 50°

2

θ = 122°

3

θ = 154°

- Landing gear was not deployed
- Hump present at 158° and NPR = 1.8 is now absent at 154° and NPR = 1.6
- Hump in spectra at 50°
Predictions and Flight Data Comparisons

NPR = 2.0
Centerline Array

1/3 Octave

Narrowband

• Results similar to NPR = 1.8
• Landing deployed
  – Apparent cavity tones and tire noise present
Impact of Number of Array Elements

![Graph showing the impact of number of array elements on EPNL (dB) for different numbers of microphones, with two lines representing 'Mics 7 to 14' and 'Mics 14 to 7' datasets. The x-axis represents the number of microphones, ranging from 0 to 8, and the y-axis represents EPNL in dB, ranging from 104.8 to 106.0. The graph illustrates the fluctuation in EPNL as the number of microphones changes.]
Effective Perceived Noise Levels
Centerline Array

- NATR ΔEPNdB decreases with increasing EPR
- Flight EPNdB decreases by ~0.5 EPNdB with tones removed
- Increasing temperature in SAE model increases EPNdB by 1.5 dB for each 100 °F

Tones not removed in flight data computation
Effective Perceived Noise Levels

**Left Array**

- Flight Number
- EPR
- Flight SAE
- Stone 2
- NATR Exit

**Right Array**

- Flight Number
- EPR
- Flight SAE
- Stone 2
- NATR Exit

**Right Engine at Idle**

**EPNdB**

- Flight Number
- EPR
- Flight SAE
- Stone 2
- NATR Exit

**EPNdB Under Flight Data**

- 1.6
- 1.8
- 2.0

**EPR**

- 1.6
- 1.8
- 2.0
Conclusions

- EPNL from predictions and scale-model data were **below** that for the flight data for all engine EPRs
  - SAE model: 2.5 – 3.5 EPNdB
  - Stone 2 model: 1 – 2 EPNdB
  - Scale-model data: 3 – 5 EPNdB

- Differences between EPNL computed for flight and scale-model or ANOPP models are likely due to uncertainty in engine conditions
  - An increase in engine temperature of 100° F results in 1 – 2 EPNdB increase

- Source distribution assumptions in the shear layer corrections for scale-model data had slight impact on spectra but not on EPNL

- Flights tests should include multiple microphones for averaging spectra to reduce uncertainty