Outline

• ACRP 02-44 Objectives
• Project Team
• Background
• Technical Approach
• Outcomes
• Discussion
ACRP 02-44 Objectives

1. Review, evaluate, and document current helicopter noise models.
2. Identify potential improvements to INM/AEDT to better capture the unique complexity of helicopter and tiltrotor* operations.
3. Develop a supplemental document providing guidance for modeling and helicopter noise.

Motivation: “The fixed-wing aircraft noise prediction techniques employed in INM/AEDT rely on the widely accepted methodologies described in documents such as SAE International’s SAE-AIR-1845 and the European Civil Aviation Conference’s Document 29. However, in contrast to guidance related to fixed-wing aircraft, there is no peer-reviewed guidance document describing an integrated modeling technique for the prediction of helicopter noise.”

* Tiltrotors are included in this study to a limited degree.
ACRP 02-44 Team

- **Wyle**
  - Juliet Page, Principal Investigator
  - Chris Hobbs, Benjamin May
- **The Volpe Center, DOT**
  - Eric Boeker, Lead
  - David Senzig
- **National Aerospace Laboratory, Netherlands**
  - Harry Brower, Lead
  - Marthijn Tuinstra
- **K.B. Environmental**
  - Clint Morrow, Lead
Background: Spectral Content

- Significant Low-freq. energy for Rotorcraft
- INM 50Hz:10kHz /AEDT 10Hz:10kHz

(AEDT Database might need expansion)

Data: AAM CH-146, 1000 Ft AGL, POI 1000Ft Laterally (Port side), 5Ft AGL, Spectra at Lmax, USSTD Atmos.

Comparison of Helicopter and Fixed Wing Spectra
normalized to 60dB at 1000 Hz

Bell-412, RNM/AAM Data
Boeing 737-INM derived Data
Background: Complex Noise Source

- Helo Noise Emission: function(Flight Path Angle)
  - Approach Physics: Blade-Vortex-Interaction (BVI)
- INM/AEDT: 6° Approach Only (Single App. NPD)

6°

3°

9°
Background: Complex Directivity

- INM/AEDT: Right-Center-Left Directivity

Decimated Noise Spheres, 30° and 45° Spacing, SPL (dBA)
Vehicle Noise at top, Control Dots indicate Data Points. High Speed, 128 kts, Run 112.
Technical Approach

• Vary modeling fidelity to assess results sensitivity to various parameters including:
  – Source Noise Modeling (Spectral Content, Directivity)
  – Operational Modeling (Movements and Sources)
  – Propagation Modeling (Environment)
  – Receptor Modeling (Metrics for Helos / Tiltrotors)

• Conduct targeted “Mini Trade Studies”
  – Determine Sensitivity to Modeling Parameters
  – Develop Recommendations (Team & Panel)

• Seek Rotorcraft Community Review / Feedback

**Mini Trades:** Collection of targeted analyses which determine output sensitivity to various modeling features and leverage prior research.
<table>
<thead>
<tr>
<th>INM</th>
<th>AAM</th>
<th>HELENA</th>
<th>Objective</th>
<th>Analysis</th>
<th>Dataset Vehicles</th>
<th>Comparisons</th>
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<tbody>
<tr>
<td>X</td>
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<td>Model Comparison: Selected Cases</td>
<td>Multiple Comparisons using Common Datasets</td>
<td>MD902 CH146, TBD</td>
<td>Contours, Metrics @POIs</td>
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<td>Lateral Source Directivity</td>
<td>Comparisons of varying lat. Fidelity w/ Meas</td>
<td>MD902 CH146, TBD</td>
<td>Lateral metrics (max, integ.) &amp; d’, Taud, dBC...</td>
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How well do models compare? What’s driving deltas? (Source, propagation, environment?)

What is the minimum lateral granularity to capture noise sources across flight modes?

How low should the source data be defined for community noise / annoyance?

Define minimum Tiltrotor trajectory modeling Capabilities (VTOL, helo vs. airplane, etc...)

What atmospheric propagation modeling capabilities are needed?

Preliminary example to be shown
<table>
<thead>
<tr>
<th>INM</th>
<th>AAM</th>
<th>HELENA</th>
<th><strong>Objective</strong></th>
<th><strong>Analysis</strong></th>
<th><strong>Dataset Vehicles</strong></th>
<th><strong>Comparisons</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>X</td>
<td>?</td>
<td>What kinds of measurements are needed to obtain model source noise data?</td>
<td>NPDs: FAR36 vs. Mfgr INM inputs vs. AAM style flight testing vs. ???</td>
<td>TBD</td>
<td>Source characteristics. Compare w/ other trades.</td>
</tr>
<tr>
<td></td>
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<td><strong>How to best capture approach BVI noise or avoidance?</strong></td>
<td>Sensitivity to approach FPA (steady flight)</td>
<td>MD902 CH146, TBD</td>
<td>Metrics@POIs, contours dBC, BVISPL, D'</td>
</tr>
<tr>
<td>X</td>
<td></td>
<td></td>
<td>Varying Approach FPAs, incl. segmented app.</td>
<td>Simple analyses under different env. conditions</td>
<td>TBD</td>
<td>Source changes &amp; Ground Metrics</td>
</tr>
<tr>
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<td><strong>What helicopter performance modeling capabilities are needed?</strong></td>
<td>Effects of temp/humid on lower-f Helo spectra. High alt, hot day source effects? Tip-Mach effects etc?</td>
<td>TBD</td>
<td></td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>?</td>
<td><strong>What data is needed for vertical flight?</strong></td>
<td>ID ‘typical’ Ops &amp; (Heliports) single event modeling. Case studies.</td>
<td>TBD</td>
<td>Contours and Metrics @ POIs.</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td></td>
<td>HIGE/HOGE, directivity incl. <strong>tail rotor</strong> in-plane noise etc</td>
<td></td>
<td></td>
<td>Preliminary example to be shown</td>
</tr>
</tbody>
</table>
### Mini-Trade Study List

#### How well do the models predict FAR36 / ECAC Cert levels?

<table>
<thead>
<tr>
<th>INM</th>
<th>AAM</th>
<th>HELENA</th>
<th>Objective</th>
<th>Analysis</th>
<th>Dataset Vehicles</th>
<th>Comparisons</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td>Sensitivity to sources (HNM, Legacy RNM, full RNM, mfgr process)</td>
<td>Pred. vs. Published Meas data.</td>
<td>TBD. Could use Mfgr input.</td>
<td>Levels at FAR36 / ECAC Cert locations</td>
</tr>
</tbody>
</table>

#### How to best capture maneuvering flight noise (gentle commercial, not high-G military ops)?

| X   | Determine Source Modeling Reqmts. | Comparison using AAM Q-SAM method (Longit Accel FPA equival.) | TBD, Possible NASA data | Metrics at POIs, Comparison w/ Meas data |

#### How and when can you substitute one vehicle for another?

| X   | X   | Substitution Guidance . General size classes vs. individual models. | Limited sensitivity trade: Weight, # blades, class. Leverage past studies | TBD | Source Level & Spectral Class comparison |
Low Frequency Content

• Tested CH146 empirical spheres against spectral data with other resolutions
  – Examine effects of including various low frequency third octave bands (beyond INM spectral class data)

  – Results depend on metric chosen:
    • SEL (dBC, unweighted) show strong differences as low-f energy is removed (as expected)
    • SEL (dBA), LmaxA, EPNL and PNLT_{max} show no changes
Low-f Band Decimation (Slow, 78 kts)

Lmax Comparison

SEL (Unweighted) Comparison

SEL (dBA) Comparison

SEL (dBC) Comparison

Low Frequency Content Mini-Trade
Low Frequency Content Mini-Trade

**SEL (dBC) Comparison**
(Entire Flyover Event)

- **Starboard**
- **Distance from Track (ft)**
- **Port**

**Graph Details:**
- **Full Resolution**
- **Band10Zeroed**
- **Band11Zeroed**
- **Band12Zeroed**
- **Band13Zeroed**
- **Band14Zeroed**
- **Band15Zeroed**
- **Band16Zeroed**

**Graph Axis:**
- SEL (dBC) on the Y-axis: 65 to 100
- Starboard, Distance from Track, Port on the X-axis: -25000 to 25000

**Subtitle:**
- Slow, 78 kts, Sphere 120

**Legend:**
- Markers indicate different frequency bands and resolution levels.
Lateral Directivity

- Create decimated CH146 spheres with reduced lateral fidelity
  - Linear interpolation between source definition in modeling software (INM & AAM)
- Measurement fidelity drives model accuracy
  - Microphone data from tests used to develop spheres
  - Spheres used to model helicopter operations
- Characterize the modeling sensitivity as a function of lateral resolution
  - Metric dependent
Lateral Directivity Method

- Reduce Phi Resolution:
  - Full resolution to every 30, 45, and 90 degree resolution with linear interpolation between points
Lateral Variation in Metrics

- Phi decimated spheres, High Speed flight

![Graph showing Lateral Variation in Metrics](image-url)
## Metrics at Lateral POIs

### Lateral Source Directivity Mini-Trade

**POINT OF INTEREST RESULTS - High Speed, 128 kts (Sphere 112)**

<table>
<thead>
<tr>
<th>POI (feet)</th>
<th>Lmax (dBA)</th>
<th>SEL (dBC)</th>
<th>SEL (dBA)</th>
<th>EPNL (dB)</th>
<th>PNLMAX (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All Phi</td>
<td>30-Deg</td>
<td>45-Deg</td>
<td>MaxDelta</td>
<td>All Phi</td>
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<tr>
<td>-25000</td>
<td>33.3</td>
<td>32.9</td>
<td>33.0</td>
<td>0.4</td>
<td>75.1</td>
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<tr>
<td>-6300</td>
<td>64.3</td>
<td>54.9</td>
<td>56.7</td>
<td><strong>9.4</strong></td>
<td>86.4</td>
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<tr>
<td>-2000</td>
<td>67.8</td>
<td>68.0</td>
<td>67.7</td>
<td>0.2</td>
<td>93.5</td>
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<td>30.8</td>
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<td>71.6</td>
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</table>
Explanation of Metric Asymmetry

Noise metrics vary due to non-symmetric radiation patterns
Condition Specific Spectral Requirements

- Noise generated by helicopter is specific to configuration and flight condition
  - Blade Vortex Interaction (BVI) noise spectrally different from non-BVI landing approaches
  - Directivity patterns differ between impulsive noises and standard ops noises.
BVI: Descent Phenomena

- BVI common during approach
- Loading, FPA, drag/thrust angle affect BVI
- Configuration Specific

**Parallel BVI**

**Oblique BVI**

**Impulsive Noise**
- Flight Boundary
- Speed, knots
- Rate of Climb, FPM
- Speed in Knots
- Maximum main rotor impulsive noise
- Main rotor impulsive noise boundary
- Continuous main rotor impulsive noise

**Forward Flight**

BVI Mini-Trade
Noise Spheres: BVI Evident

- 3 degree approach sphere 120
- (max BVI) 6 degree approach sphere 175
- 9 degree approach sphere 179
## Metric: BVISPL

- **SPL of spectral data for third octave bands containing frequencies from the 6\textsuperscript{th} to the 40\textsuperscript{th} main rotor harmonic (Ch146/Bell 412 shown)**
- **Isolates MR**

<table>
<thead>
<tr>
<th>Frequency (Hz)</th>
<th>Region</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 Hz</td>
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<tr>
<td>21.6 Hz</td>
<td>MR BPF</td>
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<tr>
<td>55.3 Hz</td>
<td>TR BPF</td>
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<tr>
<td>129.6 Hz</td>
<td>Lower Limit</td>
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<tr>
<td>864 Hz</td>
<td>Upper Limit</td>
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<tr>
<td>1k Hz</td>
<td>Beginning of most serious atmospheric attenuation</td>
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<tr>
<td>10k Hz</td>
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**BVI Mini-Trade**
Analysis Approach

- Three approach angles, three spheres
- Single approach angle, three spheres (forced selection)
• Significant energy in BVI bands during 6 degree approach

• BVI mitigation strategies involve ‘flying around’ BVI flight profile. Needs to be captured in modeling!

• Need to capture directivity beyond 45° (1500ft)
6 deg, 3 spheres: Max BVISPL

3,6,9 degree approach spheres at 3,6,9 angle

3,6,9 degree approach spheres at 6 degree angle
Discussion

- Series of Mini-Trade Studies Underway
- Preliminary Helicopter and Tiltrotor Modeling Recommendations will be developed by the Team and reviewed by the ACRP Panel
- White Paper will be produced and provided to the International Rotorcraft Community for Feedback
- Study outcome will be a document ready for Standards Committee Review (SAE document)

Got data? 😊