Aircrew Multi-Axis Vibration Exposures During Operation of the Blackhawk UH-60L Helicopter

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Suzanne D. Smith, PhD\textsuperscript{2}
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Background

- Military aircrews continue to report back discomfort, pain, and injury associated with flying rotary-wing aircraft.
- The Defense Centers for Public Health – Aberdeen (DCPH-A) and USAF are collaborating on a project to expand limited data on aircrew operational vibration exposure.
- The project is funded by the National Defense Center for Energy and Environment, Safety & Occupational Health Focus Group.
- It focuses on four platforms in addition to an initial study conducted on the HH-60M and UH-72.
- This presentation focuses on the UH-60L Blackhawk.
Objectives

Characterize and assess aircrew vibration exposure aboard the UH-60L.

- Investigate multi-axis acceleration spectra for targeted flight test conditions.
- Apply MIL-STD 1472/ACGIH (ISO 2631-1) to assess comfort and health risk.
- Conduct an aircrew survey regarding discomfort, vibration, and equipment.
- Document data in the AFRL Collaborative Biomechanics Data Network (CBDN).
Methods – Data Collection Unit

- Remote Vibration Environment Recorder (REVER)
- Portable and Battery-operated
- Four systems required for flight test

Photo by AFRL - Suzanne Smith
## Methods - Seat Locations

<table>
<thead>
<tr>
<th>Station</th>
<th>Measurement Site</th>
<th>Sensor Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pilot (right cockpit seat)</td>
<td>Seat Base</td>
<td>Triaxial Accelerometer Pack</td>
</tr>
<tr>
<td></td>
<td>Seat Pan</td>
<td>Triaxial Acceleration Pad</td>
</tr>
<tr>
<td></td>
<td>Seat Back</td>
<td>Triaxial Acceleration Pad</td>
</tr>
<tr>
<td></td>
<td>Helmet</td>
<td>Six-Axis Helmet Mount</td>
</tr>
<tr>
<td>Crew Chief/Flight Engineer (mid cabin, side-facing right seat)</td>
<td>Floor beneath Seat</td>
<td>Triaxial Accelerometer Pack</td>
</tr>
<tr>
<td></td>
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<td>Triaxial Acceleration Pad</td>
</tr>
<tr>
<td></td>
<td>Seat Back</td>
<td>Triaxial Acceleration Pad</td>
</tr>
<tr>
<td>Crew Chief/Flight Engineer (mid cabin, side-facing left seat)</td>
<td>Floor beneath Seat</td>
<td>Triaxial Accelerometer Pack</td>
</tr>
<tr>
<td></td>
<td>Seat Pan</td>
<td>Triaxial Acceleration Pad</td>
</tr>
<tr>
<td></td>
<td>Seat Back</td>
<td>Triaxial Acceleration Pad</td>
</tr>
<tr>
<td>Crew Member (aft cabin, rear-facing right seat)</td>
<td>Floor beneath Seat</td>
<td>Triaxial Accelerometer Pack</td>
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<td></td>
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<td>Triaxial Acceleration Pad</td>
</tr>
</tbody>
</table>
Methods - Vest and Helmet Setup

Photo by DCPH-A, Steven Chervak
Methods - Crew Seat Setup

Pilot Seat (Cockpit)

- Seat Back Acceleration Pad
- Seat Pan Acceleration Pad
- Seat Base Accelerometer Pack

Crew Chief Seat (Mid Cabin)

- Seat Back Acceleration Pad
- Seat Pan Acceleration Pad
- Floor Accelerometer Pack
- Small and Large Battery Packs
- Small DAU

Photo by DCPH-A, Steven Chervak
Methods - Rear Seat Setup

(Note: Actual measurements taken at rear-facing seats)

Photo by DCPH-A, Steven Chervak
### Methods – Test Conditions

- **Flight Test Conditions**
  - Per Task
  - Multiple Records
- **Data Collection**
  - Acceleration time histories collected for 20 sec. for each condition upon trigger activation

#### Test Conditions

**Flight Test Conditions**

- Per Task
- Multiple Records

**Data Collection**

- Acceleration time histories collected for 20 sec. for each condition upon trigger activation

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<table>
<thead>
<tr>
<th>Flight Test Conditions</th>
<th>Data Collection</th>
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</thead>
<tbody>
<tr>
<td><em>Per Task</em></td>
<td><em>Accelerator</em></td>
</tr>
<tr>
<td><em>Multiple Records</em></td>
<td><em>Time Histories</em></td>
</tr>
</tbody>
</table>

**Methods**

- **Test Conditions**
  - **Per Task**
  - **Multiple Records**

**Data Collection**

- Acceleration time histories collected for 20 sec. for each condition upon trigger activation

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**FLIGHT TEST CARD**

<table>
<thead>
<tr>
<th>AC/:</th>
<th>LOCATION/DATE:</th>
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**Other:**

- Flight:

**Test Conditions**

- **Task**: Flight Test Conditions
  - **Per Task**
  - **Multiple Records**

**Data Collection**

- Acceleration time histories collected for 20 sec. for each condition upon trigger activation

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<table>
<thead>
<tr>
<th>CONDITON</th>
<th>ALT (ft MSL)</th>
<th>A/S (KIAS)</th>
<th>COMMENTS (Wind, Day, Night, etc.)</th>
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<tbody>
<tr>
<td>TASK 1242 Before Starting Through Before Landing</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>A. Engine Idle</td>
<td>0</td>
<td>0</td>
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</tr>
<tr>
<td>B. Ground Flight 100%</td>
<td>0</td>
<td>0</td>
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<tr>
<td>C. Takeoff Normal</td>
<td>A/R</td>
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<tr>
<td>D. Takeoff Vertical</td>
<td>Record #</td>
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<tr>
<td>E. Takeoff Minimum</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F. Hover IGE*</td>
<td>3</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>G. Hovering Taxi IGE*</td>
<td>3</td>
<td>0</td>
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<tr>
<td>H. Hover IGE*</td>
<td>50-10K</td>
<td>0</td>
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</tr>
<tr>
<td>I. Transverse Flow*</td>
<td>Record #</td>
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</tr>
<tr>
<td>J. Landing</td>
<td>0</td>
<td>0</td>
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<tr>
<td>TASK 1062 Perform VMC Flight Maneuvers</td>
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<tr>
<td>K. Climb</td>
<td>&lt;10K</td>
<td>50-50</td>
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<tr>
<td>L. Level Flight*</td>
<td>&lt;10K</td>
<td>89</td>
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<tr>
<td>M. Level Flight*</td>
<td>&lt;10K</td>
<td>100</td>
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<tr>
<td>N. Level Flight*</td>
<td>&lt;10K</td>
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<tr>
<td>N2. Level Flight*</td>
<td>&lt;10K</td>
<td>149</td>
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<tr>
<td>O. Sidewall Turn</td>
<td>&lt;10K</td>
<td>5120</td>
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</tr>
<tr>
<td>P. Steep Rate Turn</td>
<td>&lt;10K</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>Q. Descent</td>
<td>120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>R. AVCS Off</td>
<td>&lt;10K</td>
<td>120</td>
<td></td>
</tr>
<tr>
<td>S. Normal Approach to IGE Hover*</td>
<td>&gt;50</td>
<td>5120</td>
<td></td>
</tr>
<tr>
<td>T. Steep Approach to IGE Hover*</td>
<td>&gt;50</td>
<td>5120</td>
<td></td>
</tr>
<tr>
<td>U. Normal Approach to IGE Hover*</td>
<td>5</td>
<td>5120</td>
<td></td>
</tr>
<tr>
<td>V. Steep Approach to IGE Hover*</td>
<td>5</td>
<td>5120</td>
<td></td>
</tr>
<tr>
<td>W. NOE*</td>
<td>0-25</td>
<td>5120</td>
<td></td>
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**Other:**

- Flight: Flight Test Conditions

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**Improving Health and Building Readiness. Anytime, Anywhere – Always**

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**AFRL**

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Methods – Data Processing

• Unweighted Acceleration Spectra (1–150 Hz)
  ▪ Identify the frequency location/magnitude of major peaks.
  ▪ PRF: Propeller Rotation Frequency
  ▪ BPF: Blade Passage Frequency

• Weighted Overall Accelerations (1–80 Hz, ISO 2631-1)
  ▪ Assess the comfort reaction and health risk.
  ▪ pVTV: point vibration total value (vector sum of overall accelerations for three directions at seat pan and seat back)
  ▪ oVTV: overall vibration total value (vector sum of pan and back pVTVs)
  ▪ Estimate allowable exposure duration associated with no health risk
Results – Unweighted Acceleration Spectra

![Graphs showing unweighted acceleration spectra for different flight conditions and configurations.](image-url)
Results – Comfort Reactions (ISO 2631-1)

- Overall Vibration Total Value (oVTV) (m/s² rms)

- Not Uncomfortable
- Little Uncomfortable
- Fairly Uncomfortable
- Uncomfortable
- Very Uncomfortable

- Tasks:
  - TASK 1024 Before Start - Before Leave Helo Checks
  - TASK 1026 NOE
  - TASK 1038 Perform Hovering Flight
  - TASK 1040 Perform VMC Takeoff
  - TASK 1052 Perform VMC Flight Maneuvers
  - TASK 1058 Perform VMC Approach

- Levels:
  - PILOT COCKPIT LEFT
  - CREW CHIEF MID LEFT
  - AIRCREW AFT LEFT

- Conditions:
  - LAND
  - TRANSVERSE FLOW
  - HOVER OGE
  - HOVER TAXI IGE
  - HOVER STAT IGE
  - TO MIN POWER
  - TO VERTICAL
  - TO NORMAL
  - ENGINE IDLE
  - GRD FLT 100%
  - NA OGE HOVER
  - SA OGE HOVER
  - NA IGE HOVER
  - SA IGE HOVER
  - LEVEL FLT 145°
  - LEVEL FLT 120°
  - LEVEL FLT 90°
  - CLIMB
  - DESCEND
  - LEVEL FLT 80°
  - NA OGE HOVER
  - SAGE HOVER
  - SA OGE HOVER
  - NAP OF EARTH

- Reactions:
  - Little Uncomfortable
  - Uncomfortable
  - Very Uncomfortable
Results – Unweighted/Weighted Overall Acceleration
Results – Blackhawk Comparison

[Graph showing acceleration levels and potential health risks for HH-60M and UH-60L pilots in different cockpits.]
Results – Blackhawk Comparison (Comfort)
Results – Aircraft Level Flight Comparison

<table>
<thead>
<tr>
<th>Aircraft Level Flight Comparison</th>
<th>Potential for Health Risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>UH-1H Huey</td>
<td>&lt; 1 Hour Exposure</td>
</tr>
<tr>
<td>AH-1Z Super Cobra</td>
<td>1-2 Hour Exposure</td>
</tr>
<tr>
<td>CV-22 Osprey Airplane</td>
<td>2-4 Hours Exposure</td>
</tr>
<tr>
<td>CV-22 Osprey Conversion</td>
<td>4-8 Hours Exposure</td>
</tr>
<tr>
<td>UH-72 Lakota</td>
<td>&gt; 8 Hours Exposure</td>
</tr>
<tr>
<td>HH-60M Medevac</td>
<td></td>
</tr>
<tr>
<td>CV-22 Osprey Airplane</td>
<td></td>
</tr>
<tr>
<td>UH-60L Blackhawk</td>
<td></td>
</tr>
</tbody>
</table>

POINT VIBRATION TOTAL VALUE (pVTV)

LEVEL FLIGHT (ms⁻² rms)

- Pilot
- Pilot A Front
- Pilot A Back
- Pilot B Front
- Pilot
- Flight Engineer
- Crew Chief
- Pilot
- Flight Engineer
- Crew Chief
- Pilot
- Crew Chief
- Medic
- Pilot
- Pilot Left
- Crew Chief Left
- Aircrew Left

Potential for Health Risks:

- < 1 Hour Exposure
- 1-2 Hour Exposure
- 2-4 Hours Exposure
- 4-8 Hours Exposure
- > 8 Hours Exposure
Conclusions

• Aircrew are exposed to significant higher-frequency multi-axis vibration (above 10 Hz).
• The assessment shows aircrew comfort and potential for health risks can occur in as little as 1-2 hours due to exposures over current recognized threshold limits (ACGIH, MIL-STD).
• Active aircraft vibration mitigation technologies can sufficiently reduce this threat.
• The mechanism(s) by which vibration may affect aircrew physiology and health risk are still not clear and further research is needed to improving mitigation concepts.
• The vibration data collected will be used to establish appropriate criteria for developing effective mitigation concepts through modeling.
Acknowledgement

DCPH-A and AFRL would like to thank the NDCEE for their support.