USAF NEEDS/DIFFERENCES, CURRENT RESEARCH & IDENTIFIED KNOWLEDGE GAPS w/ FUTURE EVTOL SYSTEMS

Dr. Casey W. Pirnstill, AFRL/711th HPW/RHBFD
Biomedical Impact of Flight Branch - Biodynamics Section

Mr. Nathan Wright, AFLCMC/WNU
Aircrew Egress & Survival Branch

Brief Date: JAN-19-2021
Outline

I. USAF Research & Acquisition Areas of Interest
   ❖ Who We Are!
     ✓ Research Focus & Unique Capabilities

II. Re-evaluate Current Crash Environment For EVTOL Certification Development
   ❖ Rotorcraft Crashworthiness, Mishap History Summary (Military Aviation)
   ❖ Define eVTOL Design Configurations & How Systems Will Be Utilized (Mission Envelope)
   ❖ Understand eVTOL Crash Differences Compared W/ Legacy Aircraft (FAR 23)/Rotary (FAR 27) Mishaps
   ❖ eVTOL Operational Expectations & Crashworthiness Moving Forward
     ✓ Evaluate AW Using Combo (Aircraft/Rotorcraft) Requirements

III. The Gaps: Current USAF Airworthiness Certification Processes (Transport Aircrafts & Rotorcraft)

IV. Differences In USAF & FAA AW Certification Process: (Transport Aircrafts/Rotorcraft)
   ❖ USAF AW Process Risk Based & FAA AW Process (Pass/Fail)
   ❖ Lack Injury Risk Curves, Pass/Fail Criteria For Most FAA Criteria Locations
   ❖ FAA Limited Anthro Range, Include, 50th% Hybrid III Aero/FAA/ES-II: All 50th% Occupants
     ✓ Need valid injury risk curves, across full anthropometric range (5th% Female thru 95th% Male)

V. Examples Of Recent Seat AW Programs & Resulting Issues Based Existing STD Gaps
   ❖ Military Rotorcraft Seating
   ❖ C-17/C-130; Negative Pressure Conex/Conex Light (NPC/NPCL) Side-Facing Troop Seat
As part of a research effort at the request of AMC & AFOTEC, Biodynamics Team conducted impact assessment of C-17 side-facing troop seats for integration into Negatively Pressurized Conex (NPC) model, which was developed to support COVID-19 relief efforts by transporting infectious, ambulatory & litter patients in global operations.
Why AFRL Aircrew Biodynamics & Protection Team?

- Expertise:

- Unique DoD Facility:

Resources
- **Civilians**: 12
- **Military**: 8
- **Contractors**: 15
Big Picture Questions:

- Do current USAF injury risk requirements, identified in airworthiness standards, continue to improve occupant protection in Aircraft, Rotorcraft & VTOL seat design applications?

- How do we define considerations for survivable in USAF Operational Mishaps & is definition same across Gov’t agencies?

- Is equivalent occupant protection expected in VTOL seating design certification processes, using existing requirements?

- What crash profiles should be use to assess VTOL occupant safety in seating platforms? *(combined rotorcraft/aircraft crash profiles)*

- How do we further improve mishap survivability for cabin occupants in future seating system designs?

- Do current USAF crash survivability requirements allow equivalent injury risk identification across expected occupant anthropometric ranges?
Overarching Model

- Laboratory (Controlled Performance)
- Operational Mishap Data (Context)
- Injury Criteria (Objective Metrics)
Evaluate Crash Safety Envelope: Development Of Certification Requirements For VTOL Occupant Seating Systems
Rotary Wing (Army) Operational Mishap Data

TOP 10 MAJOR AND FATAL INJURIES:
1. Head
2. Chest
3. Lower Extremities
4. Spine
5. Abdomen
6. Upper Extremities
7. Pelvis
8. Multi-trauma
9. Neck
10. Not Spec

* Rate of injury for cabin occupants significantly greater than pilot/copilot

*Potentially fixed w/5pt restraint

Army UH-60 Operational Mishap Data

"Moderate" contusions, lacerations, abrasions in any area(s) of the body. Sprains of the shoulders or principal articulations of the extremities. Uncomplicated, simple or green-stick fractures of extremities, jaw, or malar structures. Concussion as evidenced by loss of consciousness not exceeding 5 minutes, without evidence of other intracranial injury.

Compound or comminuted fractures:

Simple fractures of vertebral bodies:

Skull fracture:

Loss of consciousness:

Eiband results correlate w/ operational mishap injury types & severities
Airworthiness Process & Gaps In Seat Safety Design Requirements: USAF Aircraft & Rotorcraft Occupant Seating Crashworthiness Survivability Standards
GAP - VTOL Crash Profile Vs. Historical Mishaps: Aircraft & Rotorcraft (FAR 23, 25 & 27)

- Anticipated Difference In DoD Operational Mishap Data, Existing Injury Outcomes & Crashworthiness Criteria (Aircraft/Rotary) Vs. VTOL Application
  - Need to **Understand & Define** eVTOL operational expectations
  - Determine if existing crash scenarios & future VTOL applications are representative
  - Define crashworthiness criteria moving forward, accommodating VTOL occupant seat safety in addition to Aircraft & Rotorcraft Vehicles

  - Success of approach dependent on similarity W/ defined & expected operational envelope in VTOL system as compared to historical Aircraft & Rotorcraft crash scenario defined based on operational mishap data & strong understanding of the crash profile
Do Measured Crash Events Match FAA & USAF eVTOL Expectations?

- **Transport Aircraft Seating:**
  - FAR 25.562: *Emergency Landing Dynamics Conditions*
  - FAR 25.785: *Seats, Berths, Safety Belts & Harnesses*
  - FAA PS-ANM-25-03-R1: *Technical Criteria Approving Side-Facing Seats*
  - FAR 49.571.208 & 49.571.214: *Criteria Crash Protection*
  - FAR 49.572: ATDs

- **Rotorcraft Seating:**
  - FAR 27/FAR 29 (Normal/Transport): *AW Standards*
    - 27.561, 27.785 & 27.1413
    - 29.561, 29.785 & 29.1413
  - FAR 23: 23.561, 23.785 & 23.1413
  - FAR 91: 91.107 & 91.203

Do Existing Requirements & STDs Reflect eVTOL Crashes Sufficiently?

- **Transport Aircraft & Rotorcraft Seating:**
  - MIL-HDBK-516C
    - SAE Standard AS8049 *w/expanded population*

- **Rotorcraft Seating:**
  - MIL-STD-85510(AS)
  - MIL-S-58095(AS)
  - JSSG-2010-7

---

**GAP - FAA & USAF Crashworthiness Certification Processes**

**Risk-Based Certification**

- Rigor of Certification follows Risk-Based Structure
- Aircraft, and Intended Use Considered

---

THE AIR FORCE RESEARCH LABORATORY

DISTRIBUTION A: Approved for public release; distribution unlimited (AFRL-2020-0580)
GAP - Current FAA & USAF Crashworthiness Differences:
Should VTOL injury be assessed as Rotorcraft or Transport Aircraft?

**FAA Airworthiness Process (Pass/Fail)**
- FAA: Most injury locations lack risk curves (Pass/Fail)
- Structural Assessment (Pass/Fail)
- Lap Belt remains on pelvis? (Pass/Fail)
- Torso rotation remains <40°? (Pass/Fail)
- Upper restraint remains on shoulders? (Pass/Fail)
- Occupant motion sufficiently restrained? (Pass/Fail)

**USAF Airworthiness Process (Risk Based)**
- Hard landing/crash AIS >2 % injury risk @ associated injury mechanism/location
- Combined total occupant injury risk (effect on EGRESS)
- Assess structure against 95th% male ATD (~245lb), LARD

<table>
<thead>
<tr>
<th>FAA Criteria</th>
<th>Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pelvis / Lumbar Loads (lbs)</td>
<td>1,500</td>
</tr>
<tr>
<td>Head Injury Criteria (HIC)</td>
<td>700</td>
</tr>
<tr>
<td>Resultant Shoulder Load (lbs)</td>
<td>1,850</td>
</tr>
<tr>
<td>L/R Shoulder Strap Loads (lbs)</td>
<td>1,750</td>
</tr>
<tr>
<td>Left / right femur bending angle</td>
<td>&lt; 35°</td>
</tr>
<tr>
<td>Seat must remain attached to structure</td>
<td>P/F</td>
</tr>
<tr>
<td>If seat is damaged, it must not impede egress</td>
<td>P/S</td>
</tr>
</tbody>
</table>

Figure 6 - Type A-T seat/restraint system dynamic tests
Valid Injury Probability Criteria Over Full Anthro Range: Female 5th% Through 95th% Male

- Current FAA Approved ATDs In FWD/AFT Facing Rotorcraft & Transport Airplane Seats Include: Hybrid III 50th Aero ATD & FAA Straight Spine 50th ATD

- Current FAA Approved ATDs In Side-Facing Rotorcraft & Transport Airplane Seats Include: ES-II 50th Percentile Male ATD

- USAF Requires Injury Criteria Valid Across Full Anthro Range (LOIS - LARD) W/ Injury Probability Curves In Future VTOL Applications
  - Initially, combine Transport/Rotorcraft airworthiness standards into new operational case, unless VTOL crash profiles expected to drastically vary from Aircraft/Rotorcraft cases

  - AF requires injury risk probability estimates @ relevant anatomic locations for all anticipated injury methods
  - FAA Crashworthiness Certification Criteria historically imposes (Pass/Fail) test limits which must not be exceeded for acceptability: Specified acceptable safety metrics do not have associated injury risk probability estimates assigned during required crash test loading scenarios
Examples For Crashworthiness Assessments of Occupant Seat Survivability
Personnel Survival Chain

**Seat Dependent**
- Seat Strength
- Adequate Restraint
- Seat Performance
  - Energy Attenuation
  - Flail Reduction

**Aircraft Dependent**
- Seat A/C Interface
- Survivable Space

Egress → Survival
Side-Facing Seats

CV-22 Seat

C-17 Seat
Example 1: Military Rotorcraft Seating
Background

- Purpose to evaluate current and prototype rotorcraft seat survivability across USAF anthro population
- Testing Partially Based On MIL-STD-85510(AS) & Legacy Seat Testing
- Impact Testing Using AFRL Horizontal Impact Accelerator (HIA) & Vertical Deceleration Tower (VDT)
- Seats from H-60, V-22, CH-53, and prototypes tested
Orientations, accel levels based on ~1960s mishap data (Crash Survival Design Guide)
**Instrumentation**

- **Lightest Occupant In Service (LOIS) 5th% Female (~107lb)**
- **Large Anthropomorphic Research Device (LARD) 98th% Male (~245lb)**
- **Manikin Instrumentation:**
  - Head accelerations (linear & angular)
  - Upper/Neck forces & moments
  - Lumbar/Chest accelerations
  - Lumbar forces & moments

- **Seat Mount Forces**
- **Seat Acceleration**

<table>
<thead>
<tr>
<th></th>
<th>LOIS (lb)</th>
<th>LARD (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Upper Torso</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manikin</td>
<td>45.3</td>
<td>108.8</td>
</tr>
<tr>
<td>Instrumentation</td>
<td>1.8</td>
<td>1.6</td>
</tr>
<tr>
<td>Cables</td>
<td>1.4</td>
<td>1.8</td>
</tr>
<tr>
<td><strong>Lower Torso</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manikin w/Abdomen</td>
<td>47</td>
<td>118.6</td>
</tr>
<tr>
<td>Instrumentation</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>AFE</td>
<td>10.6</td>
<td>15.6</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>107.5</td>
<td>247.8</td>
</tr>
</tbody>
</table>

*Side-facing program
General Test Matrix (From Side-facing study)

<table>
<thead>
<tr>
<th>Cell</th>
<th>Orientation</th>
<th>Acceleration (G)</th>
<th>Delta V (ft/s)</th>
<th>Rise Time (ms)</th>
<th>Manikin</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>CV</td>
<td>24</td>
<td>40</td>
<td>30</td>
<td>LOIS</td>
</tr>
<tr>
<td>B</td>
<td>CV</td>
<td>30</td>
<td>48</td>
<td>26</td>
<td>LOIS</td>
</tr>
<tr>
<td>C</td>
<td>CV</td>
<td>24</td>
<td>40</td>
<td>30</td>
<td>LARD</td>
</tr>
<tr>
<td>D</td>
<td>CV</td>
<td>30</td>
<td>48</td>
<td>25</td>
<td>LARD</td>
</tr>
<tr>
<td>E</td>
<td>CH</td>
<td>18</td>
<td>46</td>
<td>78</td>
<td>LARD</td>
</tr>
<tr>
<td>F</td>
<td>CH</td>
<td>24</td>
<td>53</td>
<td>62</td>
<td>LARD</td>
</tr>
<tr>
<td>G</td>
<td>PV</td>
<td>15</td>
<td>32</td>
<td>35</td>
<td>LOIS</td>
</tr>
<tr>
<td>H</td>
<td>PV</td>
<td>34</td>
<td>46</td>
<td>26</td>
<td>LOIS</td>
</tr>
<tr>
<td>I</td>
<td>PV</td>
<td>15</td>
<td>32</td>
<td>35</td>
<td>LARD</td>
</tr>
<tr>
<td>J</td>
<td>PV</td>
<td>34</td>
<td>46</td>
<td>26</td>
<td>LARD</td>
</tr>
</tbody>
</table>

*Orientations/levels based on MIL-S-85510(AS) & H-60A/L acceptance testing, though do not strictly adhere to standards

Vertical Tower Tests

Horizontal Track Tests
Combined Horizontal Video: CV-22 Seat, LARD, 24.36G, 53.02ft/s, 62.3ms Rise Time
Combined Vertical Video: CV-22 Seat, LARD, 29.71G, 48.93ft/s, 18.4ms
Data Analysis

- Seat Structural Strength
- Injury Criteria Primarily From Full Spectrum Crashworthiness Report (2011); Other Historical Criteria Used For Comparison

<table>
<thead>
<tr>
<th></th>
<th>Recommended by FSC</th>
<th>Criteria Used</th>
<th>CV</th>
<th>PV</th>
<th>CH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head</td>
<td>HIC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neck</td>
<td>Nij</td>
<td>Nij</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Chest</td>
<td>Belt Loads</td>
<td>Chest Accel and Belt Loads</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Lumbar</td>
<td>Peak Loads</td>
<td>Peak Loads and DRlz</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Whole Body</td>
<td></td>
<td>Eiband 85510</td>
<td></td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>
Example 2: Negatively Pressurized Conex/Conex Light (NPC/NPCL)
Assessment Of Side-Facing Troop Seat: Negatively Pressurized Conex/Conex Light (NPC/NPCL)

PLAN:
- NPC leveraged Other Transactional Authority (OTA) agreement to rapidly procure prototype NPC system. Design based upon concept of modified 40-foot ISO container (Conex) w/ negative pressure system to provide max possible capacity on C-17 to transport diagnosed/symptomatic passengers & patients, while also mitigating risk to aircrew & aeromedical evacuations specialists.

HOW:
- NPC designed to be safe-to-fly on C-17, maximize passenger capability w/ a configurable interior (ambulatory & litter) & meet requirements of USTRANSCOM JUON “Need for High Capacity Airlift of COVID-19 Infected Passengers” & NPCL designed to be safe-to-fly on C-130’s & smaller cargo aircrafts.
- Part of OUE is impact assessment of proposed seat, to be used by medical crew while in NPC.

NPC

NPC has two areas, anteroom & patient area, separated by steel door. Patients loaded into NPC through patient doors & remain in patient area, outfitted w/ two restrooms, for duration of flight. Aeromedical crew enter & exit through anteroom, where they can doff & decon-equipment. At rear of Conex is redundant blower, creating negative pressure environment, driving laminar flow from anteroom into patient area. Design considerations incorporate communications, power, back-up, aeromedical requirements, transportability, modularity, configurability & more.
Assessment Of Side-Facing Troop Seat: Negatively Pressurized Conex & Conex Light (NPC/NPCL)

HOW:

- **AS8049** requirement for vertical impact conducted on AFRL Vertical Deceleration Tower (VDT)

- **Vertical Impact Requirements:**
  - Seat Upright Side-Facing W/ Aircraft Rearward Pitch Angle Of 30°
  - Peak Impact Acceleration ≥ 14 G
  - Time-To-Peak Acceleration ≤ 80 ms
  - Velocity Change ≥ 35 ft/s

- VDT facility successfully met required impact conditions

- **AS8049** Impact Requirements/Results:

<table>
<thead>
<tr>
<th>Criteria</th>
<th>[25th Percentile Hybrid III]</th>
<th>Limit</th>
<th>Test</th>
<th>Prob. Int. ASQ2+ [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural Analysis, Seat-Panel Structure, Broke, Resulting In ABDressed downward stuck inside Seat-Panel Frame: FA</td>
<td></td>
<td></td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Velocity (ft/sec)</td>
<td>&gt;35</td>
<td>35</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Acceleration (G)</td>
<td>&gt;14</td>
<td>14</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Lumbar Load (lbs)</td>
<td>3,250</td>
<td>3,250</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Head Injury Criteria (HIC15)</td>
<td>700</td>
<td>700</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Femur Load (lbs)</td>
<td>2,750</td>
<td>0</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Neck Injury Criteria (Nij)</td>
<td>0.5</td>
<td>0.107</td>
<td>11.5%</td>
<td></td>
</tr>
<tr>
<td>Resultant Shoulder Load (lbs)</td>
<td>1,850</td>
<td>450</td>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>

- **Pass**
- **Fail**
- **Marginal**
- **Cannot Assess**
Assessment Of Side-Facing Troop Seat: Negatively Pressurized Conex/Conex Light (NPC/NPCL)

**HOW:**

- **AS8049** requirement for horizontal impact conducted on AFRL Horizontal Impulse Accelerator (HIA)

**Horizontal Impact Requirements:**

- Seat Upright W/ Yaw Angle Of 0°
- Peak Impact Acceleration ≥ 16 G
- Time-To-Peak Acceleration ≤ 90 ms
- Velocity Change ≥ 44 ft/s

- HIA facility successfully met required impact conditions

- **AS8049** Impact Requirements/Results:
Recognized Gaps:
- VTOL Crash Profile Vs. Historical Mishaps
- FAA & USAF Crashworthiness Certification Processes
- Current FAA & USAF Crashworthiness Differences
- Limited ATD Range

Recommendations:

- Define eVTOL operational crash profiles. "How will we crash?"
- Develop definitive injury criteria for MIL ATDs
- Better align FAA and MIL crashworthiness criteria
  - Define appropriate injury metrics for operational crash environment
  - Establish acceptable injury severity level probability during a mishap
Questions?