Development of Crash Injury Protection in Rotorcraft

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Civil Aerospace Medical Institute
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Pre World War I

Otto Lilienthal 1891-1896

Manned Gliders

Belief was in quick escape
Pre World War I

“The operator should in no wise be attached to the machine. He may be suspended by his arms or sit upon a seat, or stand on a running board, but he must be able to disengage himself instantly from the machine should anything go wrong, and be able to come down upon his legs in landing”
First Fatality

September 17, 1908

Lt Thomas Selfridge
Early Belts

Pre- WWI Early Lap Belt
Early Belts
Early Belts

WWI mass produced belts
Early Belts

Martin Waligorski
Spitfiresite.com
1946
The Physics of Impact

- **Hugh DeHaven** – considered by many to be the father of aircraft crashworthiness, developed the first systematic statements of the principles of crashworthiness
  - In 1942 published work analyzing survival after free falls from height of 50 to 150 feet, stopping distances of 4 to 45 inches
  - Similar findings in egg drop research in 1946 at the medical college at Cornell from 150 feet onto a 1.5 inch thick pad
  - Packaging principles of light aircraft design - 1952
The Physics of Impact

Survivable Crash Characteristics

- Sufficient Volume (occupiable space)
- Low G (within human tolerance)
- No immediate post crash fire
  (time for evacuation)
The Physics of Impact

What’s a G?

F = MA  (Newton’s 2\textsuperscript{nd} Law)

Force on something is equal to its Mass times the Acceleration applied to it

The Acceleration of Earth’s Gravity causes a person with 170 lbm of Mass to exert a Force of 170 lbf on the seat they are sitting in
History of the Standards

• Original requirements focused on seat and restraint system strength

• Static test requirements were essentially the same since 1958
  – Title 14, Section 561 of Parts 23,25,27 and 29: Emergency Landing Conditions, General.
  – TSO C39b: Aircraft Seats and Berths (cites NAS 809)
  – TSO C22f: Safety Belts (cites NAS 802)
History of the Standards

Loads applied slowly with wooden blocks in multiple directions. Does not apply forces in the same way an actual occupant would

Forward Static Test

Lateral Static Test
History of the Standards

Dynamic testing revealed serious problems with seats that met the static test standards.
Development of Standards

• The General Aviation Safety Panel (GASP) was Instrumental in Formulating Dynamic Performance Standards

• Represented a broad constituency from the General Aviation Community

• Objectives
  – Analyze Results of Existing Crash Dynamics Research
  – Develop Crash Dynamics Design Standards

A 1979 photo by Brian Smith of the wreck of Cessna 172 N734YH at the end of Maguire’s Runway 18
## Development of Standards

- **The Development and Application of Crash Dynamics Technology Fostered the Dynamic Performance Standards**
  - **US Army’s Aircraft Crash Survival Design Guide**
    - Hughes AH-64A Apache
    - Sikorsky UH-60A Blackhawk
  - **FAA/NASA Crash Dynamics Research**

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**Table:**

<table>
<thead>
<tr>
<th>TEST</th>
<th>CONFIGURATION</th>
<th>PARAMETER</th>
<th>LIMITS</th>
<th>LIMITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Dummy Inertial Load</td>
<td>1 sec</td>
<td>30°</td>
<td>10°</td>
</tr>
<tr>
<td>2</td>
<td>Dummy Inertial Load</td>
<td>1 sec</td>
<td>30°</td>
<td>10°</td>
</tr>
<tr>
<td>3 &amp; 4</td>
<td>Dummy Inertial Load</td>
<td>1 sec</td>
<td>30°</td>
<td>10°</td>
</tr>
</tbody>
</table>
Development of Standards

New standards for small aircraft were developed based on full-scale fuselage impact tests.

- vertical drop tests
- combined horizontal / vertical impact tests
Development of Standards

FAA/NASA General Aviation Airplane Impact Tests
Development of Standards

New standards for large aircraft were developed based on:

– Full scale tests
– Modeling
– Existing floor strength
Development of Standards

Vertical Impact Scenario
Development of Standards

- New standards for rotorcraft were based primarily on analysis of accident data.
- Large data base available from the military.
Development of Standards

![Graph showing the development of standards for crash injury protection in rotorcrafts. The graph illustrates the impact velocity on longituudinal and vertical axes, with different lines representing various categories such as U.S. Civilian Helicopters, U.S. Army Helicopters, U.S. Navy Helicopters, and Current Design Requirements. The graph indicates survival rates at different impact velocities.](image-url)
The Physics of Impact

Large horizontal velocity change over a relatively long period of time
The Physics of Impact

Small vertical velocity change and a moderate horizontal velocity change over a short time period
The Physics of Impact

Small vertical velocity change over a very short time period
Development of Standards

Frequency Of Major And Fatal Injuries To Each Body Region As Percentages Of Total Major And Fatal Injuries In Survivable Accidents

- U.S. CIVILIAN HELICOPTERS, 1974 - 1978
- U.S. ARMY AIRCRAFT, 1971 - 1976

Development of Crash Injury Protection in Rotorcraft

October 2018
Human Tolerance to Impact

Just How Tough Are You?

It’s not all that easy to find out...
Human Tolerance to Impact

Colonel John Paul Stapp, M.D., Ph.D.
Human Tolerance to Impact

Elmer the Original Crash Test Dummy
Human Tolerance to Impact

A tolerance that can be measured by a test dummy is needed for each critical body part.
Human Tolerance to Impact

Head

\[ HIC = (t_2 - t_1) \left[ \frac{1}{(t_2 - t_1)} \int_{t_1}^{t_2} a(t) \, dt \right]^{2.5}_{MAX} \]
## Human Tolerance to Impact

### Chest

<table>
<thead>
<tr>
<th>AGE GROUP</th>
<th>SHOULDER BELT LOAD</th>
</tr>
</thead>
<tbody>
<tr>
<td>31 YEARS</td>
<td>1900 - 2000 LBS</td>
</tr>
<tr>
<td>35 TO 50 YEARS</td>
<td>1350 - 1800 LBS</td>
</tr>
<tr>
<td>60 YEARS</td>
<td>1100 - 1350 LBS</td>
</tr>
</tbody>
</table>

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![Chest Tolerance Images]

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**Federal Aviation Administration**

October 2018
Human Tolerance to Impact

Abdomen
Human Tolerance to Impact

Lumbar Spine
Human Tolerance to Impact

Lumbar Spine

Military Ejection Seat

Civilian Helicopter Seat
Human Tolerance to Impact
Human Tolerance to Impact

Lumbar Spine

PROBABILITY OF SPINAL INJURY

LUMBAR LOAD CELL - LBS

SEAT PAN DRI

9% 20% 50%
The Civics of Crashworthiness

How much can you afford?

Social Willingness-to-Pay

approx. 100X income per capita

Multiples of consumption per capita

Age (years)
## Injury/Pass-Fail Criteria

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Injury Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head Injury Criteria (HIC)</td>
<td>1000</td>
</tr>
<tr>
<td>Shoulder Harness loads</td>
<td>1750 lb. (single) 2000 lb. (dual)</td>
</tr>
<tr>
<td>Lumbar Load Fz</td>
<td>1500 lb.</td>
</tr>
<tr>
<td>Femur Load (axial)*</td>
<td>2250 lb.</td>
</tr>
</tbody>
</table>

Specified in Part 23.562, 25.562, 27.562, and 29.562
Measured for Part 572 Subpart B (Hybrid II)
* (part 25 only)
Seat Safety Standards

Specified floor deformation based on post crash observations
Seat Safety Standards

Requirements for **NEW**
- General Aviation Aircraft
- Transport Aircraft
- Rotorcraft

### Test-1 Condition

<table>
<thead>
<tr>
<th>Combined Vertical Horizontal Orientation</th>
<th>Small Airplanes (Part 23)</th>
<th>Transport (Part 25)</th>
<th>Rotorcraft (Part 27)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gpk (gs)</td>
<td>19</td>
<td>15</td>
<td>14</td>
</tr>
<tr>
<td>Impact Velocity (f/s)</td>
<td>31</td>
<td>31</td>
<td>35</td>
</tr>
<tr>
<td>Onset Time (Tpk)</td>
<td>0.05</td>
<td>0.06</td>
<td>0.08</td>
</tr>
</tbody>
</table>

![Diagram](image1.png)

**From Right Side**

### Test-2 Condition

<table>
<thead>
<tr>
<th>Horizontal 10° Yaw Orientation</th>
<th>Small Airplanes (Part 23)</th>
<th>Transport (Part 25)</th>
<th>Rotorcraft (Part 27)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gpk (gs)</td>
<td>26</td>
<td>21</td>
<td>16</td>
</tr>
<tr>
<td>Impact Velocity (f/s)</td>
<td>42</td>
<td>42</td>
<td>44</td>
</tr>
<tr>
<td>Onset Time (Tpk)</td>
<td>0.06</td>
<td>0.08</td>
<td>0.09</td>
</tr>
</tbody>
</table>

![Diagram](image2.png)

**From Above**

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October 2018

Federal Aviation Administration
Recent Injury Research

• Taneja & Wiegmann study Published April 2003
  – Data from 74 fatal helicopter accidents, 1993-1999
  – Injuries classified by body region/organ system

• FAA Study Presented in 2015
  – CAMI data from 97 fatal helicopter accidents, 2008-2013
  – Classified data using injury categories from Taneja and Wiegmann study
  – Autopsies from pilot or pilot certificated passengers only, so doesn’t capture all occupants onboard the aircraft
Recent Injury Research

• In 25 years (1989-2014) since the effective date of the 27/29.562 rule:
  – ≈ 4,200 rotorcraft accidents with ≈ 9,000 total occupants
  – Only 2% of the rotorcraft involved in those accidents were 27/29.562 compliant
Current Research

Occupant protection for legacy rotorcraft

– The goal of the research is to add safety to legacy rotorcraft
– This research will look at new safety equipment/technology that can be retrofitted onto legacy rotorcraft.
Current Research
Current Research
Upcoming Research (FY-19 Start)

Injury mechanism analysis:
– Procedure development and validation
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