Crash Dynamics Summary

Presented to: FAA/EASA/Industry
Composite Transport Fatigue, Damage Tolerance, Maintenance and Crashworthiness Workshop

By: Joseph Pellettiere, Chief Scientific and Technical Advisor for Crash Dynamics

Date: 19 May 2011
Overview

• History
  – Provide basis of regulations

• Modeling and Simulation
  – How to apply M&S to regulations
Crash Dynamics Summary

History

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Date: 19 May 2011
Total Transportation Fatalities

43,986 Total Fatalities in 1999

39,397 Total Fatalities in 2008

Aviation < 2%

- Highway 41,611
- Rail 805
- Marine 853
- Aviation 691
- Pipeline 26

- Highway 37,261
- Rail 777
- Marine 779
- Aviation 572
- Pipeline 8
Aviation Related Fatalities

691 Aviation Fatalities in 1999 534 Aviation Fatalities in 2009

General Aviation ~ 90%

- General 628
- Air Taxi 38
- Commuter 12
- Airlines 12
- Foreign/Unregistered 1

- General 474
- Air Taxi 17
- Commuter 0
- Airlines 52
- Foreign/Unregistered 4
Performance Standards Developed for Each Aircraft Category

- General Aviation Aircraft
- Rotorcraft
- Transport Category Aircraft
- Commuter Category Aircraft
Rationale for Seat Dynamic Test Criteria

- **Static Tests**
  - Body blocks may apply an unrepresentative load distribution

- **Static Tests can only assess**
  - Structural adequacy of seat/restraint/attachments
  - Structural deformation
Rationale for Seat Dynamic Test Criteria

• **Dynamic Tests**
  – Anthropomorphic Dummy(s) apply a more representative load distribution

• **Dynamic Tests can assess**
  – Structural adequacy of seat / restraint / attachments
  – Structural deformation
  – Restraint system behavior and loads
  – Potential for Occupant Injury
The General Aviation Safety Panel

• The General Aviation Safety Panel (GASP) was Instrumental in Formulating Dynamic Performance Standards
• Formed at the Request of the FAA Administrator
• Represented a Broad Constituency from the General Aviation Community
  – Research
  – Regulatory
  – Manufacturers of G/A Products
  – G/A User Groups
GASP Objectives

• Analyze Results of Existing Crash Dynamics Research
• Develop Crash Dynamics Design Standards
• Establish Milestones for Implementation of any Developed Recommendation
Early Pioneers

• The Development and Application of Crash Dynamics Technology Fostered the Dynamic Performance Standards

• US Army’s Aircraft Crash Survival Design Guide
  – Hughes AH-64 Apache
  – Sikorsky UH-60A Blackhawk

• FAA/NASA Crash Dynamics Research
## US Army Requirements

**For Seats Having At Least 12 inches Of Vertical Stroke**

<table>
<thead>
<tr>
<th>TEST</th>
<th>CONFIGURATION</th>
<th>PARAMETER</th>
<th>COCKPIT SEATS</th>
<th>CABIN SEATS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$t_1$ SEC</td>
<td>0.066</td>
<td>0.081</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$t_2$ SEC</td>
<td>0.100</td>
<td>0.127</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G MIN</td>
<td>28</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G MAX</td>
<td>33</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\Delta V$ MIN FT/SEC</td>
<td>50</td>
<td>50</td>
</tr>
</tbody>
</table>

**CREW SEATS:** SHOULD MEET THE REQUIREMENTS OF MIL-S-58095

- SEAT HEIGHT ADJUSTMENT TO BE AT THE FULL-UP POSITION
- 95th PERCENTILE ATD TO BE USED

**CABIN SEATS:** SHOULD MEET THE REQUIREMENTS OF MIL-S-85510

- SEAT HEIGHT ADJUSTMENT TO BE AT FULL-AFT AND UP POSITION
- 95th PERCENTILE ATD TO BE USED
FAA/NASA General Aviation Airplane Impact Tests
Example Time Histories

NORMAL CABIN FLOOR PULSES

DECELERATION
G UNITS

TIME - SEC

APPROXIMATION
RECORDED
Experimental Normal Impulse Data

\[ \Delta G t \text{ - SEC} \]

NORMAL VELOCITY CHANGE - M/SEC

NASA G.A. AIRPLANES CRASH TESTS

ANALYTICAL TRIANGULAR PULSE
Experimental & Calculated Impulse Data

Longitudinal Impulse $\Delta G \ t - \text{SEC}$

NASA G.A. AIRPLANES TEST DATA

Analytical Pulse Shapes
- Triangular
- Half Sine
- Square Wave

Velocity Change at Impact - m/sec
Impact Pulse Duration as a Function of Impact Attitude

\[ \Delta t = 4.4 \times 10^{-4} (\theta + 4)^2 + 0.052 \]

\( \gamma = -15 \)

AIRCRAFT PITCH ANGLE - \( \theta \) DEGREES

NORMAL PULSE DURATION \( \Delta t \) - SEC

-32 -16 0 16 32

\( V_{fp} \approx \text{CONSTANT} \)
NASA/FAA Full-Scale Impact Tests

PULSE DURATION
SEC

VERTICAL VELOCITY CHANGE - FT/SEC

NASA/FAA IMPACT TESTS

(11 TESTS)

(9 TESTS)
Accident Survivability for Longitudinal/Lateral Impact Velocity Components

LONGITUDINAL VELOCITY - FT/SEC

CIVIL ROTORCRAFT DATA

95th PERCENTILE SURVIVABLE ACCIDENTS

95th PERCENTILE ALL EVALUATED ACCIDENTS
Peak Vertical Acceleration vs Velocity Change and Seat Stroke for Various Pulse Durations

![Graph showing peak vertical acceleration vs velocity change and seat stroke for various pulse durations. The graph includes lines for different pulse durations: 0.065, 0.10, and 0.15 seconds, and peak vertical accelerations of 12 G's. The x-axis represents seat stroke in inches, and the y-axis represents velocity change in terms of velocity change per second (ft/sec).]
GASP Established a Pass/Fail Performance Criteria

• Performance Criteria Relates Selected Measured Dynamic Test Parameters to Injury Criteria

• Performance Criteria Evaluates the Seat/Restraint System’s Potential for Preventing or Minimizing Injuries from:
  – Primary Impacts
  – Secondary Impacts
  – Occupant Skeletal Loads
Rotorcraft

- Technical Data Review
- Rotorcraft Accident Analysis
- Accident Scenarios
- Impact Envelopes
- Performance Criteria
- Dynamic Performance Standards
- 14 CFR Part 27, Amendment 27-25
- 14 CFR Part 29, Amendment 29-29
  - Effective Date – December 13, 1989
Crash impact design conditions with landing gear extended

<table>
<thead>
<tr>
<th>Condition No.</th>
<th>Impact Direction (Aircraft Axes)</th>
<th>Velocity Change (ft/s)</th>
<th>Object/Surface Impacted</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Longitudinal (cockpit)</td>
<td>20</td>
<td>Rigid vertical barrier</td>
</tr>
<tr>
<td>2</td>
<td>Longitudinal (cabin)</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Vertical*</td>
<td>42</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Lateral, Type I</td>
<td>25</td>
<td>Rigid horizontal surface</td>
</tr>
<tr>
<td>5</td>
<td>Lateral, Type II</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Combined high angle*</td>
<td>42, 27</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Vertical</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Longitudinal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Combined low angle</td>
<td>14, 100</td>
<td>Plowed soil</td>
</tr>
<tr>
<td></td>
<td>Vertical</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Longitudinal</td>
<td></td>
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</tbody>
</table>
Design Velocity Change Envelope
95\textsuperscript{th} Percentile Survivable Accident

Velocity Change - FT/SEC
## Accident Frequency – Civil Rotorcraft

<table>
<thead>
<tr>
<th>SCENARIO TYPE</th>
<th>DESCRIPTION</th>
<th>NO. OF ACCIDENTS</th>
<th>PERCENTAGE</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>HIGH VERTICAL IMPACT VELOCITY</td>
<td>70</td>
<td>29.2</td>
</tr>
<tr>
<td>2</td>
<td>HIGH LONGITUDINAL IMPACT VELOCITY</td>
<td>21</td>
<td>8.5</td>
</tr>
<tr>
<td>3</td>
<td>ROLLOVER</td>
<td>34</td>
<td>13.7</td>
</tr>
<tr>
<td>4</td>
<td>WIRE STRIKE</td>
<td>25</td>
<td>10.1</td>
</tr>
<tr>
<td>5</td>
<td>WATER IMPACT</td>
<td>24</td>
<td>9.7</td>
</tr>
<tr>
<td>6</td>
<td>HIGH YAW RATE</td>
<td>21</td>
<td>8.5</td>
</tr>
<tr>
<td></td>
<td>ALL OTHERS</td>
<td>53</td>
<td>21.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>248</strong></td>
<td><strong>100.0</strong></td>
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</table>
# Crash Hazard Ranking

## RANK-ORIENTED LISTING OF CRASH HAZARDS FOR THE CIVILIAN ROTORCRAFT FLEET

<table>
<thead>
<tr>
<th>HAZARD No.</th>
<th>SIGNIFICANCE GROUP</th>
<th>DESCRIPTION</th>
<th>FREQUENCY INDEX</th>
<th>SEVERITY INDEX</th>
<th>ACCUMULATED AIS</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>BODY EXPOSED TO FIRE WHEN FUEL SYSTEM FAILED ON IMPACT</td>
<td>B</td>
<td>I</td>
<td>147</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>BODY RECEIVED EXCESSIVE DECELERATION FORCE WHEN AIRCRAFT AND SEAT ALLOWED EXCESSIVE LOADING</td>
<td>B</td>
<td>I</td>
<td>145</td>
</tr>
<tr>
<td>14</td>
<td>7</td>
<td>BODY EXPOSED TO CHEMICAL AGENTS ON IMPACT</td>
<td>E</td>
<td>III</td>
<td>1</td>
</tr>
</tbody>
</table>
Occurrence of Vertical Impact Velocity

![Graph showing the occurrence of vertical impact velocity for military (42 ft/sec) and civil (26 ft/sec) with the 95th percentile highlighted.](image)

**95th PERCENTILE**
- MILITARY 42 FT/SEC
- CIVIL 26 FT/SEC

**CUMULATIVE FREQUENCY (PERCENT)**
Civil and Military Comparison

- Civil and Military Comparison

**Legend:**
- **CIVIL**
  - 95TH% ALL ACCIDENTS
  - 95TH% SURVIVABLE

**Lines:**
- **U.S. CIVILIAN HELICOPTERS**
- **U.S. ARMY HELICOPTERS, 95TH% CURRENT DESIGN REQUIREMENTS**
- **U.S. ARMY OH-58A, 95TH% SURVIVABLE**
- **U.S. NAVY HELICOPTERS 95TH% SURVIVABLE**
- **LAND**
- **WATER**

**Axes:**
- Vertical Impact Velocity - FT/SEC
- Longitudinal Impact Velocity - FT/SEC

**Range:**
- 0 to 140 FT/SEC
Injury Distribution Used to Select Injury Criteria

Frequency Of Major And Fatal Injuries To Each Body Region As Percentages Of Total Major And Fatal Injuries In Survivable Accidents
Upper Torso Restraint Raises the Onset Point for Serious and Fatal Injuries

**LONGITUDINAL VELOCITY - FT/SEC**

- **REGION OF MINOR INJURY**
- **REGION OF ONSET OF SERIOUS INJURY**
- **95 TH PERCENTILE SURVIVABLE ACCIDENTS**
Transport Category Aircraft

- Accident Data Review
- Full Scale Tests
- Parametric Studies (KRASH)
- Controlled Impact Demonstration (CID)
- Performance Criteria
- Seat Dynamic Test Series
- Transport Category Aircraft Seat Dynamic Performance Standards
- 14 CFR Part 25, Amendment 25-64
  - Effective Date – June 16, 1988
Crash Dynamics Program Plan

- Analysis of Accident Data
  - Crash Characterization
    - Accident Scenarios
  - Crash Dynamic Analytical Programs KRASH/DYCAST
    - Douglas Model DC-10 Fuselage Segment
    - Simulated Lockheed Model 1649 Aircraft
    - Boeing Model 720 Aircraft
    - Lockheed Widebody Aircraft

- Boeing Model 720 Aircraft Full-Scale Crash Test
  - Measured Cabin Floor/Seat/Occupant Responses
  - Quantitative/Qualitative Evaluation of New Design Cabin Interior Configurations

- Data Analysis Airframe Cabin Floor Responses (Time Histories)
  - Seat/Occupant Analytical Program SOMTA-T
    - Human Impact Tolerance Levels
    - Seat/Occupant Responses (Time Histories)
    - CAMI Transport Category Aircraft Seat Tests

- Data Analysis Analytical Programs Validation
  - Technical Data Base
    - Analytical Methodologies Validation
    - Recommended Design Standards

- Lockheed Model 1649 Aircraft Full-Scale 1965 Crash Test
  - Douglas Model DC-10 Fuselage Segment Drop Tests
## Candidate Crash Scenarios

<table>
<thead>
<tr>
<th>CANDIDATE CRASH SCENARIO</th>
<th>IMPACT CONDITIONS</th>
<th>ACCIDENT TYPE</th>
<th>TERRAIN</th>
<th>HAZARD</th>
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</thead>
<tbody>
<tr>
<td>GROUND-TO-GROUND, OVERRUN</td>
<td>LOW SINK SPEED</td>
<td>TAKEOFF ABORT</td>
<td>RUNWAY</td>
<td>DITCH</td>
</tr>
<tr>
<td></td>
<td>LOW FORWARD VELOCITY</td>
<td>LANDING OVERRUN</td>
<td>HARD GROUND</td>
<td>MOUND</td>
</tr>
<tr>
<td></td>
<td>SYM. A/P ATTITUDE</td>
<td></td>
<td></td>
<td>SLOPE</td>
</tr>
<tr>
<td></td>
<td>GEARs EXTENDED</td>
<td></td>
<td></td>
<td>SLAB</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>LIGHT STANCHION</td>
</tr>
<tr>
<td>AIR-TO-GROUND HARD LANDING</td>
<td>HIGH SINK SPEED AND</td>
<td>HARD LANDING</td>
<td>RUNWAY</td>
<td>NONE</td>
</tr>
<tr>
<td></td>
<td>LOW SINK VELOCITY</td>
<td>UNDERSHOT</td>
<td>HARD GROUND</td>
<td></td>
</tr>
<tr>
<td></td>
<td>SYM. A/P ATTITUDE</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>GEARs EXTENDED</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AIR-TO-GROUND IMPACT</td>
<td>HIGH SINK SPEED AND</td>
<td>UNCONT/CONT</td>
<td>WOODED</td>
<td>TREES</td>
</tr>
<tr>
<td></td>
<td>LANDING VELOCITY</td>
<td>GRD COLLISION</td>
<td>HILLY</td>
<td>SLOPES</td>
</tr>
<tr>
<td></td>
<td>UNSYM. A/P ATTITUDE</td>
<td>STALL</td>
<td></td>
<td>BLDGS</td>
</tr>
<tr>
<td></td>
<td>GEARs EXTENDED/RET</td>
<td>UNDERSHOT</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Structural and Seat Test Velocity Change Envelopes

VERTICAL VELOCITY CHANGE - FT/SEC

LONGITUDINAL VELOCITY CHANGE - FT/SEC

KRASH PARAMETER STUDY
TRANSPORT CATEGORY AIRCRAFT SEAT PULSE ENVELOPE

STRUCTURAL INTEGRITY ENVELOPE
Fuselage Section Drop Tests

Provide Basic Airframe Data

• Lower Fuselage Crush Characteristics
  – Stress analysis
  – Static tests
  – Section drop tests

• Obtain Load/Deflection Experimentally

• Address Failure Modes

• Verify Analytical Predictions

• Input for Aircraft Models

• Investigated Both “Hard” and “Soft” Sections
# FAA/NASA Full-Scale Airframe Impact Tests

<table>
<thead>
<tr>
<th>AIRPLANE TYPE</th>
<th>TEST SPECIMEN</th>
<th>TEST CONDITION</th>
</tr>
</thead>
<tbody>
<tr>
<td>NARROW BODY</td>
<td>FORWARD FUSELAGE SECTION</td>
<td>VERTICAL IMPACT 20 FPS</td>
</tr>
<tr>
<td>NARROW BODY</td>
<td>CENTER FUSELAGE SECTION</td>
<td>VERTICAL IMPACT 20 FPS</td>
</tr>
<tr>
<td>NARROW BODY</td>
<td>FORWARD FUSELAGE SECTION</td>
<td>VERTICAL IMPACT 20 FPS</td>
</tr>
<tr>
<td>NARROW BODY</td>
<td>AFT FUSELAGE SECTION WITH CARGO</td>
<td>VERTICAL IMPACT 20 FPS</td>
</tr>
<tr>
<td>NARROW BODY</td>
<td>AFT FUSELAGE SECTION WITH CARGO</td>
<td>VERTICAL IMPACT 35 FPS</td>
</tr>
<tr>
<td>WIDE BODY</td>
<td>AFT FUSELAGE SECTION WITH CARGO</td>
<td>VERTICAL IMPACT 20 FPS</td>
</tr>
<tr>
<td>WIDE BODY</td>
<td>FUSELAGE SECTION WITH CARGO</td>
<td>VERTICAL IMPACT 20 FPS</td>
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<tr>
<td>WIDE BODY</td>
<td>FUSELAGE SECTION WITH CARGO</td>
<td>VERTICAL IMPACT 25 FPS</td>
</tr>
<tr>
<td>NARROW BODY</td>
<td>FULL AIRPLANE LAURINBURG</td>
<td>VERTICAL IMPACT 17 FPS</td>
</tr>
<tr>
<td>NARROW BODY</td>
<td>FULL AIRPLANE - CID WITH CARGO</td>
<td>VERTICAL IMPACT 17.3 FPS/141.5 KTS</td>
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</tbody>
</table>
Transport Category Aircraft Longitudinal Impact Tests

<table>
<thead>
<tr>
<th>TEST PROGRAM</th>
<th>PEAK LONGITUDINAL ACCELERATION G’s</th>
<th>LONGITUDINAL VELOCITY CHANGE FT/SEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>MODEL 1649</td>
<td>10</td>
<td>26</td>
</tr>
<tr>
<td>CID</td>
<td>2 - 4</td>
<td>8</td>
</tr>
<tr>
<td>FAR PART 25</td>
<td>16</td>
<td>44</td>
</tr>
</tbody>
</table>
Typical Floor Track Strength Envelope

INCREASING UP LOAD

INCREASING DOWN LOAD

VERTICAL DIRECTION

LOAD COMBINATIONS OUTSIDE THIS BOUNDARY EXCEEDS STRENGTH CAPABILITY

TYPICAL TEST DATA POINTS

INCREASING LOAD

FORWARD DIRECTION
Static/Dynamic Load Factor Requirements

Load Factor - G's

Dynamic FAR 25.562
Static FAR 25.561 With 1.33 Fitting Factor

Time - Seconds

Crash Dynamics Summary
19 May 2011
16 G’s/44 fps Nominal Impact Test

TOTAL OF SEVENTEEN TESTS

AFT LEG VERTICAL REACTION - LBS

- MD80
- B727/B737
- B747

Federal Aviation Administration
Crash Dynamics Summary
19 May 2011
Two Distinct Dynamic Test Conditions

• Combined Vertical/Longitudinal
  – Velocity change not less than 35 fps
    • Vertical 30.3 fps
    • Longitudinal 17.5 fps
    • Peak Deceleration 14 G’s minimum
  – Evaluates spinal loads and injury

• Longitudinal
  – Velocity change not less than 44 fps
    • Peak deceleration 16 G’s minimum
  – Assess occupant restraint system
  – Assess seat structural performance
Current Regulations

14 CFR 23.562 Emergency Landing Conditions
   Amendment 23-50 Effective Date March 11, 1996

14 CFR 25.562 Emergency Landing Conditions
   Amendment 25-64 Effective Date June 16, 1988

14 CFR 27.562 Emergency Landing Conditions
   Amendment 27-25 Effective Date December 13, 1989

14 CFR 29.562 Emergency Landing Conditions
   Amendment 29-41 Effective Date November 28, 1997
## Performance Standards Summary

### Dynamic Test Requirements

<table>
<thead>
<tr>
<th>Test</th>
<th>Part 23</th>
<th>Part 25</th>
<th>Part 27</th>
<th>Part 29</th>
</tr>
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<tbody>
<tr>
<td>Test 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test Velocity (FT/SEC)</td>
<td>31</td>
<td>35</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Seat Pitch Angle (Degree)</td>
<td>60</td>
<td>60</td>
<td>60</td>
<td>60</td>
</tr>
<tr>
<td>Seat Yaw Angle (Degree)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Peak Decel. (G’s)</td>
<td>19/15</td>
<td>14</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Time to Peak (Seconds)</td>
<td>0.05/0.06</td>
<td>0.08</td>
<td>0.031</td>
<td>0.031</td>
</tr>
<tr>
<td>Floor Deformation (Deg.)</td>
<td>None</td>
<td>None</td>
<td>10 Pitch/10 Roll</td>
<td>10 Pitch/10 Roll</td>
</tr>
<tr>
<td>Test 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test Velocity (FT/SEC)</td>
<td>42</td>
<td>44</td>
<td>42</td>
<td>42</td>
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<tr>
<td>Seat Pitch Angle (Degree)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Seat Yaw Angle (Degree)</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
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<tr>
<td>Peak Decel. (G’s)</td>
<td>26/21</td>
<td>16</td>
<td>18.4</td>
<td>18.4</td>
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<tr>
<td>Time to Peak (Seconds)</td>
<td>0.05/0.06</td>
<td>0.09</td>
<td>0.071</td>
<td>0.071</td>
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<tr>
<td>Floor Deformation (Deg.)</td>
<td>10 Pitch/10 Roll</td>
<td>10 Pitch/10 Roll</td>
<td>10 Pitch/10 Roll</td>
<td>10 Pitch/10 Roll</td>
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<tr>
<td>Quantitative Compliance Criteria</td>
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</tr>
<tr>
<td>Max HIC</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
<td>1000</td>
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<tr>
<td>Lumbar Load (lb)</td>
<td>1500</td>
<td>1500</td>
<td>1500</td>
<td>1500</td>
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<tr>
<td>Femur Loads (lb)</td>
<td>N/A</td>
<td>2250</td>
<td>N/A</td>
<td>N/A</td>
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</tbody>
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Conclusions

• Recommendations based on
  – Accident data
  – Parametric studies
  – Existing guidelines
  – FAA/NASA research

• General Aviation Crashworthiness Project
  – NTSB confirmed GASP recommendations

• Continued testing beyond initial development