A Comparative Evaluation of Two Helicopter Crash Tests

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6th Fire and Cabin Safety Conference
Atlantic City, New Jersey
October 25-28, 2010
OUTLINE

• Introduction
  - Subsonic Rotary Wing (SRW) Crash Research Program
  - Composite Honeycomb Deployable Energy Absorber (DEA)
  - Summary of DEA development
  - Presentation Objectives

• Full-Crash Crash Test Program
  - Test article set-up, component testing, and test conditions
  - Onboard experiments and instrumentation

• Comparative Results
  - Test video
  - Structural damage
  - Occupant injury assessment

• Conclusions
SRW CRASH RESEARCH OBJECTIVES

➢ Develop an advanced composite structural concept for improved energy absorption
  • Develop an externally-deployable composite honeycomb energy absorbing concept and study deployment options
  • Demonstrate the effectiveness of the concept through testing utilizing a building block approach
  • Optimize the concept for multi-terrain applications

➢ Demonstrate improved prediction of rotorcraft crashworthiness
  • Multi-terrain impact simulation
  • Human occupant simulation and injury prediction
  • Probabilistic analysis and uncertainty quantification
  • System-integrated helicopter crash test, simulation, and model validation study

Artistic depictions of DEA rotorcraft applications
**DEPLOYABLE ENERGY ABSORBER (DEA)**

- A novel composite honeycomb energy absorber deployed using mechanical or pneumatic methods
- GOAL: Demonstrate the effectiveness of the concept using a building block approach
- Optimize the concept for multi-terrain applications

**Square cell schematic**

**Flexible hinge**

**Linear deployment**

**Radial deployment**

**Component crush test**

Crush Stress, psi

Crush Stroke, %
SUMMARY OF DEA DEVELOPMENT

Materials Testing
- Dynamic Crush Tests
  - Soft soil, 38-fps
  - Water, 25-fps
  - Rigid surface, 38.4-fps

Three-Pt Bend Testing of Single Hex Cells
- ±45° Kevlar fabric loaded in tension

Dynamic Crush Tests
- 59- and 104-Cell DEA components

Multi-Terrain Impact Testing
- Rigid surface, 38.4-fps
- Water, 25-fps
- Soft soil, 38-fps
SUMMARY OF DEA DEVELOPMENT

Crash Test of an MD-500 with DEA

System-Integrated Finite Element Model

Close-up View

Shell-Based Model of the DEA
OBJECTIVES

This presentation will:

• Describe the full-scale crash test program including test conditions, hardware set-up, instrumentation, and onboard experiments

• Provide test video highlighting two crash tests of the MD-500 helicopter, one test performed with an external energy absorber and the second without

• Summarize and compare test results including: structural damage, and occupant injury assessment
FULL-SCALE CRASH TEST PROGRAM

- Test conducted at NASA Langley Landing and Impact Research Facility (LandIR)
- MD-500 test article and solid geometry provided by US Army Mission Enhanced Little Bird (MELB) Program
- Conduct two full-scale crash tests of the MD-500 helicopter with and without deployable energy absorber (DEA) at LandIR
- 26-ft/s vertical and 40-ft/s forward velocity, zero pitch
- 3,000 lb expected gross takeoff weight (airframe weight ~ 500 lb)
Test Objectives

- To evaluate the performance of the DEA under realistic crash test conditions

- To generate test data to validate a system-integrated LS-DYNA finite element model that includes accurate physical representations of the:
  - airframe
  - shock struts
  - occupants
  - skid gear
  - seats
  - restraints
  - ballast
  - impact surface
  - external DEA

- To generate test data to evaluate thoracic injuries, including aortic rupture, during helicopter crash impacts
FULL-SCALE CRASH TEST PROGRAM

Test Article: MD-500 Helicopter

- Manufactured by MD Helicopters
- 3,000-lb max gross weight
- Defender - Manned military version
- Little Bird - US Army Special Operations
- Civilian utility helicopter
- 156 knots max speed
- 300 nautical mile range
- 31-ft long, 9-ft tail height
Photograph of as-received helicopter

Test Article Modifications

• Repaired damage caused by tie-down pull tests

• Due to anticipated attachment failures, replaced the existing oleo-pneumatic shock struts with inversion crush tube struts designed in-house

• Added four layers graphite/epoxy fabric to cover openings in the lower skin

• Purchased and installed two crew seats and one bench passenger seat with restraints

• Added ballast to represent the engine, rotor transmission, fuel, and tail cone

• Fabricated and installed two DEA blocks (front block at 20°, rear block at 0°)
Crush Tube Shock Strut Design and Testing

Graphite Overwrap

Shock strut compression test

Cut-away view of crush tube post-test

Drop Mass

Guide Rails

Test Article

Test Fixture Base

Load response of crush tube

Load, lb.

Time, s

FULL-SCALE CRASH TEST PROGRAM

Crush Tube Shock Strut Design and Testing

Graphite Overwrap

Full-scale crash test program

Shock strut compression test

Cut-away view of crush tube post-test

Graphite Overwrap

Load response of crush tube

Load, lb.

Time, s
<table>
<thead>
<tr>
<th>Role</th>
<th>Crew Position</th>
<th>Anthropomorphic Dummy Type</th>
<th>Restraint Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pilot</td>
<td>Front left crew</td>
<td>50th percentile Hybrid III male</td>
<td>4-pt. restraint</td>
</tr>
<tr>
<td>Copilot</td>
<td>Front right crew</td>
<td>50th percentile Hybrid II male</td>
<td>4-pt. restraint</td>
</tr>
<tr>
<td>Passenger</td>
<td>Rear left side</td>
<td>HSTM/50th Hybrid III male</td>
<td>3-pt. restraint</td>
</tr>
<tr>
<td>Passenger</td>
<td>Rear right side</td>
<td>50th percentile Hybrid II male</td>
<td>3-pt. restraint</td>
</tr>
</tbody>
</table>
• Two DEA blocks were mounted beneath the belly skin of the airframe

• Each DEA block consisted of multiple hexagonal cells, with 1-in. cell wall length, fabricated of ±45° Kevlar-129 fabric/epoxy

• The cells in the front block were canted by 20° with respect to the vertical direction, while the cells in the rear block were oriented vertically. This configuration improved vehicle stability.

Each block weighed 14-lb. and was designed for 20-psi crush stress.
FULL-SCALE CRASH TEST PROGRAM

Instrumentation Summary

- 46 ATD channels
- 8 belt loads
- 1 IRIG
- 32 single strain gages
- 7 strain gage rosettes
- 12 single vertical accels
- 12 tri-axial accels
- 4 load cells

160 total channels
Video of MD-500 Crash Test with DEA
Video of MD-500 Crash Test without DEA
### COMPARATIVE RESULTS

#### Test Conditions

<table>
<thead>
<tr>
<th>Impact Condition</th>
<th>Planned Values</th>
<th>Test #1 Actual</th>
<th>Test #2 Actual</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forward velocity</td>
<td>40-fps</td>
<td>38.7-fps</td>
<td>39.1-fps</td>
</tr>
<tr>
<td>Vertical velocity</td>
<td>26-fps</td>
<td>25.5-fps</td>
<td>24.2-fps</td>
</tr>
<tr>
<td>Resultant velocity</td>
<td>47.8-fps</td>
<td>46.3-fps</td>
<td>46.0-fps</td>
</tr>
<tr>
<td>Roll attitude</td>
<td>0°</td>
<td>7.0°</td>
<td>6.2°</td>
</tr>
<tr>
<td>Pitch attitude</td>
<td>0°</td>
<td>5.7°</td>
<td>1.9°</td>
</tr>
<tr>
<td>Yaw attitude</td>
<td>0°</td>
<td>9.3°</td>
<td>2.1°</td>
</tr>
</tbody>
</table>
COMPARATIVE RESULTS

Structural Damage – Test #1 with DEA

- Minor damage to the front right side subfloor and outer skin, which was repaired
- No damage to seats, keel beam, or airframe
- Skid gear, shock struts, seats, and restraints were replaced for the second test
COMPARATIVE RESULTS

Structural Damage – Test #2 without DEA

- Failure of crew and passenger seats
- Failures of keel beam & subfloor frames
- Outer skin buckling and rupture
- Bearing failures of the skid gear
- Buckling of the center bulkhead
**COMPARATIVE RESULTS**

### Shock Strut Crush Data

<table>
<thead>
<tr>
<th>Crush Tube Position</th>
<th>Test #1 Stroke, in.</th>
<th>Test #2 Stroke, in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front Left</td>
<td>3.5</td>
<td>6.1</td>
</tr>
<tr>
<td>Front Right</td>
<td>5.3</td>
<td>5.5</td>
</tr>
<tr>
<td>Rear Left</td>
<td>2.5</td>
<td>5.7</td>
</tr>
<tr>
<td>Rear Right</td>
<td>5.0</td>
<td>5.8</td>
</tr>
</tbody>
</table>

Total stroke difference = 6.8 inches. For an average crush load of 2,000-lb, the total energy dissipated is 1,133 ft-lb, which is equivalent to 0.87-ft/s lower vertical velocity for the 2nd test.

Post-test photo of shock struts following Test #1
COMPARATIVE RESULTS

Passenger Floor, Vertical Response

Occupants Exposed to Minor and Severe Vertical Loads

No DEA

DEA
COMPARATIVE RESULTS

Pilot Lumbar Load Response

- JSSG = 2,065 lb
- FAA = 1,500 lb

No DEA
DEA

Lumbar Load (lb) (E+3)

Time (sec)
Both Hybrid III and HSTM experienced similar loading through the pelvis and spine

- Matched peak decelerations and deceleration shape
- Introduction of DEA reduced peak deceleration by 67% (28 g)
Increased surrogate biofidelity provides soft-tissue responses not previously investigated.

Test with DEA shows a significant drop in pressure response.

Pressure levels for drop test without DEA indicate potential for serious injury.
Conclusions

- Two full-scale crash tests of an MD-500 helicopter were conducted, one retrofitted with an external energy absorber and the second in a baseline configuration.

- Excellent performance demonstrated by DEA’s:
  - Floor level acceleration peaks reduced from 40- to 12-g
  - Lumbar loads reduced from 2,000 lb. to 700 lb.

- Successful application of a biofidelic dummy to generate soft-tissue responses.