Full-Scale Crash Testing of Transport Rotorcraft

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50th ANNUAL SAFE SYMPOSIUM
22 October 2012
Outline

• Motivation
• Landing and Impact Research Facility
• NASA Rotary Wing Crashworthiness Research
• Transport Rotorcraft Airframe Crash Testbed (TRACT)
• Summary
Motivation- Recent Studies


Conclusions

• For cargo and utility helicopters, Combat hostile action loss rate nearly six times lower, and fatality rate four times lower, for OEF/OIF vs. Vietnam.

• A high percentage of helicopter losses are survivable.

• “To reduce personnel injuries and fatalities for combat threat losses and mishaps, improve airframe crashworthiness and crash protection for passengers. DoD crashworthiness standards have not been updated since the 1970s and need to be expanded in scope to cover a wider set of aircraft and environmental conditions.”
Conclusions

• Crashworthy fuel systems have virtually eliminated fatalities and severe injuries due to post-crash fire.

• Onboard systems such as lap belts, shoulder restraints, inertia reels, and load limiting seats are effective in improving crash performance.

• The 90th-percentile survivable impact ground speeds and vertical speeds for aircraft designed to crashworthy criteria were generally higher than those for the previous generation of aircraft. The AH-64 exceeded the AH-1 in both ground speed and vertical speed for both direct-to-terrain crashes and post-obstacle crashes. Likewise, the UH-60 exceeded the comparable speeds for the UH-1.
Motivation - Recent Studies


Conclusions

- ‘85-’94 vs. ‘95-’05: DoN fatality rate (per 100,000 flight hours) reduced from 5.8 to 3.15, and injury rate (per 100,000 flight hours) reduced from 3.92 to 2.14

- Decadal differences attributed to improved policies, guidelines, training procedures and equipment for overseas operations

- Head injuries are an important cause of morbidity in helicopter mishaps.

- Non-pilot personnel appear to be at greater risk for injury.
• AATD sponsored effort to develop comprehensive crash design requirements for a wide range of rotorcraft classes, types, configurations, and operating conditions that continue over the life cycle of the rotorcraft system.

• Identify the key components that contribute to a system’s crashworthiness

• Crashworthiness Index (CI) proposed as new design standard to replace ADS-11B current specification, with a higher score contribution due to basic airframe crashworthiness

<table>
<thead>
<tr>
<th>Basic Airframe Crashworthiness Rating Summary</th>
<th>Optimum Score</th>
<th>Accessed Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Crushing of Occupied Areas</td>
<td>15</td>
<td>16.52</td>
</tr>
<tr>
<td>1a Crushing of Cockpit</td>
<td>15</td>
<td>16.52</td>
</tr>
<tr>
<td>1b Crushing of Cabin</td>
<td>15</td>
<td>16.53</td>
</tr>
<tr>
<td>2 Absence of “Plowing” Tendency</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>3 Resistance to Longitudinal Impact Loads</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>4 Resistance to Vertical Loads</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4a Vertical Impact, Gear Extended</td>
<td>80</td>
<td>81.5</td>
</tr>
<tr>
<td>4b High Mass Retention</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>5 Resistance to Lateral and Rollover Impact Loads</td>
<td>15</td>
<td>13.5</td>
</tr>
<tr>
<td>5a Lateral Impact</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>5b Static Rollover</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>6 Landing Gear Vertical Force Attenuation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6a Vertical Impact, Gear Retracted</td>
<td>40</td>
<td>36.8</td>
</tr>
<tr>
<td>6b High Angle Vertical Impact</td>
<td>20</td>
<td>6.9</td>
</tr>
<tr>
<td>6c Low Angle Vertical Impact</td>
<td>20</td>
<td>18.3</td>
</tr>
<tr>
<td>6d Tail Boom Protection</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>7 Landing Gear Location</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>8 Effects of Blade Strike</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>9 Effect of Fuselage Separation</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>TOTAL</td>
<td>295</td>
<td>264.0</td>
</tr>
</tbody>
</table>

Example from RDECOM TR 12-D-12
• Many conditions not currently modeled and evaluated accurately for occupant casualty response
  – Post-obstacle vs. direct-to-terrain
  – Multi-terrain impact (water, soft soil, prepared surface)
  – Crushing of subfloor/ landing gear stroke
  – Crashworthy seats / troops benches
  – Restraints
• These factors will alter the magnitude and duration of the acceleration pulses imparted into the occupant
• A comprehensive method is required to associate impact velocities, attitudes and terrains to seat interface and occupant G-loads
Motivation-Crashworthiness Analytical Capabilities

**KRASH**
- Lumped parameter modeling of fixed and rotary wing
- Vehicle kinematics captured, minimal computational time
- Hybrid approach with finite element models (FEM)
- Limited support for further development

**MADYMO**
- Detailed representations of Anthropomorphic Test Devices (ATD) and whole-body models, heritage within automotive crashworthiness
- Highly integrated multi-body/FE capability that can be coupled with other explicit codes

**LS-DYNA/ PAM-CRASH/ Radioss/ ABAQUS-Explicit**
- Finite element analysis tools
- Detailed representations of ATD’s and airframes
- Accurate modeling of terrain (less than 20% of all mishaps occur on prepared surfaces)
Landing and Impact Research Facility (LandIR)

Constructed in early 1960’s as a lunar landing simulator

70-foot Drop Tower

Hydro-Impact Basin constructed 2010

240'

265'

400'
Landing and Impact Research Facility (LandIR)

Military Aircraft Crashworthiness Research
- Full-scale crash test  ◆ - Vertical drop test  ■ - Hover test  ● - Wire Strike Protection System (WSPS)

(#) - indicates number of tests performed
NASA Fundamental Aeronautics, Rotary Wing Project

Develop and Validate Tools, Technologies and Concepts to Overcome Key Barriers for Rotary Wing Vehicles

**Vision**
- Improve capabilities, performance and acceptance of existing and future rotorcraft configurations for civil and dual-use military missions
- Explore and develop new capabilities for rotorcraft use as commercial transportation in national airspace

**Scope**
- Conventional and non-conventional light, medium, heavy and ultraheavy rotorcraft
- Technologies that address performance, noise, efficiency, safety, passenger acceptance and affordability
Rotary Wing Crashworthiness Research

- Evaluate a novel, externally-deployable energy absorber (DEA)
- Two tests conducted, with and without the DEA
- Developed a system-integrated FEM of the test article that included skid gears, airframe, seats, occupants, restraints, DEA, ballast and the impact surface
- Model calibrated using conventional and multi-dimensional calibration methods
- Evaluated the impact response of a biofidelic dummy torso from the Johns Hopkins University Applied Physics Laboratory
Rotary Wing Crashworthiness Research

System-Integrated Model Calibration

Updated model based on improvements in spatial and temporal response of FEM against measured test accelerations and velocities.
Rotary Wing Crashworthiness Research

Composite Airframe Impact Testing and Simulation

- Does the design building block test sequence for material characterization & analysis methods validation encapsulate all critical modes of failure for composites, primarily Carbon Fiber Reinforced Plastics (CFRP)?

- Current models are phenomenological models and parameters in the simulation are determined by curve fitting or calibration.

- Goal: Conduct impact tests and simulations of composite airframe structures to assess feasibility for crash load attenuation, and to evaluate analytical capabilities to predict failure initiation, damage progression, and energy absorption.
Composite Airframe Impact Testing and Simulation

Coupons

Tensile Coupon FEM

Subfloor Cruciform

Cruciform FEM
Composite Airframe Impact Testing and Simulation

Subfloor-Longitudinal Impact

Frame section - Vertical Impact

Frame section FEM

Subfloor FEM
Rotary Wing Crashworthiness Research

- How do we predict occupant injuries for aircraft crash and spacecraft landing conditions?
- Do we have the correct tools to predict injury?
- Evaluate adequacy of human occupant models under vertical loading
- Hybrid II, Hybrid III, THOR/NT
Transport Rotorcraft Airframe Crash Testbed (TRACT)

- Objective: Evaluate transport category rotorcraft crash response under combined horizontal and vertical loading
- Two CH-46 airframes provided by PMA-226
- Likely impact conditions
  - 20-30 ft/sec vertical
  - 20-30 ft/sec horizontal
  - 2-4 degree pitch up attitude
  - Soft soil impact
• Collaborators
  – NAVAIR
  – AATD
  – FAA

• Discussions for supplementary experiments
  – Crashworthy side-facing troop seats?
  – Floor mounted and side mounted seats?
  – New seat energy absorber concepts?
  – Pre-tensioning/active retraction systems for inertia reel?
  – Advanced cargo restraints?
  – Available ATD’s (Hybrid II, Hybrid III Aerospace, THOR, SID, ES-2)?
TRACT-Instrumentation Options

• LandIR capability: > 600 channels of data
  – Ruggedized onboard data acquisition system
  – Accelerometers
  – Strain gages
  – Strap load cells (restraint loads)
  – ATD load cells (thoracic and lumbar spine)
  – Pressure gages (for hydrodynamic pressures due to ditching)

• Full-field photogrammetry (high speed)
  – Velocity, attitude, pitch rates
  – Panel Strains

• Interior cameras
  – Occupant flail and strike envelope
TRACT-Tentative Schedule

- First swing test scheduled for Summer 2013, considered “baseline” test
- Second swing test scheduled for FY14, evaluate energy absorbing subfloor concept
- Potential for fuselage frame section drop tests prior to swing test
- Potential for ditching test in Hydro Impact Basin following land tests
TRACT- Pre-test Analysis

H-46 NASTRAN Model Provided by PMA 226

Increased refinement around stub-wings for Nonlinear Static Analysis

TRACT LS-DYNA Finite Element Model (FEM)

- ~50,000 nodes, ~60,000 elements
- Combination of mass, bar, and shell elements
- Elastic-plastic aluminum properties
- Current weight ~ 10,000 lb
- Overhead mass = 3,250 lb (750 fwd, 2,500 aft)
- Cockpit mass = 1,400 lb
- Cargo Floor Mass = 2,000 lb

Model Converted to LS-DYNA for Explicit FEA Crash Simulation
TRACT-Pre-test Analysis

Impact Conditions:
24 ft/sec vertical, 24 ft/sec horizontal, 2 Degree Pitch-Up attitude

- Diagram of a spacecraft with labeled sections
- Graph showing vertical acceleration (g) versus time (sec) for different cabins: Aft Cabin, Mid Cabin, Forward Cabin
TRACT-Pre-test Analysis

- The shear panels in the subfloor contribute 30-40% to the overall internal energy absorption (plastic deformation).
- Can advanced composite concepts implemented in the subfloor reduce overall floor loads?
  - Maintain stiffness and strength performance while increasing specific energy absorption capability.
  - Sandwich composite (honeycomb, Rohacell).
  - Hybrid materials laminates (Kevlar, Zylon, Glass, Carbon).
- Can this behavior be predicted analytically?
Summary

• Combined test and analysis capabilities at NASA Langley Research Center provide an integral, effective, and unique approach to studying crashworthiness
  - Full-scale testing with combined loading
  - Improved prediction of system-level vehicle response
  - Improved prediction of hydrodynamic loads due to water impact
  - Biofidelic dummy models and injury assessment
  - Structurally efficient composite concepts for improved crash performance
• Full-scale transport category crash tests planned for 2013-2014 with the goals of:
  – Characterizing complex interaction of airframe/seat/restraints/occupant under multi-terrain impact
  – Assessing both crew and troop dynamics assessed
  – Evaluating new crashworthy technologies

Ultimate Objective is Improved Crashworthiness and Crash Certification by Analysis