Helicopter Crashworthiness — Part Two

In this second of a two-part series, the author discusses crashworthiness tests and proposes actions to improve crash safety features for future rotorcraft designs.

by

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Part One of this series reviewed efforts to study and improve crash survival in helicopter accidents. It described designs for energy attenuating seats by the Crashworthiness Project Group (CPG) that was established by the Rotorcraft Airworthiness Requirement Committee (RARC) of the Aerospace Industries Association of America (AIAA).

For future civil helicopter designs, the Crashworthiness Project Group recommended two dynamic seat tests with a CFR (Code of Federal Regulation) 14, Part 572 dummy weighing 170 pounds (77 kg). These dynamic seat tests should replace static seat testing, because the loading during a crash is dynamic, not static.

Test No. 1 is a pure forward impact test with a ten degree yaw to simulate an aircraft longitudinal impact. This test will verify that a seat, restraint and seat attachment can accept the crash loads. The criterion recommended was a velocity change of 42 feet per second (12.8 m/s) with a peak deceleration of 18.4G, using a symmetrical triangular pulse with a .142-second duration. Some deformation of the seat is acceptable as long as the other criteria are met.

Test No. 2 is a combined vertical impact test. The seat is oriented as if the aircraft were in a 30-degree nose-down attitude and dropped vertically. This test attitude induces a combined forward and vertical crash loading. The seat impacts at 30 feet per second (9.1 m/s) with a 30G peak using a symmetrical triangular pulse with a .062-second duration. This gives a 26-foot-per-second (7.9-m/s) velocity component that is vertical relative to the aircraft floor.

The dummy would be restrained by a lap belt and a shoulder harness per SAE AS-8043. The seat cushion must be installed for all tests. The seat system must withstand this impact and stroke vertically (relative to the aircraft floor) at a 12 +1G load level. The loads experienced by the instrumented dummy must not cause serious injury. Although this test is described as a combined vertical drop test, a horizontal sled with a reoriented test seat can also be used to meet this requirement. As with Test No. 1, some seat deformation is acceptable if the other criteria are met.

Helicopter manufacturers have been developing energy attenuating seats without civil regulatory requirements or criteria. A large part of this is due to the military influence. Table 4 shows the helicopter manufacturers known to the author that have been or are involved in developing energy attenuating seats. The industry can supply acceptable energy attenuating seats; what is needed are realistic standardized regulatory requirements.

The fixed-wing and rotary-wing aircraft industries of the
United States have been deeply involved with the FAA over the last few years in developing new regulations which improve occupant crash protection. Although a common requirement for all aircraft seats would be ideal, this is not possible because vastly different types of aircraft have different crash energy absorption needs (Figure 3). Light fixed-wing aircraft and helicopters of all sizes have a common problem: limited depth of crushable structure beneath the floor. The vertical deceleration loads will be high and will require shoulder harnesses and energy attenuating seats. Conversely, the large fixed-wing transports have a large stopping distance due to the distance from floor to fuselage belly. Thus, crash survival features and criteria will be somewhat different.

Table 4 – Energy Attenuating Seats

<table>
<thead>
<tr>
<th>Aircraft</th>
<th>Military</th>
<th>Civil</th>
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<tr>
<td>Agusta</td>
<td>X</td>
<td></td>
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<tr>
<td>Aerospatiale</td>
<td>X</td>
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<td>Bell</td>
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<td>Enstrom</td>
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<tr>
<td>MD/MB</td>
<td>X</td>
<td></td>
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<tr>
<td>Sikorsky</td>
<td>X</td>
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</table>

Figure 3 – Energy Absorption Differences

Cooperation between the FAA and aviation community has fostered a coordinated FAA crashworthiness improvement program. This is important, because many aspects such as acceptance criteria related to human tolerances, are common. The following is a summary of the different industry segments and FAA activities related to improved occupant restraint.

The General Aviation Manufacturers Association (GAMA) recommended to the FAA that passenger shoulder harnesses be required on all Part 23 airplanes with nine passengers or less. GAMA further stated that their members would voluntarily make this change on all airplanes manufactured after January 1, 1985. The FAA responded with Notice of Proposed Rule Making (NPRM) 85-11. The subsequent final rule required that passenger shoulder harnesses be installed in aircraft manufactured after December 12, 1986.

The final rule under NPRM 86-19 was issued in 1988. It requires dynamically tested energy attenuating seats for future Part 23 airplanes with nine passengers or fewer.

As discussed above, the RARC Crashworthiness Project Group recommended to the FAA that future Part 27 and 29 helicopters be required to have energy attenuating seats and shoulder harnesses for all occupants. It also recommended that two dynamic seat tests be required. The FAA responded with NPRM 87-4 (9), which would require that future Part 27 and 29 helicopters have dynamically tested energy attenuating seats with shoulder harnesses. A public meeting was held in April 1988 to gather more public comments on the NPRM.

The AIA Transport Airworthiness Requirement Committee recommended to the FAA that two dynamic seat tests be required. The FAA response was NPRM 86-11, which would require two dynamic seat tests for future Part 25 large transport airplanes. The final rule was issued in 1988. NPRM 88-8, for retrofit of the improved seats in existing Part 25 airplanes, was released in 1988.

The FAA developed and released the following draft Advisory Circulars (AC) that could be used to show compliance:

AC XX.562-1 Dynamic Evaluation of XXXXXXXX Seats (Draft)
AC 21-22 Injury Criteria for Human Exposure to Impact
AC 21-X Analytical Methods in Impact Dynamics (Draft)
AC 20.XX Shoulder Harness-Seat Belt Installations (Draft)

Recently, the FAA requested SAE to develop a document for crew and passenger seats related to the new dynamic seat testing. SAE established an ad hoc seat committee to develop an SAE Aeronautical Standard on the new seats for Part 25, 27, and 29 aircraft. The intent is to have the Aeronautical Standard completed and available if the FAA elects to use it as the basis for a new TSO or AC. The committee members include representatives from large fixed-wing transport airplane manufacturers and seat manufacturers (U.S. and European), airlines, the RARC Crashworthiness Project Group, General Aviation Manufacturers Association (GAMA), the Air Line Pilots Association (ALPA), the Air Transport Association (ATA), and the FAA. The draft standard they are developing has common
showed that post-crash fires were the most serious threat to the occupants of civil helicopters. A crash-resistant fuel system (CRFS) contains fuel long enough for occupants to escape a survivable crash before a post-crash fire becomes significant. It is not expected to prevent all fires, but only to delay the sudden massive fire (fireball) until the occupants have escaped. If, for example, a small fire near the engine area gradually grows to a roaring fire in five or 10 minutes, the CRFS will have performed its function.

The RARC Crashworthiness Project Group recommended to FAA that future helicopter designs be required to have lightweight CRFS to preclude massive post-crash fires in survivable accidents. The characteristics recommended for CRFS fuel cell material are shown in the box of Table 9. Although Uniroyal and FPT materials are shown, other manufacturers make comparable materials. The CRFS should tolerate relative motion from the structural deformation occurring in a crash without allowing significant deformation.

### Time and Means to Escape

The last crash survival requirement is for time to escape and a means of doing so. Emergency exits have worked quite well, but the main threat is the lack of time to escape a massive post-crash fire. Table 1 in Part One of this series showed that post-crash fires were the most serious threat to the occupants of civil helicopters. A crash-resistant fuel system (CRFS) contains fuel long enough for occupants to escape a survivable crash before a post-crash fire becomes significant. It is not expected to prevent all fires, but only to delay the sudden massive fire (fireball) until the occupants have escaped. If, for example, a small fire near the engine area gradually grows to a roaring fire in five or 10 minutes, the CRFS will have performed its function.

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fuel spillage. The aircraft design should minimize ignition sources where practical. Table 9 shows the criteria for a standard bladder (one typical of those used under present FARs) and a military CRFS bladder shown for comparison.

The RARC Crashworthiness Project Group has concluded that military criteria are excessive and unrealistic for survivable crashes of civil helicopters. The testing methods of MIL-T-7422B (11) should be used, but the criteria should be for civil helicopters.

For the tests of Table 9, the fuel cells were drop-tested while 80 percent full. A fuel cell 80 percent full of water is equivalent in weight to one full of jet fuel. In addition, water gives the cell a severe slosh test. The vertical drop height of 50 feet (15.2 m) produces an impact velocity of 56 feet per second (17.1 m/s), which is well in excess of the 50-foot-per-second (15.2 - m/s) resultant velocity of military helicopters (4).

Fuel cell material can be punctured during the massive structural deformation of a crash. The screwdriver test results given in Table 9 indicate the civil CRFS fuel cells flying today are 15 times more puncture resistant than standard fuel cells. The importance of realistic requirements is shown in the weight increase row of Table 9.

Some CRFS have been introduced into the civil helicopter fleet voluntarily over the last few years. As far as this author knows, the civil helicopters that either have a CRFS installed as standard equipment or have a kit available are shown in Table 10. Very few kits are being sold. Apparently it will be necessary to make CRFS a mandatory requirement, not an option, if the use of this safety feature is to become widespread.

Table 9 – CRFS Material Comparison

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<tr>
<td>Drop height (H-ft)</td>
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<td>Tensile strength (ksi)</td>
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<td>Impact penetration (5 lb chisel)</td>
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<td>Screwdriver</td>
<td>NA</td>
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<td>6.7</td>
<td>6.7</td>
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Table 10 – CRFS In Commercial Helicopters

GASP II investigated the post-crash fire problem of Part 23 airplanes, and recommended to the FAA that each future Part 23 airplane designed for nine passengers or less have a CRFS that meets the following criteria:

- The wing/fuselage juncture;
- The firewall/engine-mount juncture;
- The tip tanks and wings juncture; and,
- The dry-bay area behind an engine if used to carry fuel.

GASP II also recommended that any fuel tank located in an engine nacelle or between the engine and an area occupied by either pilots or passengers, or external to the wing’s external contour (but not including tip tanks) should comply with the requirements of MIL-T-27422B, Type II, Class A, with the following exceptions from MIL-T-27422B:

- Constant tear rate — the minimum energy for complete separation shall be 20 foot-pounds;
- Impact penetration — the drop height of a five-pound chisel shall be eight feet;
- Impact tear — the drop height of a five-pound chisel shall be eight feet and the average tear shall not exceed one inch;
- Crash impact Phase I — delete; and,
- Crash impact test of full-size production test cell — the cell shall be filled to 80 percent of normal capacity with water, and the air removed. The cell shall be placed upon a platform and dropped from a height of 50 feet, without leakage after impact.
To estimate the potential effectiveness of crash survival improvements, one must have clear distinctions between known configurations. The helicopter fleet was grouped by engine (single piston, single turbine, and twin turbine) for the period from 1975 through 1979. In these three groups, the most prominent models, models 47, 206, and 212, were broken out individually as well. The accident rates for these different groups are shown in Figure 4.

Relative Risk of Serious Injury

Should the above criteria be applied to future civil helicopters that apply for type certificate under Part 27 (under 6,000 pounds (2,722 kg) gross weight) or Part 29 (over 6,000 pounds (2,722 kg) gross weight) or both? Analysis was made of NTSB accident data and FAA flight hours of existing helicopters over and under 6,000 pounds (2,722 kg) gross weight. Many of the existing helicopters were certified under Civil Aviation Regulations, CAR 6 and 7, which were the predecessors of FAR Parts 27 and 29. Both piston and turbine engines are used in each category. Accident data for the two weight classes were compared with those for single-piston-engine and twin-piston-engine fixed-wing aircraft. The results show that the accident rate for helicopters weighing more than 6,000 pounds (2,722 kg) was the lowest of the group studied and that for helicopters under 6,000 pounds (2,722 kg) was the highest.

However, a true comparison of occupant risk must consider the number of people on board, their injuries, and the accident frequency. This is simply the probability of an accident occurring multiplied by the probability of receiving a serious (major or fatal) injury. This is expressed as:

\[
R_{si} = \frac{\text{Number of Accidents}}{\text{Flight Hours}} \times \frac{\text{Number of Serious Injured}}{\text{Total Number on Board}}
\]

The Relative Risk of Serious Injury \((R_{si})\) is the likelihood that an individual will receive a serious injury per occupant flight hour. A comparison of the relative risk of serious injury for helicopters in the two weight categories and single and twin piston fixed wing aircraft shows that the occupant risk is about the same for helicopters under and over 6,000 pounds (2,722 kg), with the risk for those under 6,000 pounds (2,722 kg) being somewhat lower. Thus, newly type-certified helicopters both under and over 6,000 pounds should benefit from improved crash safety criteria.
pant flight hours. This is 68 percent less than that for a Model 212 occupant. This risk reduction penalized the weight of the Model 412 by 157 pounds (71.2 kg) — the amount by which its passenger seats, passenger restraints, and fuel system outweigh the corresponding standard items in the Model 212.

Conclusions

Future helicopter designs should have the following realistic crash safety features:

- Shoulder harness for all occupants;
- Energy attenuating seats for all occupants; and,
- A crash-resistant fuel system.

Dynamic seat testing, rather than static testing, should be used to simulate a crash.

New requirements should be introduced into initial design concepts to minimize weight increases.

Voluntary introduction of crash safety features is unlikely, due to the economic disadvantage of the added weight in a highly competitive operators’ market. Regulatory action is needed to decrease the occupant risk.

References


