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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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(From a paper presented before the Flight Safety Foundation's 34th Annual Corporate Aviation Safety Seminar (CASS) in Dearborn, Michigan, U.S., April 1989)

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 0.142-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 $\pm$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.

		Military	Civil
Agusta	A129A	X	
Aerospatiale	AS332B (Drop Test)	X	
Bell	222, 412, 214ST, AH-1, UH-1N, OH-58	X	X
Boeing	UH-61 (UTTAS Prototype) CH-47 MODS, V-22	X	
Enstrom	F-28, F280 (Kit)		X
MBB/Kawasaki	BK-117 (Being Investigated)		X
MBB	BO-105 (Being Investigated)		X
MDHC	AH-64, MD520N (Being Investigated)	X	X
Sikorsky	UH/SH-60, CH/HH-53, H/SH-3	X	

Table 4 – Energy Attenuating Seats

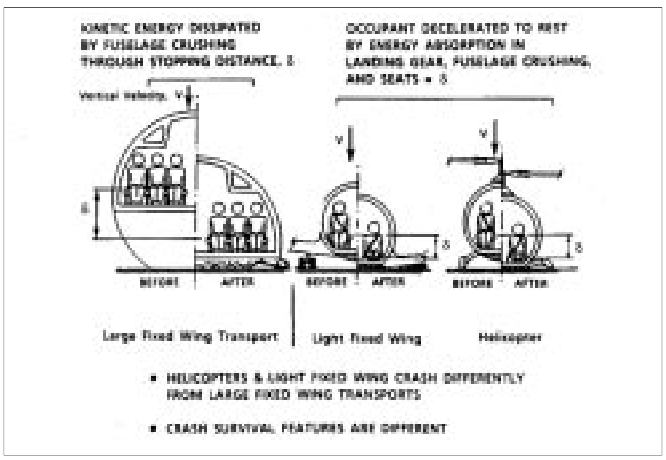

Figure 3 – Energy Absorption Differences

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 testing procedures and acceptance criteria. The impact conditions will still be unique to the specific type of seat. The goal is to have this SAE Aeronautical Standard completed in 1989.

The major changes of the NPRMs for improved seats requiring dynamic testing are discussed below. *Table 5* shows the load factors required under the original FARs (before the NPRMs). Load factors under TSO-C39A are included in parentheses. *Table 6* shows the new load factors proposed by the NPRMs. NPRMs 86-11 and 86-19 have progressed to final rule, whereas final rule on NPRM 87-4 has not yet occurred. Since helicopter seats would have significant energy attenuating seat stroke, the static load factor of 20G is only applicable after completion of the total seat stroke. During stroking, the stroking load is set at 12G.

		DIRECTION (Gs)				
FAR	TYPE	UP	FWD	SIDE	DOWN	REAR
23.561	Normal F/W	3.0	9.0	1.5 (3.0)	3.0 (7.0)	—
23.561	Acrobatic F/W	4.5	9.0	1.5 (3.0)	3.0 (9.0)	—
27.561	Normal R/W	1.5	4.0	2.0	4.0	—
29.561	Transport R/W	1.5	4.0	2.0	4.0	—
25.561	Transport F/W	2.0	9.0	1.5 (3.0)	4.5 (6.0)	—

"Items of mass that could injure an occupant if it came loose in a crash" except XX.787 items cargo. Mass items to be restrained to XX.561 loads. Occupant is 170 #. TSO-C39A ( )

Table 5 – Pre-NPRM Load Factors

The dynamic seat testing required would be consistent among Part 23, 25, 27, and 29 aircraft. All seats would be required to meet Test No. 1 (combined vertical/forward, 30 degrees nose down) and Test No. 2 (forward with 10-degree yaw). The testing methods, seat orientation, instrumented dummy, and acceptance criteria are identical. However, the testing impact conditions and seat/restraint configurations would be unique to the type of seat.

The impact conditions for the dynamic seat tests are shown in *Table 7* for the Part 23, 25, 27, and 29 aircraft. The seat attachment warpage requirement is to ensure that the seat does not detach if the floor warps or distorts during a crash sequence.

The common acceptance criteria to be used during the dynamic seat testing are shown in *Table 8*. The restraint criteria of TSO-C114 will be used. If dummy testing shows a head strike to be possible, the Head Injury Criteria (HIC) value must be less than 1,000. Part 25 seats have a unique requirement that femur loads must be less than 2,250 pounds (10,008 N).

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.

		DIRECTION (Gs)				
FAR	TYPE	UP	FWD	SIDE	DOWN	AFT
23.561	Normal F/W	3.0	9.0	1.5	—	—
	– In cabin	3.0	18.0	4.5	—	
23.561	Acrobatic F/W	4.5	9.0	1.5	—	—
	– In cabin	3.0	18.0	4.5	—	
27.561	Normal R/W	1.5	8.0	2.0	4.0	—
	– In cabin	4.0	16.0	8.0	20.0*	
29.561	Transport R/W	1.5	8.0	2.0	4.0	—
	– In cabin	4.0	16.0	8.0	20.0*	
25.561	Transport F/W	2.5	9.0	4.0	6.0	1.5
25.561	FINAL RULE	3.0	9.0	4.0	6.0	1.5

*After seat stroking

Table 6 – NPRM Load Factors

	23		27/29	25
	PILOT	OTHER ROWS		
Test #1 Combined Vertical (30°)				
Impact velocity (FPS)	31	31	30	35
Min. peak G	19	15	30	14
Time to peak (sec)	0.05	0.06	0.031	0.08
Shoulder harness	Yes	Yes	Yes	Crew Only
Vertical E. A.	Yes	Yes	Yes	No
Test #2 Forward (10° Yaw)				
Impact velocity (FPS)	42	42	42	44
Min. peak G	26	21	18.4	16
Time to peak (sec)	0.05	0.06	0.071	0.09
Seat Attach Warp				
(10° pitch & 10° lat roll)	10° Pitch*	10° Pitch*	10° Pitch & 10° Lat roll	10° Pitch & 10° Lat roll

*FINAL RULE ADDED 10° LATERAL ROLL

Table 7 – NPRM Dynamic Test Conditions

DRAFT ADVISORY CIRCULARS

XX.562-X Dynamic evaluation of XXXXXXX seats
21-22 Injury criteria for human exposure to impact
21-X Analytic methods in impact dynamics

NPRMs TEST CRITERIA

170# Part 572, Sub B, instrumented dummy (lumbar load cell)
Seat attachment warped
Crew dual shoulder belt load < 2000#
Crew diagonal shoulder belt load < 1750#
Lumbar load < 1500#
Head HIC < 1000
Each femur load < 2250# *

* Part 25 only

Table 8 – Acceptance Criteria

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 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*.

TEST / DESCRIPTION	STANDARD BLADDER US-566RL	CIVIL CRFS SAFETY CELL US-779	SAFETY CELL US-756	FPT** FPT/ CR.615	MILITARY MIL-T-27422B US-751
Drop height with No spillage (Ft)	N.A.	50 80% (Full)	50* 80% (Full)	65 (Full)	65 (Full)
Constant rate tear (Ft-lb)	N.A.	400	216.0	42	400
Tensile strength (lb)					
Warp	140	168	1717	NA	NA
Fill	120	158	1128	NA	NA
Impact penetration (5 lb chisel)					
Drop height (ft)					
Parallel / Warp	N.A.	1.2	8.5	10.5	15
45° Warp	N.A.		8.5		15
Screw driver (lb)	25	333-444	370.5	NA	NA
Material weight (lb/ft²)	.12	.36	.40	.55	1.04
Weight increase factor	1.0X	3.0X	3.3X	4.6X	8.7X
* Also dropped from 65 ft with no spillage					

**350% Elongation
NA is Not Available

Table 9 – CRFS Material Comparison

Note that the fuel cell bladder material for the civil helicopter is over 3 times heavier than today's standard material. This is considerably below the unrealistic 8.7 times weight increase for military aircraft. Going from civil CRFS criteria to military CRFS criteria only increases weight, with little or no increase in post-crash fire protection for survivable civil helicopter accidents.

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.

MANUFACTURER / MODEL	STANDARD EQUIPMENT	KIT AVAILABLE
Bell 214B	X	
Bell 206B3 (W/91 gal tank)	X	
Bell 206L-3	X	
Bell 222	X	
Bell 222B	X	
Bell 222UT	X	
Bell 412	X	
Bell 412SP	X	
Bell 214ST	X	
Boeing Vertol 234	X	
Aerospatiale AS332L Super Puma		X
MDHC 530 E		X
MDHC 530 F		X
Sikorsky S-76		X

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:

> Fuel lines designed so that no more than eight ounces of fuel spillage per fitting will occur in the junctures of lines and connections and in the following areas:
>
> • 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.

The GASP II CRFS material requirements of MIL-T-7422B, with the five exceptions listed above, are the center helicopter CRFS material of *Table 9*. The FAA has taken the recommendations of the RARC Crashworthiness Project Group and GASP II under consideration. When a CRFS is used, the structure around the fuel cell should be designed with care. Special attention should be given to minimizing the chance of puncture. It is unwise to increase fuselage strength around fuel cells beyond original requirements, as this causes fuselage disruptions elsewhere. For fuel cells under the floor, it causes floor disruption and possible release of the occupant seats. The best approach is to design the fuel cell bags to be tough and puncture resistant to contain the fuel, and to disregard any structural strength increases.

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.

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*.

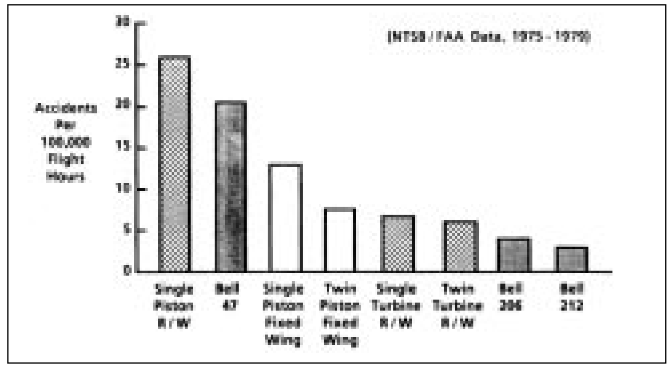

Figure 4 – G.A. Accident Rates

The single and twin-turbine helicopter accident rates were quite low. Computing the relative risk of serious injury for these groups showed that the relative risk of serious injury to occupants of a twin-turbine helicopter was 29 percent lower than that for occupants of a piston helicopter *(Figure 5)*. Likewise, the relative risk of serious injury to occupants of a single-turbine helicopter was 41 percent lower than that for occupants of a twin-turbine helicopter.

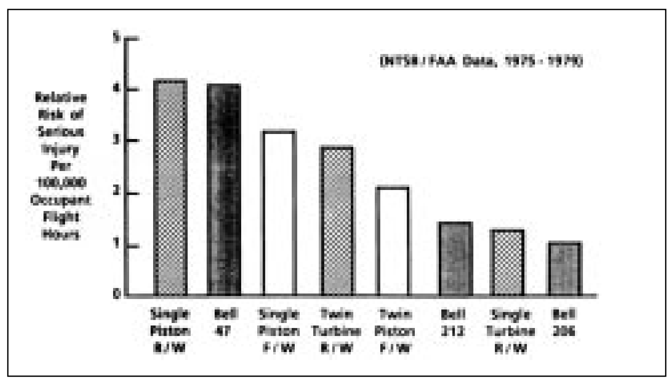

Figure 5 – Relative Occupant Injury Risk

One can best predict the improvements in crash survival by comparing similar configurations such as the Model 212 and the Model 412. Althought there are mechanical differences betweeen these models, there is no reason to expect a different accident rate at fleet maturity. The only difference is in crash safety features. The 412 has energy attenuating seats, shoulder harnesses, and a crash-resistant fuel system. Thus the relative risk of serious injury should be significantly less in a 412 than in a 212.

Since 1981, when the Model 412 was introduced in the United States, it has flown 197,907 hours. For this period, its relative risk of serious injury is 0.51 per 100,000 occupant 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.

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