ROTORCRAFT OCCUPANT PROTECTION WORKING GROUP (ROPWG)

TASK 6

FINAL ANALYSIS REPORT TO THE AVIATION RULEMAKING ADVISORY COMMITTEE (ARAC)

Revised: September 27, 2018

EXECUTIVE SUMMARY

BACKGROUND

This report contains the Rotorcraft Occupant Protection Working Group (ROPWG) Task 6 recommendations for rulemaking and other actions to improve occupant crash protection in previously manufactured helicopters. The report also contains recommendations on research programs, accident investigation data collection, recommended changes to current occupant protection regulations, recommendations regarding Public Rotorcraft, and recommendations to industry.

ROPWG TASK 6 RECOMMENDATIONS

After considerable analysis and deliberation, the Working Group has agreed on 20 recommendations to the Aviation Rulemaking Advisory Committee (ARAC) on how best to improve the crash safety of the existing fleet of rotorcraft. Many of these aircraft do not meet the current occupant protection standards since they were certified prior to implementation of the current occupant protection requirements of 27/29.561, .562, .785, and .952. Due to the technical and economic impediments to retrofitting most of the current regulations into existing rotorcraft, only a small portion of the current standards can be practically applied to existing rotorcraft.

Among the most significant hazards to personal survival in a potentially survivable crash are post-crash fire and inadequate restraint, particularly inadequate upper torso restraint. Although a very significant hazard, post-crash fire in survivable crashes can be effectively eliminated through the incorporation of crash resistant fuel bladder technology. Likewise, injuries associated with upper torso flailing in survivable rotorcraft crashes due to lack of upper torso restraint can be rectified through a requirement that appropriate upper torso restraint be provided at each seating location. The analysis in this report demonstrates that crash resistant fuel bladders and upper torso restraint can be cost-effectively installed (retrofitted) on most existing rotorcraft. These requirements would essentially eliminate post-crash fires and would greatly reduce injuries due to upper torso flailing. For these reasons, **the ROPWG strongly recommends that, where lacking, all Normal Category U.S. rotorcraft be required to install crash resistant fuel bladders and upper torso restraints, with few exceptions**. While the ROPWG does not recommend a specific set of exceptions, the ROPWG feels strongly that exceptions should not be granted to helicopters engaged in carrying passengers for hire, general commercial operations, or flight training operations.

The ROPWG also strongly recommends that proper restraint systems be provided to all rotorcraft occupants regardless of the age of the occupant. Currently, children under the age of two-years are permitted to ride in aircraft without restraint on a care-givers lap. As is the case in automobiles, since it is almost impossible to hold onto a child under abrupt loading conditions exceeding approximately 1.5-2.0 g, unrestrained children are likely to be severely injured or killed in even relatively minor crashes where an appropriate child restraint system (CRS) would have protected them from injury. While the so-called “lap child exemption” may be statistically justified in Part 121 operations (airliners), it cannot be justified in rotorcraft operations, where the overall accident rate is over 30-times that of Part 121 operations. Therefore, the ROPWG strongly recommends that the lap child exemption be withdrawn for rotorcraft and that all occupants be required to have available and use a restraint system appropriate for their age. For children under two, this would be a CRS properly installed in a fixed seat.

The ROPWG and others seeking accurate crash impact and injury data in rotorcraft crashes have been consistently impeded in their efforts by the lack of crash and injury data in crash investigation reports filed by the National Transportation Safety Board (NTSB) and the Federal Aviation Administration (FAA). This lack of data was the single most significant impediment to the ROPWG accomplishing its task of recommending effective regulatory measures and other enhancements to improve occupant protection in survivable rotorcraft crashes, since it is impossible to develop effective injury reduction countermeasures if the analyst does not know the survivability of each crash or the injuries and mechanisms of injury of the occupants involved in the crash. The ROPWG recommends that the NTSB and the FAA seek the authority and funding to increase the scope of their aircraft accident investigations to include collecting and analyzing impact and injury data. In the meantime, the ROPWG recommends that the FAA commission an extensive epidemiological study of rotorcraft crashes similar to FAA study CT-85/11 (published over 30-years ago) to update knowledge of current crash injury hazards in survivable rotorcraft crashes. This data can be used to improve the current occupant protection regulations while efforts to improve crash data collection are being implemented.

In addition to the improvements in accident investigation data collection discussed above, the ROPWG is also recommending a variety of other non-regulatory interventions to improve crash safety, including incentive programs, education, voluntary recommendations, and additional research studies. While not as direct and immediate as regulatory changes, it is believed that implementation of these additional recommendations will have a significant long-term effect on improving helicopter crash safety.

All ROPWG recommendations are summarized in Table 1.

SUMMARY

Table 1. Summary of ROPWG Task 6 Recommendations
<u>High Priority Recommendations to the FAA:</u>
1. 27/29.952(a)(1)(2)(3)(5)(6), 27/29.952(f), and 27.963(g)/29.963(b): The FAA should require, in all rotorcraft, the installation (retrofit) of crash resistant fuel bladders that meet the requirements of the 50-foot fuel cell drop test in or out of structure, and that demonstrate a minimum of 250 lb puncture resistance. Note: Some potential exceptions to this rule are discussed in the main body of the report.
2. 27/29.785(c) and (g): The FAA should require installation (retrofit) and proper usage of upper torso restraints (shoulder harnesses) in all rotorcraft seating positions in all rotorcraft. Note: Some potential exceptions to this rule are discussed in the main body of the report.
3. 27/29.785: The FAA should mandate the use of appropriate restraints for all occupants of rotorcraft, regardless of the age of the occupant. “Lap Children” should not be permitted in rotorcraft.
<u>High Priority Recommendations for Legislative Changes:</u>
1. The NTSB and the FAA should seek the authority and funding through whatever means available to increase the scope of their aircraft accident investigations to include determinations of impact conditions, occupant injuries, and injury mechanisms.
2. The FAA should recommend that Congress offer tax credits and/or other financial incentives to all rotorcraft operators for installing critical safety equipment and/or upgrading to helicopter models equipped with critical safety equipment.

Recommendations for Research/Safety Studies:
1. The FAA should conduct a comprehensive injury study, similar to that reported in FAA CT-85/11, to determine impact conditions, injuries sustained by all occupants, and occupant injury mechanisms for a large set of recent rotorcraft accidents.
2. The FAA should conduct a study to determine the need for and the potential effectiveness of supplemental restraint systems.
3. The FAA should study whether adjustable weight energy absorbers and/or energy attenuating seat cushions would provide a practicable and effective means of improving vertical energy attenuation.
4. The FAA should conduct a study to determine the appropriate capabilities for flight and impact data recording systems to enable collection of flight data as well as impact velocity, acceleration, and condition data.
5. The FAA should conduct a study to ascertain the extent to which integrating Human Factors processes and education (HRO, Just Culture, HFACS, CRM, etc.) into helicopter operations would reduce accidents and contribute to reduced injury rates in crashes.
Recommended Changes to Current Regulations/Guidance:
1. The FAA should change TSO-C80, 27/29.952(g), and 27.963(g)/29.963(b) to require tear and cut resistance as well as the presently required puncture resistance in CRFS flexible bladder constructions. Note that this recommended tear and cut resistance requirement should be limited in applicability to new designs.
2. The FAA should amend FAR 91.107 (and/or other applicable regulations) to require a passenger briefing on egress procedures in addition to the presently required briefing on the operation of restraint systems.
Recommendations to Industry:
1. Helicopter industry professional organizations should encourage the use of Personal Protective Equipment (PPE) by crew and passengers when practicable and when operational conditions indicate a potential benefit.
2. Helicopter Air Ambulance (HAA) operators should use flame resistant wraps on patients transported.
3. Insurance companies should implement incentive programs for the installation and utilization of safety enhancing equipment.
Recommendations for Near-Term Implementation by the FAA:
1. The FAA should work with existing accreditation organizations to define common safety standards.
2. The FAA and/or insurance industry should establish a standardized safety rating system for rotorcraft and rotorcraft components (e.g. Seat Systems, Fuel Systems) similar to that being used by NHTSA and IIHS for automobiles.
3. The FAA should develop a centralized information exchange to communicate rotorcraft safety and technology efforts.
Recommendations for Public Rotorcraft:
1. Public Rotorcraft associations and the FAA should use education and industry standards to promote the voluntary retrofit of Crash Resistant Fuel Systems (CRFS) and Crash Resistant Seat and Structure (CRSS) in helicopters performing Public Rotorcraft operations.
2. Public Rotorcraft associations and the FAA should use education and industry standards to promote the voluntary use of Personal Protective Equipment (PPE) in helicopters performing Public Rotorcraft operations.

DISCLAIMER

The FAA has the authority to protect deliberative, pre-decisional materials, such as advisory opinions and recommendations presented by FAA staff while reaching a final determination or position on any particular matter under FAA consideration. The meetings of this Working Group are closed, and the information shared amongst the group during the deliberative and drafting stages may be of a proprietary nature to the participants. It is therefore the understanding and practice of the Working Group that such information and documents, to the extent they exist, are to be kept confidential within the Working Group and are only for use in achieving the task assigned to the Working Group by the FAA. To allow release of these documents would discourage the open and frank discussions between the Working Group members and agency employees, impede the governmental purpose of the Working Group, and potentially violate their proprietary nature.

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LIST OF ACRONYMS

A&P	Airframe and/or Powerplant
AAMS	Area Airspace Management System
AC	Advisory Circular
ACSDG	Aircraft Crash Survival Design Guide
AMOA	Air Medical Operators Association
AOPA	Aircraft Owners and Pilots Association
APSA	Airborne Public Safety Association
APSAC	Airborne Public Safety Accreditation Commission
ARAC	Aviation Rulemaking Advisory Committee
ATD	Anthropomorphic Test Dummy (or Device)
ATSB	Australian Transportation Safety Bureau
AvCIR	Aviation Crash Injury Research
AVP	Accident Investigation and Prevention
AvSER	Aviation Safety Engineering and Research
AWB	Airworthiness Bulletin
CAMTS	Commission for Accreditation of Medical Transport Systems
CAST	Commercial Aviation Safety Team
CFIT	Controlled Flight into Terrain
CRFS	Crash Resistant Fuel System
CRM	Crew Resource Management
CRSS	Crash Resistant Seat and Structure
CVR	Cockpit Voice Recorder
DOT	Department of Transportation
EASA	European Aviation Safety Agency
EURAMI	European Aeromedical Institute
FAA	Federal Aviation Administration
FAASTeam	Federal Aviation Administration Safety Team
FDR	Flight Data Recorder
FMVSS	Federal Motor Vehicle Safety Standards
FSIMS	Flight Standards Information System
GAJSC	General Aviation Joint Steering Committee
GAMA	General Aviation Manufacturers Association
GPS	Global Positioning System
GW	Gross Weight
HAA	Helicopter Air Ambulance
HAI	Helicopter Association International
HFACS	Human Factors Analysis & Classification System
HFDM	Helicopter Flight Data Monitoring
HRO	High Reliability organization
IAW	In Accordance With
IHST	International Helicopter Safety Team
IIHS	Insurance Institute for Highway Safety

IS	Intervention Strategy
ISBAO	International Standard for Business Aircraft Operations
JCABS	Joint Cockpit Air Bag System
LARS	Light Aircraft Recording Systems
LSA	Light Sport Aircraft
MAC	Management Advisory Council
MGTOW	Max Gross Take-Off Weight
MOPS	Minimum Operational Performance Standards
NAAMTA	National Accreditation Alliance Medical Transport Applications
NASA	National Aeronautics and Space Administration
NASS-CDS	National Automotive Sampling System-Crashworthiness Data System
NCAP	New Car Assessment Program
NEMSPA	National Emergency Medical Services Pilots Association
NHTSA	National Highway and Transportation Safety Administration
Nij	Neck injury criteria
NPRM	Notice of Proposed Rule Making
NTSB	National Transportation Safety Board
OEM	Original Equipment Manufacturer
PAO	Public Aircraft Operations
PCF	Post-Crash Fire
PMA	Product Manufacturing Authority
ROPS	Runway Overrun Protection System
ROPWG	Rotorcraft Occupant Protection Working Group
SAIB	Safety Airworthiness Information Bulletin
SME	Subject Matter Expert
SPS	Standard Problem Statement
STC	Supplemental Type Certificate
USHST	U.S. Helicopter Safety Team

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INTRODUCTION

ROPWG TASKING

The Federal Aviation Administration (FAA) amended regulations 14 CFR 27/29.561, 27/29.562, 27/29.785, and 27/29.952, to incorporate occupant protection rules, including those for emergency landing conditions and fuel system crash resistance, for new type designs in 1989 and 1994, respectively. These rule changes do not apply to newly manufactured rotorcraft with older type designs or to derivative type designs that keep the certification basis of the original type design (i.e., CAR 6).[1] This approach has resulted in a low incorporation rate of occupant protection features into the U.S. rotorcraft fleet. At the end of 2014, 16% of the U.S. fleet met the crash resistant fuel system requirements effective 20 years earlier, and 10% met the emergency landing requirements effective 25 years earlier.[2] A recent FAA fatal accident study demonstrated that these measures would have been effective in saving lives if they had been incorporated into all newly manufactured helicopters years ago.[3] At the present rate of incorporation of these requirements into the U.S. helicopter fleet, it will be decades before the majority of rotorcraft provide the level of occupant protection afforded by compliance with the current regulations that were established over 20 years ago.

The so-called "grandfathering" of newly-manufactured aircraft from the requirements of new regulations is based upon 14 CFR Part 21.51, which states that a Type Certificate (TC) is effective until surrendered, suspended, revoked or a termination date is otherwise established by the FAA. There is no Part 21 requirement to update a Type Design after approval and issuance of a Type Certificate. A Type Certificate permits the manufacture of the specified design forever, except when special retroactive requirements defined in 23/25/27/29.2 are promulgated. The FAA has only used this process once with Part 27 and Part 29 rotorcraft, which was to mandate safety belts and shoulder harnesses for each rotorcraft manufactured after September 16, 1992.

On November 5, 2015, the FAA tasked the Aviation Rulemaking Advisory Committee (ARAC) to provide recommendations regarding occupant protection rulemaking in normal and transport category rotorcraft for older-certification basis type designs that are still in production (legacy rotorcraft). The Rotorcraft Occupant Protection Working Group (ROPWG) was established on December 22, 2015, to study various issues related to bringing all newly-manufactured rotorcraft into compliance with current FAA occupant protection regulations, specifically 27/29.561, .562, .785, and .952, and to provide recommendations on these issues to the ARAC.[4] After completing these recommendations, the ROPWG was further tasked to develop recommendations regarding retroactive application of these standards to the existing fleet of previously manufactured rotorcraft.

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[1] Although this report refers to Parts 27 and 29 specifically, the reader is advised that ROPWG recommendations apply to all rotorcraft with older type designs or to derivative type designs that keep the certification basis of the original type design such as CAR 6.
[2] Federal Register Notice. FAA. Aviation Rulemaking Advisory Committee—New Task. Vol.80 (214), November 5, 2015, Notices.
[3] Roskop, L. Post-crash fires and blunt force fatal injuries in U.S. registered type certificated rotorcraft, CAMI Injury Mechanism Workshop, Presented November, 2015.
[4] Federal Register, op. cit., 2015.

The ROPWG was given a number of sequential tasks to accomplish in meeting their obligations. The first tasking (Tasks 1 and 2) was to provide a cost-benefit analysis of fully implementing current occupant protection regulations into all newly-manufactured rotorcraft. This report was submitted to the ARAC in November 2016, unanimously accepted by the ARAC in December 2016, and forwarded to the FAA.

On January 25, 2017, the FAA further tasked the ROPWG with the following:

> *"...make recommendations on which Paragraphs of each Section for the existing occupant protection standards cited in the referenced FR Notice can be made effective for newly manufactured rotorcraft within 3 years after the effective date of a change to §§ 27.2 and 29.2. Additionally, the FAA tasks the ROPWG to make recommendations for full compliance to these occupant protection standards within 10 years (7 additional years) after the effective date of a change to §§ 27.2 and 29.2."*

On January 27, 2017, the ROPWG was additionally tasked with providing:

> *"...an interim report to the ARAC containing initial recommendations on the findings and results related to 14CFR27/29.952 crash resistant fuel system standards by May 15, 2017. This report would be supportive of the FAA's response to the Congressional Requirements Section 2105 of the FAA Extension, Safety, and Security Act of 2016. The FAA is requesting interim proposals with respect to crash resistant fuel systems and understands that a complete recommendation report is expected 12 months after initiation of Task 3, which would be January 25, 2018."*

The ROPWG submitted the requested interim report on its preliminary recommendations on incorporating current Crash Resistant Fuel System (CRFS) standards into all newly-manufactured, legacy rotorcraft on May 11, 2017. This interim report was accepted by the ARAC on June 8, 2017 at its quarterly meeting and forwarded to the FAA.

Since the FAA request to submit an interim report on CRFS in May 2017 required the ROPWG to initially work on CRFS and report on fuel systems independent of seats and structure for the interim report, it was more convenient for the ROPWG to continue reporting separately on CRFS and Crash Resistant Seat and Structure (CRSS). Also, since there were significant differences in the available accident data for CRSS and CRFS requiring different analytical methods, it made sense to continue with a two-report format. Therefore, the ROPWG requested and was granted permission to provide separate final reports for recommendations on incorporating current CRFS and CRSS standards into newly-manufactured, legacy rotorcraft. The ROPWG Task 5 reports were delivered to the ARAC in late January 2018 and approved at the ARAC March 15, 2018, quarterly meeting.

The current report is the ROPWG report of its Task 6 recommendations relating to incorporating rotorcraft occupant protection improvements and standards into the existing rotorcraft fleet. Specifically, the Federal Register announcement requested the following after the FAA accepted the ROPWG Task 5 reports:

> *"Specifically advise and make written recommendations on incorporating rotorcraft occupant protection improvements and standards into the existing rotorcraft fleet…or [incorporating] new alternative proposed performance-based regulations."*

In making the requested recommendations, the ROPWG considered regulatory approaches as well as a gamut of other potential interventions not directly involving changes in regulations.

All ARAC-approved ROPWG recommendation reports are available on the FAA website at: https://www.faa.gov/regulations_policies/rulemaking/committees/documents/index.cfm/committee/browse/committeeID/1.

Appendix A lists the members of the ROPWG and their affiliations.

SETTING

In Tasks 3-5, the ROPWG examined and recommended regulatory actions for legacy rotorcraft that are still in production. The current task is to make recommendations for occupant protection regulations or other interventions intended to increase the crash survivability of the existing rotorcraft fleet. This involves the vast majority of the current fleet since only about 10-16% percent of that fleet met current occupant protection standards in 2014.

Appendix B provides a listing of currently registered U.S. rotorcraft by aircraft make and model and also provides the number of each model registered as well as the percentage of registered helicopters it comprises. This data allowed the ROPWG to determine what types of rotorcraft and how many would potentially have to be considered in Task 6. Approximate annual flight hours of US registered rotorcraft by helicopter category are provided in Appendix I to give an estimate of the relative exposure of each category of helicopter.

Considering the scope of this task and the complexity of applying current occupant protection standards to existing rotorcraft, the ROPWG felt it would be helpful to many readers if it provided a brief synopsis of the history of occupant protection in rotorcraft as well as a brief technical discussion of the underlying principles of occupant protection in crashes, the need for increased occupant protection, and issues related to the implementation of these concepts into current and future rotorcraft.

HISTORICAL DEVELOPMENT OF EMERGENCY LANDING CONDITIONS

Prior to 1989, emergency landing conditions were defined in 27/29.561. There was no dynamic seat rule and static requirements for the seats and surrounding structure were only 4g forward and 4g downward. The Rotorcraft Regulatory Review Conference in December 10-14, 1979, recommended the FAA increase these requirements to 20g forward as well as include more stringent design standards. Many programs and studies, including Report DOT/FAA/CT-85/11, "Analysis of Rotorcraft Crash Dynamics for Development of improved Crashworthiness Design Criteria" were published in the 1980's. These studies and FAA research resulted in proposals to amend both normal and transport category rotorcraft standards, culminating in the creation of 27.562 and 29.562, which included:

1. Addition of two specific emergency landing dynamic impact design standards for Normal Category rotorcraft seats and occupant restraint systems. Each condition is related to a potentially survivable impact condition measured at the rotorcraft floor and seat attachment, and includes respective performance standards.
2. Addition of a standard requiring use of a standard Anthropomorphic Test Dummy (ATD), also part of 27.562 and 29.562.
3. Addition of performance standards for human impact injury criteria.

In conjunction with the added dynamic seat system requirements, 27.561 and 29.561 were updated with a corresponding increase in the static design load factors by 170 to 300 percent for the seat and occupant restraint systems as well as items of mass in the cabin that could injure an occupant if they entered occupant space. As an example, the prior 4g ultimate forward load factor would be increased to 16g, ultimate. The static design standards would supplement the dynamic impact standards proposed and would identify and thereby provide for correction of possible problems in the seat, safety belt and shoulder harness, and airframe interface prior to dynamic testing. Additional changes included increasing the static design forward load factor for restraining the rotors and other items of mass above and aft of the cabin that may injure an occupant if the object came loose in an emergency landing. 27.785 and 29.785 were also modified to require a safety belt and shoulder harness, either single or double strap, for each occupant regardless of seat location and orientation in the rotorcraft.

These rule changes took effect on December 13, 1989. There was an expectation that these increased safety regulations would be implemented in new and derivative aircraft in a timely fashion. As described above, implementation has been considerably slower than anticipated primarily due to the very long life of many older model rotorcraft, which aren't required to incorporate the new safety regulations.

At the same time as this rulemaking was being completed, the FAA initiated a separate rulemaking project responding to recommendations of the NTSB as well as commenters to the 1989 rulemaking relative to mandating shoulder harnesses in production rotorcraft. This was accomplished through 27.2 and 29.2, which mandated for each rotorcraft manufactured after September 16, 1992, each applicant must show that each occupant's seat is equipped with a safety belt and shoulder harness.

27/29.561 were modified in 1996 to include rearward static loads and higher g-requirements for heavy items located above and behind the cabin. 27/29.562 were modified in 1997 to address issues of sidewall attachment of seats. This was considered a non-substantive change to the rule language.

With the adoption of Amendment 27-30/29-35 in November 1994, the FAA completed separate rulemaking requiring that crash resistant fuel systems be incorporated in all newly certificated rotorcraft. These requirements were detailed in 27/29.952 and, as discussed in the ROPWG Task 2 and Task 5 reports, have been extraordinarily successful in preventing post-crash fires both in survivable and non-survivable crashes of rotorcraft equipped with fully- or partially-compliant crash resistant fuel systems.

SURVIVABILITY

The concept of "survivability" is an extremely important, and often misunderstood, concept, which is fundamental to the development of appropriate occupant protection technology and standards. For analytical purposes, crashes are generally classified according to the survivability of the crash. To be survivable, a crash must meet two basic criteria:

1. The forces involved in the crash and transmitted to the occupants must be within the limits of human tolerance to abrupt acceleration without serious injury.
2. The structure within an occupant's immediate environment must remain substantially intact and provide a livable volume throughout the crash sequence accounting for elastic deformation as well as plastic deformation.[5]

Human tolerance to abrupt acceleration is a field in itself, but general guidelines and tolerances for a restrained human were primarily established through the work of John Stapp in the 1940s and 1950s and summarized by Eiband in 1959 and later by Snyder.[6,7] These limits have been used by aircraft designers for decades and have proven to be substantially correct in their application to current, practical, aircraft crashworthiness designs. The concepts and limitations to the derived human tolerances are summarized by Snyder as well as in the *Aircraft Crash Survival Design Guide*.[8] However, these tolerance limits have recently been shown by research on racecar crashes to understate actual human tolerance to abrupt impact when the occupant is ideally restrained and surrounded by relatively non-deformable structures exemplified by the six- to eight-point restraint systems and "bathtub" surrounding structures utilized by current Indianapolis and other racecars.[9] Although very effective and practical in the racecar environment, such designs are not practical for most aircraft.

The second element of survivability is that structure in occupied areas must be maintained throughout the crash sequence. This caveat is somewhat obvious in that it is unlikely an occupant of a crash will survive if the cabin or structures supporting high mass items collapse upon him/her during a crash. Since "collapse" is a relative term, to consider the crash as survivable, the military uses a limit guideline of no more than 15% dynamic (i.e., transient, or elastic) deformation of the structures in occupied areas of the aircraft.[10] National Aeronautics and Space Administration (NASA) crash tests have demonstrated that elastic deformation within the cabin can instantaneously reduce the livable volume to near zero and rebound to less than 15% permanent or residual deformation.[11,12] Consequently, investigators must be cautious in making determinations of structural deformation in a crash and be acutely aware that

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[5] Coltman, J. W. et al. Aircraft Crash Survival Design Guide, Volume II. Aviation Applied Technology Directorate, U.S. Army Aviation Research and Technology Activity (AVSCOM), USAAVSCOM TR 89-D-22B, 1989.
[6] Eiband, A. M. Human tolerance to rapidly applied accelerations: a summary of the literature. National Aeronautics and Space Administration, NASA Memo 5-19-59E, 1959.
[7] Snyder, R. G. Human impact tolerance. Society of Automotive Engineers, 700398, 1970.
[8] Coltman, op cit.
[9] Melvin, J. W. et al. Biomechanical analysis of Indy race car crashes. Society of Automotive Engineers, #983161, 1998.
[10] Shanahan, D.F. Human tolerance and crash survivability. NATO Research and Technology Organization, RTO-EN-HFM-113, 6-1 to 6-16, 2004.
[11] Hayduk, R.J. Comparative Analysis of PA-31-350 Chieftain (N44LV) Accident and NASA Crash Test Data. NASA Technical Memorandum 80102, 1979.
[12] https://www.youtube.com/watch?v=O1yWkbJuqkE

residual deformation after the crash may be misleading. Fortunately, extreme elastic deformations frequently leave telltale signs such as buckling marks on pillars and fractured glazing, both of which can be observed by a knowledgeable investigator.

Based upon the above two criteria, a crash may be classified as "survivable" or "non-survivable". Since forces in a crash and local deformation of structures may differ in different occupied areas of the cockpit or cabin, particularly in large airframes, a crash may also be classified as "partially-survivable." A crash where both survivability criteria are met for some occupants, but not for others may be considered a partially-survivable crash.

Probably the most important factor to recognize in the definition of survivability is that the determination of survivability of a particular crash is made entirely independent of the outcome of the occupants. Because of the variability of tolerance from one individual to the next, it is possible to have a survivable crash where all the occupants die or a non-survivable crash where all the occupants survive. For this reason, some authors prefer to classify crashes as "potentially" survivable indicating that a young, healthy individual would be expected to survive this crash, but that others may not because of extremes of age, pre-existing medical conditions, or other factors known to affect tolerance to abrupt impact.

Separating the determination of survivability from actual individual outcomes allows investigators to focus on mismatches between actual and expected outcomes in a crash. When a healthy individual is killed or seriously injured in a survivable crash, it suggests that some design factors within that aircraft such as cabin strength, anchoring strength of high-mass items, fuel system design, or seat and restraint systems designs were inadequate to protect the occupants in a crash that would have otherwise been non-injurious. These identified deficiencies can then be targeted for correction through either improved design, improved regulations or both. Likewise, when individuals survive non-survivable crashes, it may lead investigators to identify a particular design feature or technology that provided unexpectedly good protection and that should be further evaluated for incorporation into other aircraft.

As critical as the determination of detailed injury mechanisms and the survivability of crashes (crash dynamics) is to improving crashworthiness of aircraft, neither the NTSB nor the FAA usually determine survivability or injury mechanisms in the rotorcraft crashes they investigate. Consequently, analysts who wish to estimate survivability of a particular crash recorded in the NTSB database must rely on surrogate indicators of impact conditions irregularly contained within the investigation docket to make an estimate of survivability.

As an example, the ROPWG, in its Task 2 Report, estimated survivability of a group of crashes based upon the criteria listed in Table 2. In this case, severity level 1 and 2 were considered "survivable". Severity 3 was considered "partly survivable" and severity 4 was "non-survivable". Although this technique is not as accurate and refined as making actual measurements of survivability parameters during the initial investigation of the crash, analysts using similar criteria as used by the ROPWG have proven that such methods can be quite accurate.[13] The major deterrents to the effectiveness of this surrogate methodology of determining survivability are that the NTSB database does not provide in all

[13] Coltman, J.W., Bolukbasi, A.O., Laananen, D.H., op. cit. Analysis of rotorcraft crash dynamics for development of improved crashworthiness design criteria. Department of Transportation, Federal Aviation Administration, DOT/FAA/CT-85/11, June 1985.

its dockets sufficient data to make a determination of survivability and this alternative method is very labor intensive for the analysts.

Table 2. Definition of Accident Severity Levels Utilized for the CRFS Review		
Severity	**Description**	**Details/Example**
0	Non-crash	Rotorcraft normal landing after damage to the rotorcraft.
1	Minor	Hard landing where the landing gear does not fully collapse and the rotorcraft remains upright. Most autorotation accidents would fall in this category.
2	Moderate	Enough crash energy to fully collapse the landing gear and cause some fuselage crush, and/or any crash with a rollover or tipping on the side.
3	Severe	Significant impact energy and fuselage crush. Occupant living volume is maintained for at least one occupant.
4	Extreme	High-energy impact where volume is compromised for all occupants. An example would be Controlled Flight into Terrain (CFIT). This level of crash severity is often called "non-survivable."

BRIEF HISTORY OF OCCUPANT PROTECTION CONCEPTS IN AIRCRAFT DESIGN

Initial powered aircraft designs provided little or no protection to occupants in a crash. The early bi-planes designed primarily by the Wright Brothers and Glenn Curtis were "pusher" designs where the engines and propellers were at the rear of the aircraft, behind the pilot who was at the front of the lower wing. In the Wright Flyer, the pilot lay prone at the forward edge of the bottom wing apparently with no restraint and no protective structure around him. This would expose the pilot to direct impact with the ground or surface objects such as trees or manmade structures in a forward impact.[14] Subsequent early designs continued to provide little protection to pilots and passengers, but later aircraft incorporated tractor propulsion designs with the engine and propeller in front of the pilot and the pilot seated in a rudimentary cockpit behind the engine. This configuration was introduced due to its greater efficiency compared to pusher designs. It also, inadvertently, afforded the pilot much better protection in relatively minor crashes. About this same time, seat belts were introduced, not for crash protection, but to retain pilots inside the aircraft during inverted aerial maneuvers. According to Hugh De Haven of the Cornell University Crash Injury Research Center, during the period between World War I and II, "almost no deliberate engineering consideration was given to crashworthiness as a safety factor in aircraft design". What safety improvements were made were mostly singular or the fall out of changes made for other reasons rather than from a systematic attempt to improve crash safety.

As far as can be determined, in the late 1940s and early 1950s, De Haven was the first to articulate the importance of a comprehensive system design for protecting occupants of airplanes in crashes. He was also the first to widely use the term "crashworthy" referring to aircraft and component designs that provided a degree of occupant protection in a crash. Whether he actually coined the term could not be determined. De Haven viewed the problem of protection of occupants in automobile and airplane crashes as being analogous to the problem packaging engineers faced in protecting products that have to be transported from factory to distributor to seller ("goods in-transit"). He cited four basic principles in proper packaging:

[14] De Haven, H. Accident survival – airplane and passenger car. Society of Automotive Engineers, #716, January, 1952.

1. "…the package should not open up and spill its contents and should not collapse under expected conditions of force and thereby expose objects inside to damage."
2. "…packaging structures which shield the inner container must not be made of brittle or frail materials; they should resist force by yielding and absorbing energy applied to the outer container so as to cushion and distribute impact forces and thereby protect the inner container."
3. "…articles contained in the package should be held and immobilized inside the outer structure…by interior packaging. ...for it prevents movement and resultant damage from impact against the inside of the package itself."
4. "…the wadding, blocks or means for holding an object inside a shipping container must transmit the forces applied to the container to the strongest parts of the contained objects".

The next major steps in developing occupant crash protection occurred in the 1950s through the 1970s through research and development efforts sponsored primarily by the U.S. military. This research was initially sponsored through Cornell University, Aviation Crash Injury Research (AvCIR) Division under Hugh De Haven.[15] AvCIR conducted numerous full-scale crash tests of both fixed wing and rotary wing aircraft and various protective components. This research became focused primarily on helicopters as a result of helicopter crash casualties occurring in the Vietnam War. This research provided the basis for modern crash resistant helicopter designs as expressed in the compendium known as the Aircraft Crash Survival Design Guide (ACSDG). The first edition of the ACSDG was published in 1967 and updated in 1979 and 1989. Significantly, the ACSDG was the basis for the crashworthiness design criteria for the Army's UH-60 Blackhawk and AH-64 Apache helicopters, the first helicopters built to rigorous crashworthiness design standards. The ACSDG also was the basis for the first military design standard related to crashworthiness, Mil-STD-1290, Light Fixed- and Rotary-Wing Aircraft Crashworthiness and subsequent, more directed, military crashworthiness standards.[16]

Beginning in the 1980's, the FAA commissioned research to adapt military crashworthiness standards to the civil helicopter fleet and incorporated these modified standards into the current FAA occupant protection regulations in 1989 and 1994.

CRASHWORTHINESS PRINCIPLES

Not too surprisingly, the primary principles of crashworthiness design enumerated by De Haven almost seventy-years ago are equally valid today. Crashworthiness is defined as the ability of an aircraft and its internal systems and components to protect occupants from injury in the event of a crash. An important point to stress is that effective crashworthy designs require a systems approach. The precise relationship between a particular helicopter design and crash injury is complex and engineering interventions may be quite intricate. However, the basic principles of crash protection are quite straightforward, even intuitive as observed by De Haven in his enumeration of packaging principles.[17]

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[15] Administration of AvCIR was transferred to the Flight Safety Foundation and AvCIR physically moved to Phoenix, Arizona beginning in 1957. The organization underwent a name change to Aviation Safety Engineering and Research (AvSER) in 1963 and was acquired by Dynamic Science, Inc., in 1968.
[16] Singley, G.T. III. Military Standard 1290…Climaxes 15 years of aircraft crash safety research. U.S. Army Research and Development News Magazine, May-June 1975.
[17] De Haven, op. cit.

For simplicity, current concepts of crashworthiness are frequently summarized by the acronym "CREEP" as defined below:[18]

C – Container
R – Restraint
E – Energy Absorption
E – Environment (Local)
P – Post-Crash Factors

Note that the first four factors are identical to the first four principles cited by De Haven. The fifth principle was created because an aircraft "package" contains living individuals and not "goods for transit." An occupant of a crashed aircraft, unlike goods, must continue to survive after the crash, where post-crash factors such as fire, water, climate and other external exposures frequently challenge that survival. Below are brief descriptions of each of the CREEP factors.

Container

The container is the occupiable portion of the helicopter -- the cockpit and cabin. It should possess sufficient strength to prevent intrusion of structure into occupied spaces during a survivable crash, thus maintaining a protective shell around all occupants. Since structural collapse causing severe contact injury is a frequent injury hazard encountered in helicopter crashes, this point cannot be overemphasized. The container must also be designed to prevent penetration of external objects into occupied spaces. Another consideration related to the container is high-mass item retention. Transmissions, rotor systems, and engines should have sufficient tie-down strength to ensure that they do not break away and enter occupied spaces in survivable crashes. Finally, the floor and the nose of the helicopter should possess sufficient structural strength and be shaped so as to prevent plowing or scooping of earth during crashes, since plowing decreases stopping distances resulting in higher decelerative loads as well as increasing structural deformation. In general, cockpit/cabin designs should allow for no more than 15 percent dynamic (i.e., transient) deformation when subjected to the design crash pulse.

Restraint

A frequent occurrence in military helicopter crashes is that either the seat tears from its attachments or the restraint system fails. This results in complete or partial ejection of the occupant or it allows him/her to strike injurious objects. The frequency of this hazard in current civil helicopter crashes is unknown but one report of civil helicopter crashes identified this mechanism as among the top 10 hazards in survivable helicopter crashes.[19] Regardless of the strength of the container, if the occupant is not appropriately restrained throughout the crash sequence, his/her chances of survival are severely reduced. Seats, restraint systems, and their attachments should have sufficient strength to retain all occupants for the maximum survivable crash pulse. Additionally, seat attachments should be designed to accommodate significant degrees of floor warpage without failure.

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[18] Shanahan, D.F. Basic Principles of Helicopter Crashworthiness. U.S. Army Aeromedical Research Laboratory, USAARL Report No. 93-1, 1993.
[19] DOT/FAA/CT-85/11, *Analysis of Rotorcraft Crash Dynamics for Development of Improved Crashworthiness Design Criteria*, June 1985.

Since blunt force injuries occur at least five times more frequently than acceleration injuries in helicopter crashes, careful consideration should be given to restraint system design.[20] In small aircraft with confined interiors (most helicopters), both lap belt and upper torso restraint are essential for protection of crew and passengers. Not only does upper torso restraint reduce upper body flailing and contact with interior structures, it also provides for greater distribution of acceleration loads across the body than a lap belt only. A tie-down strap (crotch strap) incorporated into the restraint system helps reduce the potential for "submarining" without increasing the potential for injury. Submarining is a situation where the lap belt rides up above the bony structure of the pelvis and compresses the soft organs of the abdomen. This frequently results in serious abdominal injury or spinal distraction fractures. Many so called "seat belt injuries" can be attributed to this mechanism.

As an adjunct to standard belt-type restraint systems, more consideration should be given to the adoption of air bag systems or other supplemental restraints into rotorcraft. As in the automobile, these systems have tremendous potential for reducing the incidence of flailing injury and should be economically adaptable to civil rotorcraft applications.

Energy Absorption

Unlike large transport aircraft, helicopters and other small aircraft provide little crushable structure to attenuate crash forces, particularly on the underside of the aircraft. Since most helicopter crashes involve substantial vertical forces, additional means of absorbing crash forces in the vertical direction is necessary to prevent acceleration injury in survivable crashes of most helicopters.[21]

In general, there are three locations where vertical energy absorbing capability may be integrated into a helicopter design--the landing gear, floor structure, and seats. Some military helicopters rely heavily on fixed landing gear to provide the required attenuation of loads to meet vertical design pulse requirements. However, they are not generally practical for civil helicopter models due to their weight and the proliferation of retractable landing gear rotorcraft. Also, stroking gear are defeated in crashes into water or very soft ground. As noted above, most helicopters have very little under-structure making most concepts incorporating energy attenuation into the floor impractical.

This generally leaves energy absorbing seats as the most practical solution for vertical energy attenuation in civil rotorcraft. Energy attenuating seats have been extremely effective in preventing acceleration injury in crashes with predominately vertical force vectors. Numerous designs are now available through a number of manufacturers. Experience with these seats in crashes has produced several lessons. First, it is essential that seats have adequate tie-down strength so that they are not dislodged by crash forces. Second, designs that provide multi-axis stroking have not been as effective as those providing pure vertical stroking since they increase the head flail in an already confined interior. Third, the average load level for vertically stroking seats should not exceed 11-12 g for civil helicopters in order to accommodate the wide range of potential occupants in terms of age, weight and physical condition.[22] Finally, it is imperative that adequate stroke distance be provided to preclude "bottoming

[20] Shanahan (1993), op. cit.
[21] Coltman, op. cit.
[22] Coltman, J.W. et al. Crash-resistant crewseat limit-load optimization through dynamic testing with cadavers. U.S. Army Aviation Systems Command, USAAVSCOM TR 85-D, 1986.

out" of the seat on structure for survivable crashes since this situation may result in extremely high acceleration spikes that can lead to spinal injuries. As a point of interest, at least one manufacturer provides seats that have a variable-load energy absorber so that the seat may be adjusted to accommodate different weight occupants. This feature has considerable potential advantage where the weights of occupants vary significantly.

Local Environment

In designing an aircraft interior, it is important to consider the local environment of the occupants at all potential seating locations. A person's local environment refers to the space that any portion of his/her body may occupy during dynamic crash conditions. Any object within that space may be considered an injury hazard. The volume of that space will vary depending on the type restraint system anticipated and, to a lesser extent, on the anthropometry of the anticipated occupants. The maximum head strike flail is reduced by about 50% when upper torso restraint is utilized. Clearly, the primary concern must be for hazards within the strike zone of the head and upper torso, but objects within the strike zone of the extremities should also be considered.

It is important to consider the local environment of occupants during the design phase of an aircraft since many potentially hazardous objects may be placed outside of the strike zone if they are recognized early as hazards. In many cases, placing hazardous objects outside of the strike zone is no more expensive or difficult than placing them within the strike zone. It is simply a matter of recognizing the hazard. Potentially injurious objects that cannot be relocated can be designed to be less hazardous, padded, or made frangible.

Post-Crash Factors

Numerous aircraft accident victims survive the crash only to succumb to a post-crash hazard. These hazards include fire, fumes, fuel, oil, and water. Both civil and military crash experience has sadly shown that the most serious hazard to survival in helicopter crashes is post-crash fire. The design challenge is to provide for the escape of occupants after the crash under a host of adverse conditions. The approach may either be to control or eliminate the hazard at the source, to provide for more rapid egress, or a combination of both.

In the case of post-crash fire, controlling the hazard at the source has proven to be an extremely effective strategy for helicopters. A study performed in 1989 demonstrated that since the U.S. Army introduced CRFS into its helicopter fleet in the 1970's, there had been only one fire-related death in a survivable crash.[23] Prior to the introduction of CRFS, up to 40 percent of deaths in survivable crashes of U.S. Army helicopters were attributed to fire.[24] As noted in previous reports, the ROPWG has documented a similar level of effectiveness of CRFS in civil helicopters.

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[23] Shanahan, D.F. and Shanahan, M.O. Injury in U.S. Army helicopter crashes October 1979-September 1985. J. Trauma, 29(4): 415-422, 1989.

[24] Haley, J.L., Jr. Analysis of U.S. Army helicopter accidents to define impact injury problems. In: *Linear acceleration of the impact type,* Neuilly-sur-Seine, France: AGARD CP 88-71, 1971, pp. 9-1 to 9-12.

Other strategies employed to prevent the consequences of fire and fumes are to use fire retardant and low toxicity materials in the construction of aircraft and to provide physical separation of flammable materials from ignition sources and occupied areas.

For overwater operations, the most important post-crash hazard is drowning. Because of their high center-of-mass, most helicopters rapidly invert and sink upon water entry whether the entry is controlled or uncontrolled. A high proportion of victims involved in water landings or crashes drown because they are unable to egress. Solutions to this problem have included use of helicopter flotation devices, improvements in interior emergency lighting, increased number of emergency exits, personal underwater breathing devices, and, most importantly, intensive underwater egress training programs.

OVERVIEW OF ROPWG TASK 6 ANALYSIS AND RECOMMENDATIONS

TASK 6 DESCRIPTION

The ROPWG was tasked to recommend means of improving occupant protection in existing helicopters. Specifically, the ROPWG was charged by the ARAC to "complete the following after the FAA accepts the initial recommendation report identified in Task 5":

> *"Specifically advise and make written recommendations on incorporating rotorcraft occupant protection improvements and standards into the existing rotorcraft fleet…or new alternative proposed performance-based regulations."*

As with previous tasks, the ROPWG was admonished to document both majority and dissenting positions on the majority findings and the rationale for each dissenting position.

ORGANIZATION OF ANALYSIS AND RECOMMENDATIONS

In light of the occupant protection principles described above and in consideration of current regulations and available technology, the ROPWG divided the Task 6 analysis and recommendations into two categories:

- Recommendations regarding the incorporation of existing rotorcraft occupant protection regulations (27/29.561, .562, .785, .952) into the existing rotorcraft fleet.
- Additional recommendations not related to requiring the incorporation of existing regulations.

These recommendation categories are summarized below, and then discussed in depth in the sections that follow.

<u>Incorporation of Existing Rotorcraft Occupant Protection Regulations</u>

The ROPWG recommendations related to the incorporation of existing rotorcraft occupant protection regulations are analyzed and discussed in a similar manner to that of the previous ROPWG Task 5 reports, and include discussion of the following:

- Analysis methods
- Cost estimation
- Benefit estimation
- Cost/Benefit analysis
- ROPWG recommendations

Recommendations Unrelated to Incorporation of Existing Rotorcraft Occupant Protection Regulations

In its deliberations to develop its Task 6 recommendations, the ROPWG not only considered potential regulatory interventions, but also more novel approaches to improve crash protection in the existing fleet including:

- Educational or incentive approaches
- Development/adoption of industry standards
- Recommendations for use of personal protective equipment (PPE)
- Recommendations for new research or analysis
- Considerations for Public Rotorcraft
- Consideration of improvements to existing rotorcraft occupant protection regulations
- Changes to current law related to aircraft accident investigation
- Means of funding enhanced occupant protection in the existing rotorcraft fleet

The ROPWG was not able to estimate costs and benefits for this set of recommendations. The ROPWG's decision to recommend (or not recommend) these interventions was based on its perceived effectiveness given the experience of similar approaches taken in other fields or other modes of transportation.

ANALYSIS OF INCORPORATION (RETROFIT) OF EXISTING ROTORCRAFT OCCUPANT PROTECTION REGULATIONS INTO THE EXISTING ROTORCRAFT FLEET

In the ROPWG Task 5 reports, the ROPWG presented an analysis of the estimated cost and benefit of requiring the incorporation of some aspects of the existing rotorcraft occupant protection regulations (27/29.561, .562, .785, and .952) into newly manufactured, legacy helicopters. The ROPWG further made recommendations for regulatory requirements based on this analysis.

This section of the present report presents a similar analysis for retrofit of the current U.S. helicopter fleet. In particular, the following topics are discussed with regards to mandating the retrofit of certain portions of the existing rotorcraft occupant protection regulations (27/29.561, .562, .785, and .952) into previously manufactured helicopters operating in the U.S.:

- Technical Feasibility
- Cost
- Benefit
- Cost/Benefit Analysis
- ROPWG Recommendations

Note that this analysis, and the recommendations that follow, apply to Normal Category registered helicopters only. Restricted category helicopters are not included in the analysis as they are not subject to the same FAA oversight as Normal Category helicopters; see “Recommendations for Public Rotorcraft” section for the ROPWG recommendations regarding Restricted Category and Public Rotorcraft. Therefore, unless otherwise specified, all references to the “U.S. helicopter fleet” apply only to Normal Category helicopters.

RETROFIT FEASIBILITY

Overview

A detailed study was undertaken to determine the “technical feasibility” of incorporating (retrofitting) the following occupant protection regulations into the entire existing U.S. helicopter fleet:

- Requiring the installation of crash resistant fuel bladders,
- Requiring the installation of occupant seats that pass the vertical and horizontal dynamic seat tests of 27/29.562,
- Requiring the restraint of occupants and items of mass in the cabin at the g-levels required for newly certified helicopters (27/29.561).

The study was performed by asking the Original Equipment Manufacturer (OEM) representatives on the ROPWG, representing six of the largest manufacturers, to provide retrofit feasibility ratings, on a scale of 1 to 5 (defined below), for each helicopter model that they currently manufactured or previously manufactured. The results were then tabulated by total number of helicopters with each rating yielding a fleet-wide distribution of retrofit feasibility for each of the three potential requirements. The results were used by the ROPWG as part of the basis for its recommendations for retrofitting CRFS and CRSS into the existing U.S. helicopter fleet.

Specific Potential Requirements Studied

The retrofit technical feasibility study was performed for the potential CRFS and CRSS requirements defined below. Note that while these are similar to the requirements recommended by the ROPWG for newly manufactured legacy helicopters (as defined in the ROPWG Task 5 reports submitted on 15 March 2018 (CRFS) and 29 January 2018 (CRSS)), there are some differences as noted:

- CRFS
  - 27/29.952(a): 50-foot drop test required, conducted with or without surrounding structure.
  - 27/29.963: 250 lb puncture resistance required.
  - 27/29.952(f): Other CRFS features required as far as practicable, to include fuel vents protecting against fuel leakage following rollover.
  - Requirements NOT analyzed by the ROPWG for retrofit, but recommended by the ROPWG for newly manufactured legacy helicopters:
    - 27.952(c): Flexible fuel hoses and breakaway fittings.
    - 27.975(b)/29.975(a)(7): Fully-compliant rollover vent valves.
    - 370 lb puncture resistance required if drop test performed without structure.
- CRSS: Dynamic Seat Tests
  - 27/29.562(b)(1): Vertical dynamic seat tests:
    - Part 27: Required at 100% of current velocity requirement (26 ft/s) "where practicable", or 21.7 ft/s otherwise.
    - Part 29: Required at 100% of current velocity requirement.
  - 27/29.562(b)(2): Horizontal dynamic seat tests required at 100% of current velocity requirement for both Part 27 and 29.

  Note: These are both identical to the ROPWG recommendations for newly manufactured legacy helicopters.
- CRSS: Occupant and Items of Mass in Cabin Restraint
  - 27/29.561(b)(3): Restraint of occupants and items of mass in cabin required at 100% of current g-levels.

  Note: This is identical to the ROPWG recommendation for newly manufactured legacy helicopters.

For simplicity, these requirements will be referred to as the "potential [CRFS/Dynamic Seat/Improved Restraint] retrofit requirements" throughout the remainder of this document.

Definition of Technical Feasibility Ratings

Technical feasibility rankings were primarily based on technical considerations and impediments, as defined below:

1: Not Feasible

- Modifications would be more difficult and/or expensive than replacing the airframe, and/or severe performance penalties would be incurred.
- Examples include helicopters originally developed in the 1940's and 1950's, which would require near complete disassembly and replacement of much of the airframe and many major systems.

2: Low

- Major modifications would have to be performed at the factory, or at a service center with factory-level capabilities, and/or major performance penalties would be incurred.
- Examples include helicopters where the cabin would require substantial disassembly and rebuilding to strengthen the underlying structure.

3: Moderate

- Moderate modifications would have to be performed, requiring equipment and expertise less than factory-level but greater than an average Airframe and/or Powerplant (A&P) mechanic, and/or moderate performance penalties would be incurred.
- Examples include:
    - Helicopters where the airframe would require limited modifications to strengthen underlying structure.
    - Helicopters that would require the removal of exterior metal fuel tanks for replacement with bladder-equipped metal tanks.

4: High

- Minor modifications would have to be performed, requiring the expertise of an average A&P mechanic, and/or minor performance penalties would be incurred.
- Examples include:
    - Helicopters that only require the addition and or replacement of components that were originally designed to be replaced.
    - For instance, replacing non-stroking seats with stroking seats in cabins that are already capable of withstanding the appropriate crash loads.

5: Already Incorporated

- The helicopter model already meets the requirement, either because it was:
    - Originally designed and manufactured to meet requirement.
    - Original design and manufacture was not compliant, but the airframes were previously upgraded to meet requirement.

In addition to those listed above, the following were also among the considerations that influenced the technical feasibility rankings:

- Engineering reports for many models first developed 50+ years ago are unavailable or incomplete, meaning that substantial testing and analysis would have to be performed to simply determine the current state of compliance with the proposed regulations, much less develop revisions to demonstrate compliance.
- Older models have generally undergone many thousands of design revisions since they were first produced, making it extremely difficult to develop a retrofit kit that will work for all previously manufactured units. This is made even more difficult by the availability of Supplemental Type Certificates (STCs) and field modifications that would have been outside of the control of the original manufacturer.
- The cost of these modifications was generally not considered in the technical feasibility analysis, which is calculated in a separate section later in this report. The exception is that helicopters ranked "Not feasible" could technically be redesigned and rebuilt to be compliant, but the changes required would be so extreme as to be clearly impractical.

Applicability of Feasibility Ranking Distributions

Each OEM provided a technical feasibility ranking for each of the models currently and/or previously manufactured by that OEM. Using the U.S. helicopter fleet distribution data provided by the FAA (see Appendix B), the technical feasibility rankings by model were used to determine the percentage of helicopters that fell within each feasibility group.[25] Note that this distribution is based on the number of units that fall within each group versus the total number of ranked helicopters in the U.S. fleet, not the number of ranked models versus the total number of ranked models.

The OEMs represented on the ROPWG collectively manufactured 96% of the helicopters (units, not models) that comprise the current U.S. helicopter fleet (see Appendix B), and they cover a wide range of helicopter types. Therefore, while only 4% of the units in the U.S. fleet were not ranked, it is likely that the technical feasibility ranking of those unranked models has a similar distribution to those that were ranked. Considering the small number of unranked helicopters, even if this distribution was significantly different, the overall effect on the fleet distribution would be small. Therefore, the ROPWG believes that the technical feasibility distribution presented here is representative of the entire existing U.S. helicopter fleet.

[25] Lee D. Roskop, FAA Research Operations Analyst, Rotorcraft Directorate, Ft. Worth, TX.

Feasibility Results - CRFS

The feasibility ranking distribution for the potential CRFS retrofit regulations defined above is presented in Figure 1 below, and in tabular form in Appendix J. The data is presented separately for Part 27 and Part 29 to show the differences between these classes of helicopters.

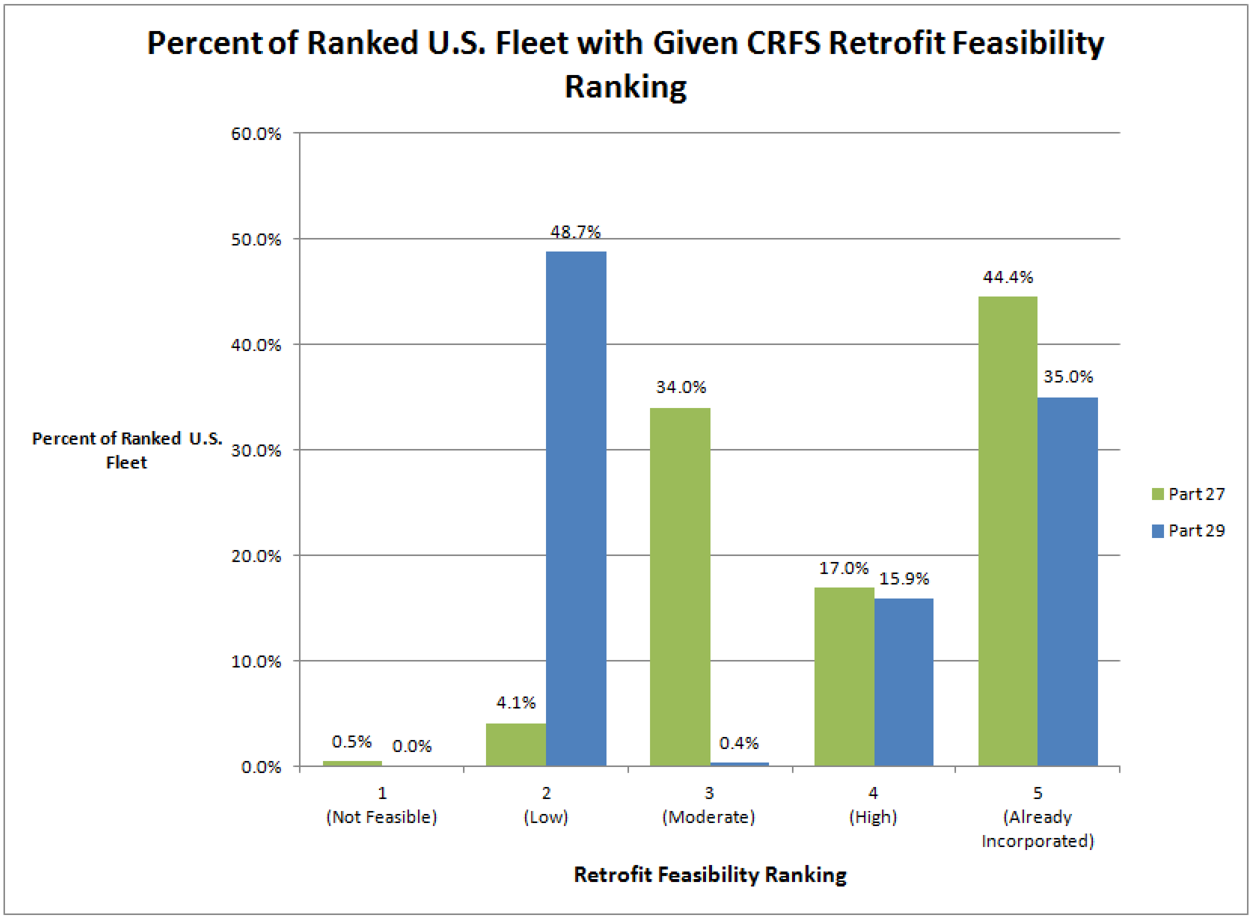

Figure 1. Percent of Ranked U.S. Fleet with Given CRFS Retrofit Feasibility Ranking

Part 27

The data show that 44% of all fielded Part 27 helicopters already meet the potential CRFS retrofit requirements defined above and would therefore not require any upgrade. Recall that the ROPWG has demonstrated that helicopters with partially compliant CRFS were equally effective at preventing post-crash fires in survivable accidents as fully compliant models.[26]

The data further show that 51% of all fielded Part 27 helicopters have a "Moderate" or "High" technical feasibility ranking for the potential CRFS retrofit requirements defined above. These helicopters would therefore incur moderate or low difficulties and expenses when retrofitted as defined above.

[26] ROPWG Task 5 CRFS Report, March 15, 2018.

Additionally, the data show that 4% of Part 27 helicopters have a “Low” feasibility ranking and would therefore likely be very difficult and costly to retrofit as proposed.

Finally, the data show that 0.5% of Part 27 helicopters are ranked “Not Feasible”, meaning that the upgrades would be extremely difficult, likely making the cost of retrofit exceed the value of the helicopter.

<u>Part 29</u>

The data presented in Figure 1 shows that, for Part 29, it would be extremely difficult to retrofit approximately 49% of fielded helicopters with CRFS meeting the requirements defined above. The reasons for the difficulty in retrofitting CRFS into previously-manufactured Part 29 helicopters vary with the model, but generally include one or more of the following:

- Many of these low feasibility helicopters were developed 40+ years ago. As a result, engineering development data is hard to find, and the designs were based on standards dramatically different from those required for compliance with the CRFS requirements analyzed.
- Many helicopters have fuel tanks located deep inside the airframe. Replacing these tanks with CRFS tanks would require substantial disassembly and modification of the airframe using tools and expertise found primarily in an OEM factory setting.

Feasibility Results - Seats Complying with Vertical and Horizontal Seat Test Requirements

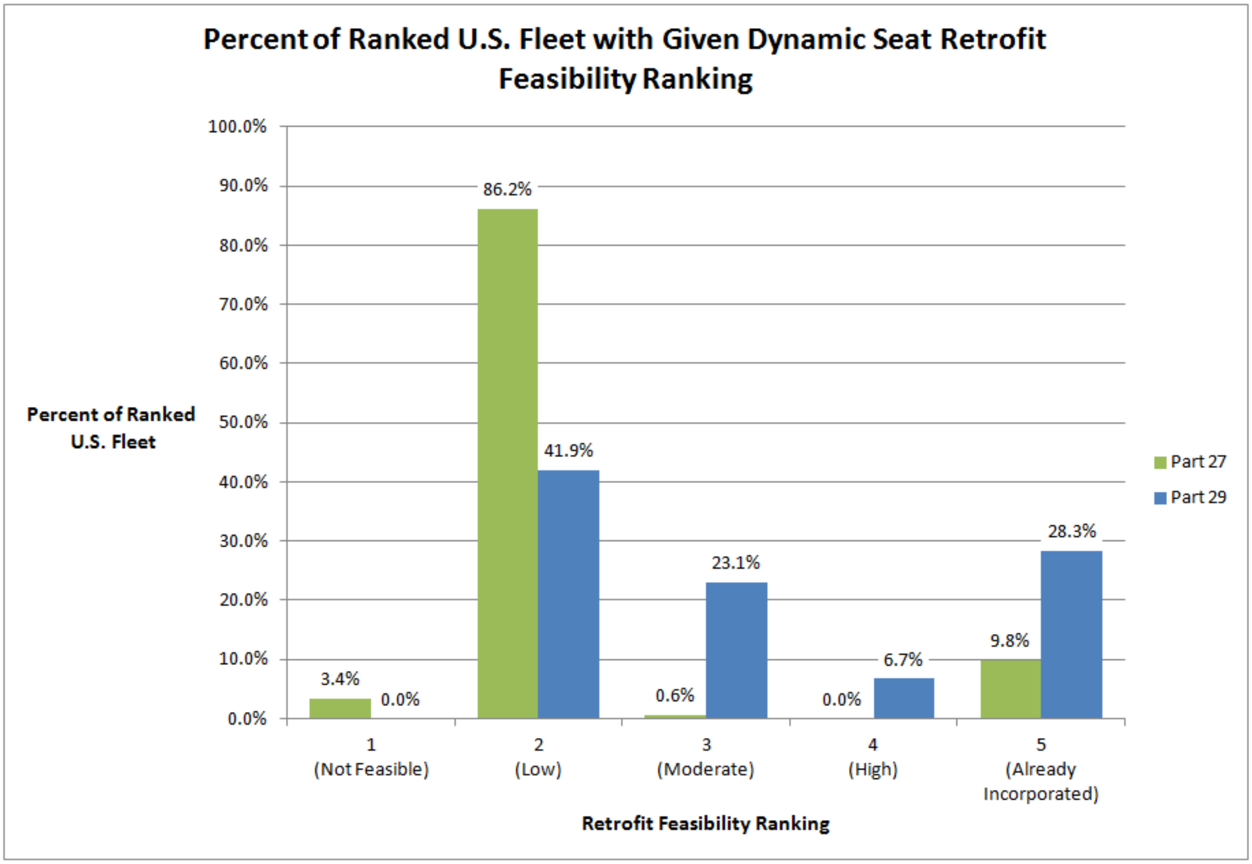

Figure 2. Percent of Ranked U.S. Fleet with Given Dynamic Seat Retrofit Feasibility Ranking

Part 27

The data in Figure 2 (also presented in tabular form in Appendix J) show that 90% of existing Part 27 helicopters have a “Low” or “Not Feasible” ranking for incorporating seats that pass the vertical and horizontal dynamic seat tests, meaning that it would be extremely difficult to incorporate such seats in the vast majority of previously manufactured Part 27 helicopters. There are several reasons such retrofits are difficult to perform:

- The vertical seat test requirement requires a significant volume underneath the seats for stroking/energy absorption, and many previously manufactured helicopters were built without sufficient free space. As a result, complying with this requirement would involve relocating or significantly modifying many critical helicopter system components such as fuel tanks and control systems. This would require redesigning and rebuilding the cabin almost from scratch, and redesigning and remanufacturing several major systems.
- Many small helicopters have integral seats, meaning the seat is a sheet metal box riveted into the cabin, as opposed to the bolt-in seats found in most larger helicopters and airplanes. Modifying these seats would require the disassembly of major portions of the cabin, and significant sheet metal rework.
- Helicopters with existing, non-compliant, bolt-in seats often do not have sufficient floor and/or ceiling strength to fully restrain the seats during dynamic seat tests. As a result, significant

structural rework would be required to strengthen the floor and cabin around the seat attachment points.

<u>Part 29</u>

The data presented in Figure 2 show that 35% of Part 29 helicopters have a retrofit feasibility ranking of “Moderate” or “High”, meaning that these helicopters could be upgraded with moderate or low difficulty. However, 42% of Part 29 helicopters have a “Low” feasibility ranking, meaning it would be extremely difficult to retrofit a significant portion of the Part 29 fleet. These results are due in part to the factors listed below:

- Many Part 29 helicopter have large cabins that are designed with bolt-in seats. As a result, for these models it is considerably easier to upgrade these seats than for smaller Part 27 helicopters with integral seats, though some cabin structural modifications may still be required.
- Like many Part 27 helicopters, many smaller Part 29 helicopters were designed without sufficient stroking space underneath at least some of the seats. As a result, retrofitting these helicopters with stroking seats would be extremely difficult for the same reasons listed above for Part 27 helicopters.

Feasibility Results - Occupant and Items of Mass in Cabin Retention

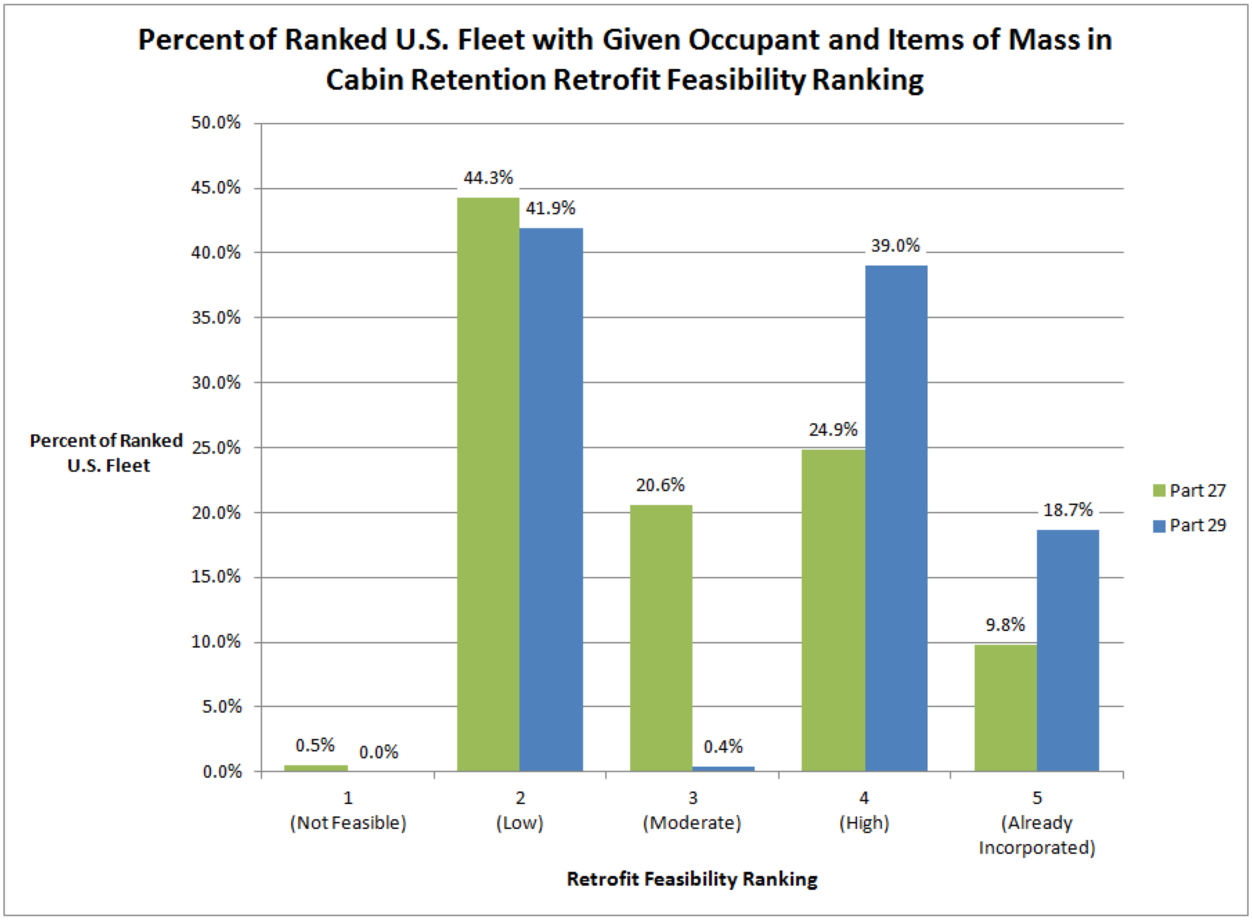

Figure 3. Percent of Ranked U.S. Fleet with Given Occupant and Items of Mass in Cabin Retention Retrofit Feasibility Ranking

The technical feasibility rankings in Figure 3 (also presented in tabular form in Appendix J) indicate the following with regards to meeting the standards for retention of occupants and items of mass in the cabin:

- Approximately 55% of Part 27 helicopters could meet the current standards with moderate or less difficulty.
- Approximately 58% of Part 29 helicopters could meet the current standards with moderate or less difficulty.
- For 42% of Part 27 helicopters and 45% of Part 29 helicopters it would be extremely difficult to comply with the current retention standards.

The difficulty in retrofitting many of these models is due in particular to the following factors:

- Increasing occupant retention strength is more difficult than simply using stronger bolts to affix the seat belts and/or seats to the floor and ceiling, since the cabin structure around the attachment points needs to be strong enough to withstand the loads imparted during crashes and crash tests. Many older designs do not have sufficient strength in these areas to meet the current requirements, and would, therefore, require significant structural modifications, which is very difficult in previously manufactured helicopters.

- Many small helicopters have integral seats, meaning the seat is a sheet metal box riveted into the cabin, as opposed to the bolt-in seats found in most larger helicopters and airplanes. Strengthening these seats would require the disassembly of major portions of the cabin, and significant sheet metal rework.

RETROFIT COST

The cost to the industry of retrofitting the existing fleet to comply with the three sets of potential occupant protection regulations discussed above were estimated by dividing the costs into three categories:

- Non-recurring costs: These are the one-time expenses for research and development, design, certification, and retooling required to design and certify a compliant retrofit kit for each model. These costs may be incurred by the OEM and/or by a third party in pursuit of an STC kit.
- Unit costs: These are the costs for parts and labor to install the retrofit kit for each individual helicopter unit that is upgraded.
- Operator costs: These are the costs to the operator that occur in the form of a reduction in passenger and/or cargo capacity, a reduction in range, and an increase in fuel burn rate.

These costs were calculated separately for each set of the potential regulations and are discussed in detail below.

Note that all costs were calculated in 2016 U.S. Dollars to be consistent with previous ROPWG reports. Present value and other more complex accounting methods were not utilized.

Non-Recurring Costs

The non-recurring costs for a retrofit kit for each model were estimated using data provided by the OEMs represented on the ROPWG. For each model of helicopter that is currently or was previously manufactured by an OEM on the ROPWG, the OEM provided an estimate of the non-recurring cost to develop and certify a retrofit kit. Note that while the OEMs provided the estimates for this report, the OEMs would not necessarily be the organizations developing the kits, as third-party companies could potentially provide STCs as well.

Of all currently operated helicopter *models* in the active U.S. helicopter fleet, 87% were manufactured by an OEM represented on the ROPWG. These helicopters covered a wide range of gross weights, passenger capacity, overall design, and typical operation. As a result, it is reasonable to expect that the non-recurring costs for the helicopter models not represented on the ROPWG are likely similar to those of similar helicopters that were estimated by the OEMs. Therefore, for those helicopter models not represented by an OEM, the ROPWG estimated a non-recurring cost equivalent to the average cost for similar helicopter models for which cost data was available.

Also note that the non-recurring costs are independent of the number of helicopters of that model in the U.S. fleet. Therefore, as discussed later in this section, those models with fewer units in service will see a higher per-unit share of the non-recurring costs. As a result, it may not be economically viable to develop retrofit kits for models with few models in service.

Note that for models where retrofit was deemed “Not Feasible”, it was assumed those models would be retired from service, and therefore the non-recurring (research and development) cost was assumed to be zero. As explained below under Unit Costs, the unit cost was assumed to be the cost of a replacement (compliant) helicopter of comparable value and utility.

The resulting non-recurring costs are presented in Table 3. Note that the "Total for All Affected Models" includes the assumed non-recurring costs for those models for which cost estimates were not available.

Table 3. Non-Recurring Costs for Complying with Potential Retrofit Requirements						
	CRFS		**CRSS - Dynamic Seats**		**CRSS - Retention**	
	Average Per Affected Model	**Total for All Affected Models**	**Average Per Affected Model**	**Total for All Affected Models**	**Average Per Affected Model**	**Total for All Affected Models**
Part 27	$7,295,909	$168,249,476	$8,209,259	$232,337,526	$2,031,793	$61,763,103
Part 29	$5,966,667	$73,061,224	$4,055,556	$74,489,796	$2,444,444	$44,897,959
Total	--	$241,310,700	--	$306,827,322	--	$106,634,062

Unit-Costs

Similar to the non-recurring costs, unit costs of a retrofit kit for each model were estimated using data provided by the OEMs represented on the ROPWG. For each model of helicopter that is currently or previously manufactured by an OEM on the ROPWG, the OEM provided an estimate of the unit cost of a retrofit kit for that model.

As with non-recurring costs, for those helicopter models not represented by an OEM, the ROPWG estimated a non-recurring cost based on the average cost for similar helicopter models manufactured by one of the ROPWG-represented OEMs. Note that the uncertainty with the overall cost to the industry is smaller for unit costs than for non-recurring costs, as 96% of all helicopter *units* in the U.S. fleet were manufactured by an OEM represented on the ROPWG.

For models where retrofit was deemed "Not Feasible", it was assumed those models would be retired from service and, therefore, the unit cost was assumed to be the cost to purchase a replacement helicopter of comparable utility. The cost of the replacement helicopter was estimated to be 70% of the new cost of the available helicopter model most similar to that being retired, which may or may not be made by the same manufacturer. The 70% factor assumes that at the time of retirement, (1) the average helicopter is halfway between scheduled overhauls, (2) that the overall cost is 50% of the cost of a new helicopter, and (3) that the value of the newly overhauled helicopter is slightly less than that when new.

The total unit cost to the industry for each model is the unit cost for each model multiplied by the number of affected units. The total unit cost to the industry to retrofit all non-compliant helicopters in the U.S. fleet is, therefore, the sum of the model-specific total unit costs. This data is presented in Table 4.

Table 4. Unit Costs for Complying with Potential Retrofit Requirements

	CRFS		CRSS - Dynamic Seats		CRSS - Retention	
	Average Per Affected Ship[2]	Total for All Affected Ships in U.S. Fleet	Average Per Affected Ship	Total for All Affected Ships in U.S. Fleet	Average Per Affected Ship	Total for All Affected Ships in U.S. Fleet
Part 27	$419,310[1]	$410,556,141	$516,843[1]	$961,398,994	$352,533[1]	$271,472,558
Part 29	$328,750	$124,913,265	$306,389	$184,219,388	$172,778	$127,882,653
Total	--	$535,469,406	--	$1,145,618,332	--	$399,355,211

Notes:

1. The average includes airframe retirement/replacement cost of "Not Feasible" models. Average unit cost for retrofit when feasible is as follows:
    a. CRFS: $147,045
    b. CRSS - Dynamic Seats: $329,532
    c. CRSS - Retention: $129,868
2. For reference, the average replacement value of an airframe in the U.S. fleet (weighted to account for more numerous models) is as follows:
    a. Part 27: $1,240,000
    b. Part 29: $7,660,000

Operator Costs

Overview

In previous ROPWG reports, operator costs were determined by estimating, for each unit of a particular model, the cost to operators of the following factors:

- The reduction in the number of passengers and/or cargo capacity due to modifications required for compliance. This reduction could be due to:
  - An increase in helicopter empty weight
  - A decrease in the number of compliant seats
  - A decrease in the available cargo volume
- The reduction in range due to the reduction in fuel load. This reduction in fuel load could be due to:
  - Replacing sheet metal fuel tanks with bladder fuel tanks
  - Incorporating smaller fuel tanks in order to provide space for stroking (energy absorbing) seats
- An increase in fuel burn rate due to greater empty weight

In the previous ROPWG reports, these costs were determined for each model by asking OEMs to provide estimates for the following for each model:

- The increase in gross weight due to the required changes
- The loss of passenger and cargo capacity
- Fuel burn rates and costs as a function of gross weight were based on FAA estimates

See the ROPWG Task 5 CRFS Report, Appendix B for a detailed explanation of these cost calculations.

Unfortunately, it was not feasible to perform such an analysis for the current retrofit task, as the number of models potentially requiring retrofit (82) was much greater than those analyzed in previous ROPWG reports - 13 non-fully compliant models still in production.

As an alternative, the operator costs associated with retrofitting the entire U.S. fleet were estimated by performing the following for each of the three sets of CRFS and CRSS potential retrofit requirements:

1. For both Part 27 and Part 29 aircraft, the average increase in operator cost, per helicopter per year, was determined based on the operator cost estimates for newly manufactured, legacy helicopters modified to comply with the ROPWG Task 5 "Partial Compliance" CRFS and CRSS recommendations.

   Note that while the ROPWG Task 5 recommendations for newly manufactured, legacy helicopters were somewhat more onerous than those for retrofit, the difference in overall operator cost was judged to be fairly small.

2. The average increase in operator cost, per helicopter per year, from #1 was then multiplied by the number of affected helicopters in the U.S. fleet, yielding an estimated industry-wide operator cost per year for the retrofit requirements.

Note that aircraft that are already fully compliant to a given retrofit recommendation were not included in this affected helicopter count.

Also, aircraft rated as "Not Feasible" were not included this helicopter count, as it is assumed that the entirety of the cost to those aircraft will be due to the retirement of the airframe.

Since the underlying operator cost data in the ROPWG Task 5 CRSS Report was presented in terms of a combined dynamic seat and retention cost, the baseline CRSS retrofit cost estimates are similarly a combined estimate for the dynamic seat and retention requirements.

The ROPWG considers the above operator cost estimates to be low, since the average cost per helicopter is based on newly manufactured helicopters, which tend to have newer designs than the average helicopter in the existing fleet. As a result, retrofitting previously manufactured helicopters is likely to require more significant changes to these helicopters, resulting in greater increases in empty weight and greater losses in fuel capacity, and therefore, greater operator costs.

The procedure described above yielded the following costs presented in Table 5 through Table 7:

Table 5. Average Yearly Operator Costs, per Helicopter per Year, for Complying with Potential Retrofit Requirements

	CRFS[1]	**CRSS: Dynamic Seats and Retention Combined[2]**
Part 27	$2,114	$8,406
Part 29	$19,786	$31,852

Notes:

1. CRFS Calculations
    a. Data from ROPWG Task 5 CRFS Report, Table 29:
        i. Part 27 total yearly operator costs = $68,561 + $295,063 + $0 = $363,624
        ii. Part 29 total yearly operator costs = $257,216
    b. Data from ROPWG Task 5 CRFS Report, page 68
        i. Fleet size contributing to operator costs, Part 27: 85 + 84 + 3 = 172 affected helicopters
        ii. Fleet size contributing to operator costs, Part 29: 13 affected helicopters
    c. Average operator cost per helicopter
        i. Part 27: $363,624 / 172 = $2,114
        ii. Part 29: $257,216 / 13 = $19,786
2. CRSS Calculations
    a. Data from ROPWG Task 5 CRSS Report, Table 23
        i. Part 27 total yearly operator costs = $316,711 + 1,129,148 + $0 = $1,445,859
        ii. Part 29 total yearly operator costs = $414,078
    b. Data from ROPWG Task 5 CRFS Report, page 72
        i. Fleet size contributing to operator costs, Part 27: 85 + 84 + 3 = 172 affected helicopters
        ii. Fleet size contributing to operator costs, Part 29: 13 affected helicopters
    c. Average operator cost per helicopter
        i. Part 27: $1,445,859 / 172 = $8,406
        ii. Part 29: $414,078 / 13 = $31,852

Table 6. Total Yearly Operator Costs for Complying with Potential Retrofit Requirements, CRFS			
	Average Yearly Operator Cost, per Helicopter, per Year, CRFS	Number of Affected Helicopters, CRFS[1]	Total Yearly Industry-Wide Operator Cost, CRFS
Part 27	$2,114	5,164	$10,916,696
Part 29	$19,786	690	$13,652,340
Total	--	5,854	$24,569,036

Notes:

1. Data from Table 47 in this report
    a. Part 27: 45 + 385 + 3158 + 1576 = 5,164 affected helicopters
    b. Part 29: 0 + 517 + 4 + 169 = 690 affected helicopters

Table 7. Total Yearly Operator Costs for Complying with Potential Retrofit Requirements, CRSS - Combined Dynamic Seats and Retention			
	Average Yearly Operator Cost, per Helicopter, per Year, CRSS	Number of Affected Helicopters, CRSS[1]	Total Yearly Industry-Wide Operator Cost, CRSS
Part 27	$8,406	8,382	$70,459,092
Part 29	$31,852	812	$25,863,824
Total	--	9,194	$96,322,916

Notes:

1. Data from Table 48 and Table 49 in this report
    a. Part 27: ((316 + 8006 + 60 + 0) + (45 + 4113 + 1914 + 2310)) / 2 = 8382 affected helicopters
    b. Part 29: ((0 + 445 + 245 + 71) + (0 + 445 + 4 + 414)) / 2 = 812 affected helicopters
    c. (number of affected helicopters is assumed to be the average of the following:
        i. Number affected by Dynamic Seat requirements
        ii. Number affected by Retention requirements

CRSS Cost Breakdown

Since the present report considers dynamic seats and retention separately, the breakdown of operator costs by dynamic seat and retention requirements was estimated by assuming that the ratio of the dynamic seat operator costs to retention operator costs was the same as the ratio of the dynamic seat unit costs to retention unit costs (data from Table 4):

- Total Unit Costs, Dynamic Seats: $1,145,618,332
- Total Unit Costs, Retention: $399,355,211
- Total Combined Unit Costs, Dynamic Seat plus Retention Costs: $1,544,973,543
- Percentage of Total Combined Unit Costs due to Dynamic Seats: $1,145,618,332 / $1,544, 937,543 = 74%
- Percentage of Total Combined Unit Costs due to Retention: $399,355,211 / $1,544,973,543 = 26%

Applying these cost ratios to the data in Table 7 yields the following individual operator cost estimates for Dynamic Seats and Retention presented in Table 8 and Table 9:

Table 8. Total Yearly Operator Costs for Complying with Potential Retrofit Requirements, CRSS - Dynamic Seats Only

	Average Yearly Operator Cost, per Helicopter, per Year, CRSS	Number of Affected Helicopters, CRSS	Total Yearly Industry-Wide Operator Cost, CRSS
Part 27	$6,220	8,382	$52,139,728
Part 29	$23,570	812	$19,139,230
Total	--	9,194	$71,278,958

Table 9. Total Yearly Operator Costs for Complying with Potential Retrofit Requirements, CRSS - Retention Only

	Average Yearly Operator Cost, per Helicopter, per Year, CRSS	Number of Affected Helicopters, CRSS	Total Yearly Industry-Wide Operator Cost, CRSS
Part 27	$2,187	8,382	$18,319,364
Part 29	$8,283	812	$6,724,594
Total	--	9,194	$25,043,958

Total 10-Year Industry Costs for Retrofit

In previous ROPWG reports, the FAA requested that cost data be presented as a total cost over the first 10 years following the effective date of the regulations. The 10-year cost data is presented in Table 10 through Table 12.

Table 10. Total 10-Year Costs for Complying with Potential Retrofit Requirements, CRFS

Cost Category	Part 27	Part 29	Total
Non-Recurring Costs	$168,249,476	$73,061,224	$241,310,700
Unit Costs	$410,556,141	$124,913,265	$535,469,406
10-Year Operator Costs	$109,166,960	$136,523,400	$245,690,360
Total	$687,972,577	$334,497,889	$1,022,470,446

Table 11. Total 10-Year Costs for Complying with Potential Retrofit Requirements, CRSS - Dynamic Seats Only

Cost Category	Part 27	Part 29	Total
Non-Recurring Costs	$232,337,526	$74,489,796	$306,827,322
Unit Costs	$961,398,994	$184,219,388	$1,145,618,382
10-Year Operator Costs	$521,397,280	$191,392,300	$712,789,580
Total	$1,715,133,800	$450,101,484	$2,165,235,284

Table 12. Total 10-Year Costs for Complying with Potential Retrofit Requirements, CRSS - Retention Only

Cost Category	Part 27	Part 29	Total
Non-Recurring Costs	$61,763,103	$44,897,959	$106,661,062
Unit Costs	$271,472,558	$127,882,653	$399,355,211
10-Year Operator Costs	$183,193,640	$67,245,940	$250,439,580
Total	$516,429,301	$240,026,552	$756,455,853

Helicopter Fleet "Lifetime" Cost

While in previous ROPWG studies, the FAA asked for cost and benefit data for a 10-year period, in this case the ROPWG concluded that it is appropriate to look at a longer time period, specifically the remaining "life" of the affected helicopter fleet (i.e., the period of time between the present and the time at which the airframes are retired). This is because the majority of the costs associated with retrofit are one-time costs due to research and development and component manufacture and installation, whereas ongoing operator costs account for only approximately 25% of costs during the first 10 years. This is in contrast to the benefit of installing CRFS and CRSS, which extends from the moment they are installed until the airframe is retired. It is the opinion of the ROPWG that limiting the cost/benefit analysis to a 10-year period understates the societal value of installing CRFS and CRSS.

To calculate the lifetime cost and benefit of retrofitting an airframe with CRFS, it was estimated that the average remaining time before airframe retirement was 25 years. While the ROPWG was not able to find specific data to determine this life, the membership agreed that a 50-year airframe life was typical for the industry. Therefore, if one assumes that the rate of airframe manufacture is constant, then the average life remaining is 50/2 = 25 years. Based on this assumption, the lifetime costs of implementing the potential retrofit requirements were determined, and are presented in Table 13 through Table 15:

Table 13. Total Lifetime (25-year Average Remaining Airframe Life) Costs for Complying with Potential Retrofit Requirements, CRFS

Cost Category	Part 27	Part 29	Total
Non-Recurring Costs	$168,249,476	$73,061,224	$241,310,700
Unit Costs	$410,556,141	$124,913,265	$535,469,406
Lifetime Operator Costs	$272,917,400	$341,308,500	$614,225,900
Total	$851,723,017	$539,282,989	$1,391,006,006

Table 14. Total Lifetime (25-Year Average Remaining Airframe Life) Costs for Complying with Potential Retrofit Requirements, CRSS - Dynamic Seats Only

Cost Category	Part 27	Part 29	Total
Non-Recurring Costs	$232,337,526	$74,489,796	$306,827,322
Unit Costs	$961,398,994	$184,219,388	$1,145,618,382
Lifetime Operator Costs	$1,303,493,200	$478,480,750	$1,781,973,950
Total	$2,497,229,720	$737,189,934	$3,234,419,654

Table 15. Total Lifetime (25-Year Avearge Remaining Airframe Life) Costs for Complying with Potential Retrofit Requirements, CRSS - Retention Only			
Cost Category	**Part 27**	**Part 29**	**Total**
Non-Recurring Costs	$61,763,103	$44,897,959	$106,661,062
Unit Costs	$271,472,558	$127,882,653	$399,355,211
Lifetime Operator Costs	$457,984,100	$168,114,850	$626,098,950
Total	$791,219,761	$340,895,462	$1,132,115,223

RETROFIT BENEFIT - CRFS

Effectiveness of Potential CRFS Retrofit Requirements

The ROPWG Task 5 CRFS Report concluded the following with regards to the effectiveness of partially-compliant CRFS at preventing post-crash fires and thermal injures:

> *"Among partially-compliant designs that passed a 50-foot drop test (with or without structure) and had a puncture resistance of at least 250 lb (models 1-4), crash performance was essentially identical to that of fully-compliant helicopters. Both groups had no significant post-crash fires or thermal injuries for survivable crashes (Severity 1-3). This is in contrast to non-compliant helicopters that had an 11% rate of post-crash fire due to fuel spillage following survivable crashes."*

Since the potential CRFS retrofit requirements include the criteria referenced in the excerpt above, for purposes of determining a monetary benefit, it was assumed that all post-crash fires and thermal injuries following survivable accidents would be eliminated if the potential CRFS retrofit requirements were adopted.

CAMI Fatal Thermal Injury Data

The monetary benefit of the potential CRFS retrofit requirements was calculated by first determining the number of fatalities and thermal injuries due to post-crash fires that occurred in the U.S. helicopter fleet from 1 January 2009 through 31 December 2017 (9 years). This data was provided by the Civil Aerospace Medical Institute (CAMI), which requested the following statement:

> *"Data was obtained from the Medical Analysis Tracking Registry (MANTRA) located at the Civil Aerospace Medical Institute. MANTRA is maintained by the Autopsy Program Team and Medical Accident Review Hazard Analysis Program."*

The data from CAMI was provided in a memorandum dated 18 May 2018 (see Appendix F). A summary of this data is provided below in Table 16.

Table 16. CAMI Data on Injuries and Fatalities Following U.S. Helicopter Accidents, 2009 through 2017		
Number of Fatal Rotorcraft Accidents		177
Number of Post-Crash Fires		118
Number of Occupants on Board		399
Number of Fatalities		323
Autopsies Available for Review by CAMI		206
Reviewed Autopsies Where Cause of Death was Listed as due to Thermal Injury[1]	Total	33
	Part 27	27
	Part 29	5
	Restricted Category	1
Percentage of Reviewed Autopsies that Listed Cause of Death as due to Thermal Injury		16%

Note:

1. Breakdown provided via email subsequent to memorandum in Appendix F

As noted in correspondence with CAMI and other FAA personnel, CAMI attempts to gather as many autopsies as possible for every fatal accident that occurs in the U.S.; this data is usually, but not always, available. In the case of the current study, autopsy data was available for 64% of the accident fatalities.

Since autopsy data was not available for all fatally injured occupants, it is likely that the number of deaths due to thermal injury in this time period was greater than the 33 noted in Table 16. In order to estimate the total number of occupants that died due to thermal injury, it was assumed that the percentage of occupants that died due to thermal injury was the same for those that had available autopsy data and those that did not. Therefore, since 16% of the available autopsy reports listed the cause of death as due to thermal injury, it is estimated that 323 * 16% = 52 occupants died due to thermal injury during this 9-year period.

It was further assumed that the ratio of thermal fatalities for Part 27 versus Part 29 versus Restricted Category occupants (27 versus 5 versus 1) was the same for those that had autopsy data and those that did not. Table 17 shows the estimated breakdown of the 52 thermal fatalities during the 9-year period, rounded to the nearest integer:

Table 17. Estimated Thermal Fatalities During 9-Year CAMI Study	
	Thermal Fatalities
Part 27	43[1]
Part 29	8[2]
Total, Part 27 & Part 29	52[3]

Notes:

1. Part 27: 52 * (27 / 33) = 43
2. Part 29: 52 * (5 / 33) = 8
3. Total, Part 27 & Part 29: 323 * 16% = 52

Non-Fatal Thermal Injuries

The CAMI data introduced above is believed to provide an accurate assessment of the number of fatalities due to thermal injury following U.S. helicopter accidents during the 9-year period studied. Unfortunately, the CAMI data does not provide similar data on non-fatal thermal injuries, and NTSB data for non-fatal thermal injuries is incomplete. Therefore, the ROPWG was unable to estimate the number of surviving occupants that sustained non-fatal thermal injuries during the 9-year period; in particular, the following data was unavailable:

- The number of occupants that received a non-fatal thermal injury after surviving one of the fatal accidents in the CAMI study
- The number of occupants that received a non-fatal thermal injury in a non-fatal accident (the CAMI data does not include accidents without a fatality)

As a result of this limitation, the benefit calculations provided below are limited to thermal fatalities, and therefore, significantly underestimate the actual benefit since thermal injuries often require extended and very expensive treatment.

Benefit Calculation

As in previous ROPWG reports, the monetary benefit of preventing fatalities due to thermal injury was estimated using the monetary values associated with the saving of a life and the prevention of serious and minor injuries that were provided by the FAA Office of Aviation Policy and Plans (APO). These values are shown in Table 18.

Table 18. Recommended Injury Values Based on the NTSB Classification of Injuries (2015 USD).		
NTSB Classification	Fractional Values of Life	Dollar Value
Fatal	1.000	$9,600,000
Serious	0.253	$2,428,800
Minor	0.003	$28,800

These values are not necessarily endorsed by members of the ROPWG. The FAA requires that these monetary values be utilized in all FAA studies, including this and all previous and future ROPWG reports, in order to provide consistency across FAA studies. Appendix F of the ROPWG Task 2 Report includes a detailed discussion on how the APO and U.S. Department of Transportation (DOT) determine these values; in brief, these values are based on the implied value consumers place on their lives as determined by wage rate differentials for risky jobs or on the prices consumers pay for products that reduce their risk of being fatally injured.

The potential retrofit CRFS recommendations under consideration would only apply to Part 27 and Part 29 helicopters. Consequently, the restricted category thermal fatalities are not included in the benefit calculation below.

The combined Part 27 and Part 29, 52 total, thermal fatalities represent the most recent 9-year time period where data is available. To be consistent with previous ROPWG reports that reported cost and benefit data for a 10-year period, it is assumed that the rate of fatal injury due to thermal injury during that 9-year period is representative of what would be expected over the extended period. The monetary benefit (in 2015 USD) of implementing the ROPWG CRFS retrofit recommendations estimated over a 10-year period is shown in Table 19.

Table 19. Benefit of Thermal Fatality Prevention by Potential CRFS Retrofit Requirements, 10-Year Period

	Thermal Fatalities Avoided	Monetary Benefit
Part 27	48[1]	$460,800,000
Part 29	9[1]	$86,400,000
Total	57	$547,200,000

Note:

1. Thermal fatalities during 10 years = Thermal fatalities during 9 years * (10/9), rounded to the nearest integer

Helicopter Fleet "Lifetime" Benefit

While in previous ROPWG studies the FAA asked for cost and benefit data for a 10-year period, in this case the ROPWG concluded that it is appropriate to look at a longer time period, specifically the remaining "life" of the affected helicopter fleet, which is defined as the period of time between the present and the time at which the airframes are retired. This is because the majority of the costs associated with retrofit are one-time costs due to research and development and component manufacture and installation, whereas ongoing operator costs account for only approximately 25% of costs during the first 10 years. This is in contrast to the benefit of installing CRFS and CRSS, which extends from the moment these systems are installed until the airframe is retired. It is the opinion of the ROPWG that limiting the cost/benefit analysis to a 10-year period understates the societal value of installing CRFS and CRSS.

To calculate the lifetime cost and benefit of retrofitting an airframe with CRFS, it was estimated that the average remaining time before airframe retirement was 25 years. While the ROPWG was not able to find specific data to determine this life, the membership agreed that a 50-year airframe life was typical for the industry. Therefore, if one assumes that the rate of airframe manufacture is constant, then the average airframe life remaining is 50 / 2 = 25 years. Based on this assumption, the lifetime benefit of implementing the potential CRFS retrofit requirements is shown in Table 20:

Table 20. Benefit of Thermal Fatality Prevention by Potential CRFS Retrofit Requirements, Lifetime (25-Year Average Remaining Airframe Life)		
	Thermal Fatalities Avoided	**Monetary Benefit**
Part 27	120	$1,152,000,000
Part 29	23	$220,800,000
Total	143	$1,372,800,000

RETROFIT BENEFIT - CRSS

Even though some crashworthiness features have been incorporated into the civil helicopter fleet to various degrees over the past several decades, it is extremely difficult to evaluate their effectiveness in preventing injury in survivable crashes due to the lack of impact and injury data in NTSB accident dockets. While military crashworthiness studies acquire the required data and allow the determination of what crashworthiness features are generally effective, these studies do not allow a precise analysis of the effectiveness of civilian helicopter crashworthiness features, as the differences between civilian and military airframes, operations, and aircrew are very significant.

Furthermore, even if one could make a reasonably precise determination of the effectiveness of current civilian CRSS standards, the lack of data regarding the effectiveness of CRSS features in the existing fleet would prevent a precise measure of the benefit to be gained by requiring the retrofit of CRSS features. For instance, if one does not know the energy absorption characteristics of all seats in the existing fleet, one cannot determine the benefit of requiring seats to be upgraded. Generally, such data is not available, even within most OEMs. Similarly, one cannot determine the benefit of meeting the occupant retention requirements of 27/29.561 if one does not know the existing mass retention strength of every helicopter in the existing rotorcraft fleet.

Although the ROPWG Task 2 report included a quantitative estimate of the benefit of full compliance with the applicable CRSS regulations, it is the opinion of the ROPWG that due to the factors discussed above, the large uncertainty in this estimate severely limits its utility. Therefore, while the ROPWG attempted to use a similar methodology to determine an estimate of benefit of retrofitting CRSS features, the ROPWG feels that there is too much uncertainty to include it in the main body of this report. However, in case the analysis proves useful for some readers, the corresponding benefit calculations for retrofit are included in Appendix E.

COST/BENEFIT ANALYSIS

CRFS

Summary

Table 21 and Table 22 summarize the CRFS cost and benefit estimates developed in the previous subsections.

Table 21. Total 10-Year Costs and Benefits for Complying with Potential Retrofit Requirements, CRFS

Cost Category	Part 27	Part 29	Total
Non-Recurring Costs	$168,249,476	$73,061,224	$241,310,700
Unit Costs	$410,556,141	$124,913,265	$535,469,406
10-Year Operator Costs	$109,166,960	$136,523,400	$245,690,360
Total Cost	$687,972,577	$334,497,889	$1,022,470,446
10-Year Benefit	$460,800,000	$86,400,000	$547,200,000
Benefit minus Cost	($227,172,577)	($248,097,889)	($475,270,446)

Table 22. Total Lifetime (25-Year Average Remaining Airframe Life) Costs and Benefits for Complying with Potential Retrofit Requirements, CRFS

Cost Category	Part 27	Part 29	Total
Non-Recurring Costs	$168,249,476	$73,061,224	$241,310,700
Unit Costs	$410,556,141	$124,913,265	$535,469,406
Lifetime Operator Costs	$272,917,400	$341,308,500	$614,225,900
Total Cost	$851,723,017	$539,282,989	$1,391,006,006
Lifetime Benefit	$1,152,000,000	$220,800,000	$1,372,800,000
Benefit minus Cost	$300,276,983	($318,482,989)	($18,206,006)

Discussion
A review of the CRFS cost/benefit data above yields the following conclusions:

- For Part 27, the costs slightly exceed the calculated benefit over the first 10 years, but the benefits exceed the costs over the remaining lifetime of the airframes that are retrofitted.
- For Part 29, the costs exceed the calculated benefit for both the 10-year and lifetime time frames.

When considering the cost/benefit data presented in Table 21 and Table 22, it is critical to remember that as discussed in the “Retrofit Benefit - CRFS” section, due to a lack of available data, the CRFS benefit calculated above does NOT include the prevention of non-fatal thermal injuries. Since thermal injuries typically require extended, very expensive treatment, the actual benefit is likely significantly greater than that detailed in these tables. Therefore, the ROPWG concludes the following with regard to the relative cost and benefit of requiring the potential CRFS retrofit recommendations:

- **For Part 27, the 10-year and lifetime monetary benefits of the potential CRFS retrofit requirements likely exceed the costs.**
- **For Part 29, the 10-year and lifetime monetary benefits of the potential CRFS retrofit requirements are likely similar to the costs.**

CRSS - Dynamic Seats

Summary

Table 23 and Table 24 summarize the CRSS – Dynamic Seats cost and benefit estimates developed in the previous subsections.

Table 23. Total 10-Year Costs and Benefits for Complying with Potential Retrofit Requirements, CRSS - Dynamic Seats

Cost Category	Part 27	Part 29	Total
Non-Recurring Costs	$232,337,526	$74,489,796	$306,827,322
Unit Costs	$961,398,994	$184,219,388	$1,145,618,382
10-Year Operator Costs	$521,397,280	$191,392,300	$712,789,580
Total Cost	$1,715,133,800	$450,101,484	$2,165,235,284
10-Year Benefit	Unknown[1]	Unknown[1]	Unknown[1]

Note:

1. As detailed in the "Retrofit Benefit - CRSS" section, the ROPWG was unable to determine a sufficiently reliable estimate for the CRSS benefit. An attempted calculation of this benefit is presented in Appendix E, but the ROPWG felt that it was too unreliable to include in the main body of this report.

Table 24. Total Lifetime (25-year Average Remaining Airframe Life) Costs and Benefits for Complying with Potential Retrofit Requirements, CRSS - Dynamic Seats

Cost Category	Part 27	Part 29	Total
Non-Recurring Costs	$232,337,526	$74,489,796	$306,827,322
Unit Costs	$961,398,994	$184,219,388	$1,145,618,382
Lifetime Operator Costs	$1,303,493,200	$478,480,750	$1,781,973,950
Total Cost	$2,497,229,720	$737,189,934	$3,234,419,654
Lifetime Benefit	Unknown[1]	Unknown[1]	Unknown[1]

Note:

1. As detailed in the "Retrofit Benefit - CRSS" section, the ROPWG was unable to determine a sufficiently reliable estimate for the CRSS benefit. An attempted calculation of this benefit is presented in Appendix E, but the ROPWG felt that it was too unreliable to include in the main body of this report.

Discussion

Due to the lack of detailed impact and injury data in NTSB accident reports, the ROPWG was unable to estimate reliably the benefit of incorporating dynamic seats via retrofit. Although the ROPWG attempted to estimate benefits associated with installing energy attenuating seats (Appendix E), the results are considered unreliable, and the ROPWG is concerned that use of these estimates would lead to misleading conclusions.

Nevertheless, without consideration of the unreliable CRSS benefit calculations in Appendix E, the ROPWG was able to make some conclusions in consideration of the remaining available data:

- For Part 27, the cost of retrofitting dynamic seats is 2.5x-3x the cost of incorporating CRFS.
- For Part 29, the cost of retrofitting dynamic seats is 1.3x higher than that for incorporating CRFS.
- FAA study CT-85/11 showed that exposure to fire following an otherwise survivable accident caused a greater number of severe injuries and fatalities than exposure to excessive vertical decelerative forces. While the ROPWG acknowledges that changes in the fleet makeup since that study could affect relative risks, the available anecdotal data suggests that post-crash fires following survivable accidents continue to be a significantly greater cause of injury and death than excessive vertical decelerative forces in survivable accidents. As a result, it is likely that the benefit of incorporating CRFS via retrofit exceeds the benefit of incorporating dynamic seats via retrofit. Therefore, if one conservatively assumes that the benefit of incorporating dynamic seats via retrofit is equal to that of incorporating CRFS, the cost/benefit ratio for incorporating dynamic seats via retrofit is as follows:
    - For Part 27, costs greatly exceed benefits, with a cost/benefit ratio of 3.7x (10-year analysis) or 2.2x (lifetime analysis).
    - Since the CT-85/11 and anecdotal data primarily concerns Part 27 helicopters, the analysis described above may not apply to Part 29 helicopters.

In consideration of this data, the ROPWG concludes the following:

Part 27

Since the cost of incorporating dynamic seats via retrofit is significantly higher than the cost of incorporating CRFS, and since the available data suggests that the benefit of incorporating dynamic seats is likely less than that of incorporating CRFS, **for Part 27 helicopters the 10-year and lifetime costs of incorporating dynamic seats via retrofit likely greatly exceed the benefits.**

Part 29

Since the cost of incorporating dynamic seats via retrofit is only modestly higher than the cost of incorporating CRFS, **for Part 29 helicopters the 10-year and lifetime costs of incorporating dynamic seats via retrofit likely exceed the benefits by an unknown margin.**

CRSS - Retention of Occupants and Items of Mass in Cabin

Summary

Table 25 and Table 26 summarize the CRSS – Retention cost and benefit estimates developed in the previous subsections.

Table 25. Total 10-Year Costs and Benefits for Complying with Potential Retrofit Requirements, CRSS - Retention

Cost Category	Part 27	Part 29	Total
Non-Recurring Costs	$61,763,103	$44,897,959	$106,661,062
Unit Costs	$271,472,558	$127,882,653	$399,355,211
10-Year Operator Costs	$183,193,640	$67,245,940	$250,439,580
Total Cost	$516,429,301	$240,026,552	$756,455,853
10-Year Benefit	Unknown[1]	Unknown[1]	Unknown[1]

Note:

1. As detailed in the "Retrofit Benefit - CRSS" section, the ROPWG was unable to determine a sufficiently reliable estimate for the CRSS benefit. An attempted calculation of this benefit is presented in Appendix E, but the ROPWG felt that it was too unreliable to include in the main body of this report.

Table 26. Total Lifetime (25-year Average Remaining Airframe Life) Costs and Benefits for Complying with Potential Retrofit Requirements, CRSS - Retention

Cost Category	Part 27	Part 29	Total
Non-Recurring Costs	$61,763,103	$44,897,959	$106,661,062
Unit Costs	$271,472,558	$127,882,653	$399,355,211
Lifetime Operator Costs	$457,984,100	$168,114,850	$626,098,950
Total Cost	$791,219,761	$340,895,462	$1,132,115,223
Lifetime Benefit	Unknown[1]	Unknown[1]	Unknown[1]

Note:

1. As detailed in the "Retrofit Benefit - CRSS" section, the ROPWG was unable to determine a sufficiently reliable estimate for the CRSS benefit. An attempted calculation of this benefit is presented in Appendix E, but the ROPWG felt that it was too unreliable to include in the main body of this report.

Discussion

Due to the lack of detailed impact and injury data in NTSB accident reports, the ROPWG was unable to determine a reliable estimate of the benefit of incorporating improved retention of occupants and items of mass in the cabin via retrofit (see Appendix E). Although the ROPWG attempted to estimate benefits associated with improved retention (Appendix E), the results are considered unreliable, and the ROPWG is concerned that use of these estimates would provide misleading conclusions.

Nevertheless, without consideration of the unreliable CRSS benefit calculations in Appendix E, the ROPWG was to able make some conclusions in consideration of the remaining available data:

- For Part 27 and Part 29, the cost of retrofitting occupant and items of mass in cabin retention is approximately 30% lower than that for incorporating CRFS.
- FAA study CT-85/11 showed that exposure to fire following an otherwise survivable accident caused a significantly greater number of severe injuries and fatalities than retention failure of occupants or items of mass in the cabin. While the ROPWG acknowledges that changes in the fleet makeup since the study could affect relative risks, the available anecdotal data suggests that post-crash fires following survivable accidents continue to be a significantly greater cause of injury and death than retention failure. As a result, it is likely that the benefit of incorporating CRFS via retrofit greatly exceeds the benefit of improved retention via retrofit.

Therefore, the ROPWG concludes the following:

- For Part 27 and Part 29 helicopters, the 10-year and lifetime costs of incorporating improved retention of occupants and items of mass in the cabin via retrofit likely greatly exceed the benefits.

Additional Considerations

In addition to the monetary costs and benefits outlined in the preceding subsections, the ROPWG considered the following when determining its recommendations for CRFS and CRSS retrofit.

Part 27 Models Where Retrofit is "Not Feasible"

While the majority of Part 27 airframes could be retrofitted with the potential retrofit requirements discussed (though at great cost for many models), there is a small but significant population of helicopter models where the (combined non-recurring and unit) cost of the retrofit would likely exceed the value of the airframe. As documented in the "Retrofit Feasibility" section of this report, the ROPWG estimates that it would not be cost effective to upgrade the following portion of the fleet for the specified requirements:

- CRFS: 45 units (0.5% of fleet)
- CRSS - Dynamic Seats: 316 units (3.4% of fleet)
- CRSS - Improved Retention: 45 units (0.5% of fleet)

These tend to be small helicopters designed in the 1940's and 1950's, which would require nearly complete disassembly and extensive modifications for even these limited requirements. As a result, if the FAA mandates, without exception, the retrofit of the potential retrofit requirements discussed in this section, it is likely that these airframes would be retired/discarded or sold to another country at a large discount. While the overall cost to the industry would be relatively small for the CRFS and Improved Retention requirements, the cost would be extreme for the small number of owners and operators forced to retire their helicopters.

Models Where Retrofit Feasibility is "Low"

For both Part 27 and Part 29 helicopters, a significant portion of the fleet (4%-86%, depending on the requirements; reference Figure 1 through Figure 3) was assigned a retrofit feasibility of "Low" for at least some of the potential retrofit requirements. A "Low Feasibility" designation was assigned to models meeting one or more of the following criteria:

- Major modifications would have to be performed at the factory, or at a service center with factory-level capabilities
- Major performance penalties would be incurred
- Examples of "Low Feasibility" models include helicopters where the cabin would require substantial disassembly and rebuilding to strengthen the underlying structure

While the long-term societal benefit may exceed the costs for certain requirements and models, the initial cost and burden of these upgrades would, nevertheless, be significant for the owners and operators affected. For instance, the average unit cost to retrofit a Part 27 helicopter to comply with the potential CRFS retrofit requirements is $147,045 (Table 4). Since this cost is the average for all models regardless of feasibility level, the cost would be somewhat greater for the 4% of Part 27 helicopters with a "Low" feasibility rating. This initial expense would likely be a greater expense than many owners and operators could afford.

Beyond the monetary cost, the CRSS upgrades may require extensive modifications to the underlying structure. This would likely require ferrying the helicopter to the factory or specialized maintenance facility and leaving the helicopter for an extended period of time while the airframe is partially disassembled, upgraded, and reassembled. The burden of ferrying the helicopter and being without its use for an extended period of time would be significant.

Models with Few Units in Service

The non-recurring costs for developing a retrofit kit are independent of the number of helicopters of that model in the U.S. fleet. Therefore, models with fewer units in service will incur a higher per-unit share of non-recurring costs than models with more units in service. As a result, it may not be economically viable to develop retrofit kits for models with few models in service.

Appendix G provides an analysis of how the combined non-recurring (research & development) and unit (installation) costs vary with the number of units in service. The results are summarized in Table 27 and Table 28.

Table 27. Total Average Per-Unit Cost to Develop and Install Kit to Comply with Potential Retrofit Requirements, Part 27

Units in Service	CRFS	CRSS - Dynamic Seats	CRSS - Retention
1	$7,442,954	$8,538,791	$2,161,661
10	$876,636	$1,150,458	$333,047
20	$511,840	$739,995	$231,458
50	$292,963	$493,717	$170,504
100	$220,004	$411,625	$150,186
500	$161,637	$345,951	$133,932
1000	$154,341	$337,741	$131,900

Note: For reference, the average replacement value of a Part 27 airframe in the U.S. fleet (weighted to account for more numerous models) is $1,240,000.

Table 28. Total Average Per-Unit Cost to Develop and Install Kit to Comply with Potential Retrofit Requirements, Part 29			
Units in Service	**CRFS**	**CRSS - Dynamic Seats**	**CRSS - Retention**
1	$6,295,417	$4,361,945	$2,617,232
10	$925,417	$711,945	$417,232
20	$627,083	$509,167	$295,010
50	$448,083	$387,500	$221,677
100	$388,417	$346,945	$197,232
500	$340,683	$314,500	$177,677
1000	$334,717	$310,445	$175,232

Note: For reference, the average replacement value of a Part 29 airframe in the U.S. fleet (weighted to account for more numerous models) is $7,660,000.

The per-unit cost data in Table 27 and Table 28, in combination with the fleet distribution data in Table 36 and Table 37 (Appendix B), can be used to determine the percentage of the helicopter fleet for which the design and installation costs will exceed a certain monetary value or a certain percentage of the value of the airframe. For instance,

- Part 27: For CRFS, the average replacement value of a Part 27 airframe is $1,240,000 (Table 27), and the average combined CRFS design and installation costs are $292,963 for models with 50 units in service (Table 27). Therefore, the average design and installation cost is greater than or equal to $292,963/$1,240,000 = 23.6% of the replacement value for Part 27 models with less than or equal to 50 units in service. Separately, Table 36 shows that approximately 5.6% of helicopters in the U.S. fleet belong to a model with less than 50 units in service. Therefore, 5.6% of Part 27 helicopters in the U.S. fleet would incur a combined design and installation cost greater than or equal to 23.6% of the value of the airframe.
- Part 29: For CRFS, a similar analysis shows that 8.7% of Part 29 helicopters in the U.S. fleet would incur a combined design and installation cost greater than or equal to 15% of the value of the airframe.

Lastly, in addition to the high cost borne by owners/operators of less common helicopters, an additional problem is that OEM's and STC owners may be unlikely to invest large amounts of time and money to develop a kit for a very limited number of customers, since it may be difficult for the OEMs and STC owners to recoup the development costs.

Reduction of Safety Margins

As discussed in the ROPWG Task 5 CRSS and CRFS reports, the ROPWG members with aircraft engineering and operator expertise expressed concerns about the possible effects of the potential regulatory changes on smaller (less than approximately 3,000 lb gross weight) Part 27 aircraft. The empty weight and fuel capacity/range penalties outlined in this present report (by reference to the ROPWG Task 5 CRSS and CRFS Reports) could potentially increase the accident rate for the following reasons:

- Operation at higher Gross Weights (GW), even when still under Max Gross Take-Off Weight (MGTOW), will reduce power margins. This creates an increased potential for loss of tail rotor effectiveness, settling with power, catastrophic rotor stall, and the inability to prevent collision with obstacles/terrain in power-limited situations.
- Increased empty weight may be offset by decreasing fuel loads. Pilots may experience pressure (self-induced and/or external) to operate closer to established fuel reserves as part of mission completion, leading to a greater incidence of accidents due to fuel exhaustion.
- Operation at higher gross weights will increase mechanical stress on affected aircraft, increasing component fatigue damage, maintenance costs, and the probability of premature component failure.

This reduction in safety margins would decrease the calculated benefit, as the reduction in post-crash thermal injuries (due to CRFS) and blunt force injuries (due to CRSS) would be partially offset by an increase in accidents and their associated non-thermal injuries. Unfortunately, it was not possible to provide a meaningful dollar estimate for the benefit reduction due to the accident rate concerns outlined above. However, the ROPWG believes these factors may be significant, especially for smaller helicopters, and should be carefully considered.

Non-Monetary Benefits of Potential CRFS Retrofit Regulations

The ROPWG Task 5 CRFS Report included a discussion of several non-monetary reasons why the ROPWG favored the adoption of CRFS in newly manufactured, legacy helicopters. While originally written in that context, many of these considerations are equally applicable to the retrofit of CRFS in previously manufactured helicopters. These non-monetary benefits have been edited as required for the present retrofit discussion, and are summarized below:

- It is the opinion of the ROPWG that many, if not most, OEMs and operators would like to implement effective CRFS in their helicopters in order to help prevent post-crash fires and thermal injuries. However, doing so unilaterally would result in increased costs compared to competitors who choose not to make similar changes due to the lack of a Federal requirement for previously manufactured rotorcraft. As a result, while there has been a recent trend towards increased voluntary adoption of CRFS by OEMs and operators, there are still OEMs and operators that would like to implement effective CRFS but are less likely to do so, as the increased cost, increased weight, and decreased range of the CRFS-equipped helicopters will make it more difficult to compete with companies that choose not to implement CRFS.
- Similarly, while there has been a recent trend towards voluntary adoption of CRFS, many segments of the helicopter market remain hesitant to pay an additional cost to voluntarily acquire safety features. A few OEMs cited examples of offering optional CRFS retrofit kits, but the limited sales did not offset the initial development cost. While some segments of the rotorcraft industry are moving forward with implementation of optional CRFS equipment, universal implementation of these life-saving modifications will likely not occur unless they are federally mandated.
- Members of the ROPWG acknowledge the public stigma of the injuries that result from crashes, especially those caused by post-crash fires. Members of the ROPWG represent a cross-section of the rotorcraft industry. This group recognizes that for the good of the public, it is incumbent upon the rotorcraft industry to move forward in implementing safety measures, despite high costs to both OEMs and operators. With a goal of evolving the industry positively towards

preventing thermal and blunt trauma injuries while also managing the financial impact to OEMs, operators, and customers, members of the ROPWG are supportive of the proposed incremental approach that we believe will provide meaningful improvements in rotorcraft safety.

- Some operators are hesitant to purchase upgrade kits and/or aircraft with partially-compliant CRFS, as they wrongly assume fuel systems that are not fully compliant are ineffective at preventing post-crash fires, and/or they are concerned that the benefit that is indeed realized by these systems will not be recognized by their customers. The recognition by the FAA of the effectiveness of partially-compliant CRFS would eliminate these concerns.

Non-Monetary Benefits of Potential CRSS Retrofit Regulations

The ROPWG Task 5 CRSS Report included a discussion of several non-monetary reasons why the group favored the adoption of CRFS in newly manufactured, legacy helicopters. These reasons are equally applicable to the retrofit of CRSS, and are summarized below:

Cost of Spinal Injuries

Army data shows most excessive decelerative force injuries in survivable helicopter crashes are spinal injuries potentially preventable with an energy absorbing seat. Many of the victims of spinal injuries are rendered paraplegic, and in some cases, quadriplegic.[27] The most common location for spinal injuries in helicopter crashes is the thoracolumbar spine. Although these injuries are not immediately threatening to life, many spinal cord injuries below the neck result in a shorter life expectancy, and the cost and suffering involved in these injuries is far greater than that for most blunt force injuries. Therefore, the societal benefit of avoiding these injuries may be higher than the figures supplied by the APO/DOT for serious injuries.

Ease of Egress

Another benefit of effective occupant protection regulations is that increased crashworthiness results in fewer injuries during the impact phase of a crash, which improves an occupant's ability to egress a damaged aircraft. This is vital when the aircraft crashes in water or when there is a post-crash fire. In both of these scenarios, occupants must rely on themselves to egress the aircraft to avoid becoming a drowning or burn victim since rescuers are rarely on scene in time to affect outcomes. Additionally, the fewer injuries a crash victim has, the better he/she is able to take care of himself/herself or fellow occupants, avoid post-crash hazards, and/or summon help. Many victims of crashes find themselves in a survival situation where reduced physical capacity can have tragic consequences.

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[27] Shanahan, D.F. and Shanahan, M.O. Injury in U.S. army helicopter crashes October 1979-September 1985. J. Trauma, 20(4):415-423, 1989.

RECOMMENDATIONS FOR INCORPORATION OF EXISTING ROTORCRAFT PROTECTION REGULATIONS INTO THE EXISTING ROTORCRAFT FLEET

OVERVIEW

This section presents the ROPWG recommendations for the incorporation (retrofit) of the current rotorcraft occupant protection regulation requirements (27/29.561, .562, .785, .952) into the existing fleet. The recommendations are based on the feasibility, cost, and benefit analysis presented in the previous section.

Organization of Recommendations

Note that the presentation of these recommendations is prior to the non-regulatory ROPWG recommendations presented later in this report. This was done for the sake of continuity with the preceding regulatory analysis and should not be interpreted as implying that the additional recommendations presented later are necessarily less critical. **While the occupant protection regulation recommendations presented in this section are considered extremely important by the ROPWG, the ROPWG emphasizes that it considers some of the additional recommendations presented later in this report to be equally critical**.

Scope of ROPWG Regulatory Recommendations

Note that the ROPWG was tasked with providing recommendations on:

> *"...incorporating rotorcraft occupant protection improvements and standards into the existing rotorcraft fleet. Occupant protection standards include either all or part of 14 CFR 27.561, 27.562, 27.785, 27.952, 29.561, 29.562, 29.785, and 29.952, or new alternative proposed performance-based regulations."*

While the ROPWG addresses those specific regulations, ROPWG members also believe that the inclusion of elements of 27.963(g)/29.963(b) (fuel tank puncture resistance), in addition to the recommendations for 27/29.952, is required in order to produce effective CRFS regulations for the existing helicopter fleet. The ROPWG recommends that elements of the requirements of these sections be mandated for incorporation into the existing rotorcraft fleet, as summarized in Table 29 and Table 30 and discussed in detail following the tables. The rationale for NOT recommending the remaining regulations (or parts thereof) is discussed after those that are recommended.

It should be stressed that the ROPWG is recommending these regulatory requirements in the context of the existing rotorcraft fleet only. This report should not be interpreted as making any recommendations for or against the amendment of current CRSS or CRFS regulations, unless explicitly stated otherwise.

Other Considerations

The preceding analysis of CRFS and CRSS effectiveness was based primarily upon analysis of the crash performance of Part 27 rotorcraft since there were insufficient numbers of Part 29 rotorcraft crashes to perform an empirical analysis of their CRFS and CRSS performance. Nevertheless, the ROPWG cautiously recommends that similar rules for Part 29 helicopters be adopted as for Part 27 helicopters, as there was no evidence strongly indicating that a different set of recommendations was more appropriate. This approach is generally consistent with current occupant protection regulations which do not provide separate criteria for Part 27 and 29 helicopters.

When forming its recommendations for retrofit, the ROPWG considered its previous recommendations for newly manufactured, legacy helicopters (ROPWG Task 5 CRFS and CRSS Reports). This was due to the fact that it would not be reasonable to recommend more stringent standards for retrofit into the existing fleet than was already recommended for currently manufactured helicopters, as any retrofit requirements would have to be implemented in the field without the obvious advantages of making changes to a helicopter under construction in a factory setting. In other words, if implementation of all or a part of the current regulations was previously deemed not practical or affordable for helicopters being manufactured, implementation of these changes certainly would not be practical or affordable for older already fielded airframes.

The recommendations presented in this report are consensus recommendations derived by a majority vote of ROPWG members. Members who did not agree with any recommendation presented in this report were encouraged to provide non-concurrence statements, which are included in the ROPWG Voting Members Statements of Non-Concurrence section at the end of this report.

SUMMARY OF RECOMMENDATIONS FOR INCORPORATION OF EXISTING ROTORCRAFT PROTECTION REGULATIONS INTO THE EXISTING FLEET

The ROPWG recommendations for incorporation (retrofit) of existing rotorcraft protection regulations into the existing fleet are summarized in Table 29 and Table 30, and discussed in detail following the tables.

Table 29. Current Occupant Protection Regulations Recommended for Incorporation into the Existing Rotorcraft Fleet - CRFS

Regulation	Recommendation	Notes
27/29.952(a)(1)(2)(3)(5)(6): Drop test requirements	Recommended	Regulation should allow bladder-only drop test (i.e., surrounding structure optional).
27/29.952(f): Other basic mechanical design criteria	Recommended	Retrofit of previously manufactured rotorcraft should include other CRFS features “as far as practicable”.
27.963(g)/29.963(b): Fuel tank puncture resistance	Recommended	250 lb minimum puncture resistance should be required.

Table 30. Current Occupant Protection Regulations Recommended for Incorporation into the Existing Rotorcraft Fleet - CRSS

Regulation	Recommendation	Notes
27/29.785(c) and (g): Seats, berths, litters, safety belts, and harnesses	Recommended	Recommendation limited to the retrofit of upper torso restraints (shoulder harnesses).

DISCUSSION OF OCCUPANT PROTECTION REGULATIONS RECOMMENDED FOR INCORPORATION (RETROFIT) INTO THE EXISTING ROTORCRAFT FLEET

27/29.952(a)(1)(2)(3)(5)(6), 27/29.952(f), and 27.963(g)/29.963(b): Fuel Cell Drop Test Requirements and Bladder Puncture Resistance

Recommendation

The ROPWG strongly recommends that, with few exceptions, that all Normal Category (Part 27 and Part 29) helicopters in the U.S. fleet be required to have crash resistant fuel bladders that meet the following requirements:

- 27/29.952(a)(1), (a)(2), (a)(3), (a)(5), (a)(6): Fuel tank/bladder drop test conducted either in-structure or out of structure at the tester's discretion
- 27/29.952(f): Other CRFS features "as far as practicable"
- 27.963(g)/29.963(b): Fuel bladder must have a minimum puncture resistance of 250 lb

Discussion

The ROPWG considered the following factors when making this recommendation:

- CT-85/11 identified post-crash fire resulting in thermal injuries as the most significant hazard in survivable helicopter crashes. It is also one of the hazards most easily prevented.
- Crash resistant fuel bladders meeting the requirements detailed above are extremely effective at preventing post-crash fires and thermal injuries following survivable accidents, even in the absence of all other CRFS features (reference: "Retrofit Benefit - CRFS ").
- Upgrading the existing fleet to include uniformly fuel bladders is expected to prevent approximately 143 fatalities due to thermal injury over the lifetime of the current fleet (reference: "Retrofit Benefit - CRFS ").
    - A significant, though unknown, number of severe thermal injuries are also expected to be prevented.
- For Part 27 helicopters, the monetary benefit of the avoided thermal fatalities and thermal injuries is equal to or greater than the total cost of the upgrades (reference: "Cost/Benefit Analysis, CRFS").
- For Part 29 helicopters, the monetary benefit of the avoided thermal fatalities and thermal injuries is likely modestly lower than or equal to the total cost of the upgrades (reference: "Cost/Benefit Analysis, CRFS").
- 27/29.952(f) and the associated Advisory Circular (AC) guidance address the same topics as 27/29.952(c), (d), and (e), but have a regulatory standard ("as far as practicable") that is more appropriate for incorporation into previously manufactured rotorcraft. As a result, the ROPWG is recommending the incorporation of 27/29.952(f) rather than 27/29.952(c), (d), and (e).
- Additional non-monetary considerations as follows (reference "Non-Monetary Benefits of Potential CRFS Retrofit Regulations"):
    - A mandate to install CRFS would allow operators to install CRFS without incurring a competitive disadvantage over operators who would choose not to if installation was optional.
    - While segments of the rotorcraft industry are moving forward with implementation of optional CRFS equipment, universal implementation of CRFS will likely not occur unless made mandatory by regulation.

Considering all the above, the ROPWG strongly recommends that the proposed CRFS requirements be mandated for all Normal Category rotorcraft operating in the U.S., and that only a limited number of highly considered exceptions be granted. However, the ROPWG recognizes that this mandate will impose extreme hardship on some operators. For this reason, the following section presents the content of the discussions held by the ROPWG regarding the possibility of exceptions.

Possible Exceptions

The ROPWG recognizes that compliance with this requirement may impose significant financial hardships on some operators, in particular:

- Those operating helicopters that do not have approved retrofit CRFS already available
- Those operating rare or unique rotorcraft
- Private owners who operate their helicopter for personal use only
- Reference: "Cost/Benefit Analysis, Additional Considerations" for further discussion

While allowing exceptions for instances like those described may initially seem reasonable, further deliberation uncovers many problems with this approach including:

- Exceptions for rare rotorcraft, or those that do not have a CRFS already available, will significantly reduce the likelihood that anyone will develop a CRFS retrofit kit for these helicopters.
- Exceptions for certain rotorcraft will provide an "unfair" competitive advantage to those operators that already own those aircraft, versus those that are forced to perform a CRFS retrofit.
- Exceptions for private operators would significantly reduce the number of avoided thermal injuries and fatalities. This is particularly true if the exceptions allowed the carrying of passengers, as the pilot and potentially multiple passengers would continue to suffer thermal injuries following many survivable accidents.

In light of these considerations, the ROPWG concluded that it is unlikely that there is any exception language that will satisfy all affected parties and not result in a significant number of injuries that could have otherwise been prevented. The ROPWG also concluded that given the complexity of the considerations with regard to possible exceptions, it was best for the ROPWG to provide insight and general guidance into the ramifications of allowing or not allowing exceptions, rather than trying to recommend a specific set of exceptions. Therefore, with the goal of reducing thermal injuries and fatalities to the extent possible, the ROPWG recommends that the FAA consider the following with regards to possible exceptions to the proposed rule:

- Exceptions should **NOT** be permitted for any of the following operations:
    - Any “commercial” operations, to include:
        - Carrying passengers for hire
        - Flight with paid pilots and/or paid crewmembers
        - Flight training
    - Charity operations
- It may be reasonable to allow an exception for private owners. If such an exception is allowed, it may be appropriate to limit operations to solo flight (flight with passengers would be prohibited, whether paid or unpaid).

Note that the ROPWG deliberately chose the word “exception”, as opposed to “exemption”, when discussing those that would not have to comply with the rule. The intent of the ROPWG recommendation is that the rule itself would detail which aircraft/operations/operators/etc. would not be required to comply. This would provide a greatly reduced certification burden versus necessitating individual “exemptions” to a rule that was written to require compliance by all aircraft/operations/operators/etc.

27/29.785 (c) and (g): Installation of Upper Torso Restraint (Shoulder Harness) at All Seating Positions

Background

Data from CT-85/11, along with military data, has shown that a lack of an upper torso restraint (shoulder harness) or ineffectiveness of upper torso restraint was a significant factor in many injuries in survivable crashes. These injuries were attributed to one of the following hazards in CT-85/11:

- Body struck aircraft structure because design provided inadequate clearance and/or restraint allowed excessive motion
- Body struck aircraft structure due to lack of upper torso restraint

Recognizing the large benefit and relatively low cost of incorporating shoulder harnesses, in the early 1990s, the FAA issued a special retroactive requirement mandating that all seats in all helicopters manufactured after September 16, 1992, be equipped with a seat belt and shoulder harness. However, helicopters manufactured prior to this date were excluded from the mandate.

The retrofit of shoulder harnesses could be mandated through the requirement to comply with 27/29.785(c) and (g). While compliance with 27/29.785 was among the CRSS regulations studied in the preceding section, the shoulder harness requirement is just one small factor in that analysis. As a result, the cost and benefit data from the previous section cannot be used to specifically evaluate the cost and benefit of a requirement to retrofit shoulder harnesses.

ROPWG Analysis

The OEMs represented on the ROPWG were asked to estimate what percentage of seats in their previously manufactured helicopters are equipped with shoulder harnesses. While it was difficult to determine this with precision due to the existence of non-OEM controlled STC kits as well as the large number of models produced over the last 50+ years, the ROPWG estimates that approximately 85% of seats in the U.S. helicopter fleet are equipped with shoulder harnesses.

While quantitative cost and benefit data is not available for a potential shoulder harness retrofit requirement, the ROPWG arrived at the following qualitative conclusions after a discussion with the OEM representatives on the ROPWG, and after a thorough review of all previous accident studies referenced in the present report:

- Upper torso restraints that prevent upper torso flailing into fixed objects or deforming structure are absolutely critical to occupant crash survival. Proper upper and lower body restraint is probably the single most important factor in occupant crash survival and without proper restraint, occupants are subject to serious or fatal injury in even minor crashes.
- The installation of shoulder harnesses would provide a very significant benefit in many accidents for occupants of those seats where a shoulder harness is added.
- The cost of developing and installing shoulder harness retrofit kits is likely to be fairly small for most models.
- As discussed in the previous section, per-unit research and development costs (strength testing of attachment points) could be significant for models with few units in service.

Recommendation

In consideration of the discussion above, the ROPWG strongly recommends that, without exception, all Normal Category (Part 27 and Part 29) helicopters in the U.S. fleet be required to have upper torso restraints (shoulder harnesses) at all seating positions. The recommended time period for implementation of this requirement is 3-5 years following acceptance of the final rule.

Note that this recommendation is intended only to require the installation of shoulder harnesses where they are currently not installed. It is NOT recommended that previously-installed shoulder harnesses be replaced with shoulder harnesses that meet more recent strength requirements. As with the 27/29.2 requirement for installing shoulder harnesses in all newly manufactured helicopters, the rule should be written to require the installation of shoulder harnesses that meet the strength requirements of the original certification basis of the helicopter.

Possible Exceptions

As with the fuel bladder recommendations in the previous subsection, the ROPWG recognizes that compliance with the shoulder harness requirement may impose significant financial hardships on some operators, and that the FAA will be under considerable pressure to grant exceptions to a shoulder harness mandate. The considerations regarding possible exceptions to a shoulder harness mandate are the same as those previously discussed for the recommended CRFS mandate, except with “CRSS” replacing “CRFS”, and “blunt force injury” replacing “thermal injury”. Rather than repeat that discussion here, the reader is referred to the exception discussion presented in the recommendation section for 27/29.952 and 27/29.963.

OCCUPANT PROTECTION REGULATIONS NOT RECOMMENDED FOR INCORPORATION (RETROFIT) INTO THE EXISTING ROTORCRAFT FLEET

SUMMARY

Table 31 and Table 32 list the current occupant protection regulations that are NOT recommended for incorporation (retrofit) into the existing rotorcraft fleet. The rationales for not recommending these regulations are discussed following the tables.

Table 31. Current Occupant Protection Regulations NOT Recommended for Incorporation (Retrofit) into the Existing Rotorcraft Fleet – CRFS

Regulation	Recommendation	Notes
27/29.952(a)(4) Drop test requirements	NOT recommended	Regulation should allow bladder-only drop test (i.e., surrounding structure optional).
27/29.952(b): Fuel tank load factors	NOT recommended	Regulation would be extremely difficult to incorporate into previously manufactured helicopters, while providing little if any benefit.
27/29.952(c): Flexible fuel hoses and breakaway fittings	NOT recommended	27/29.952(f) and the associated AC guidance address these same items but have a regulatory standard that is more appropriate for retrofit into a previously manufactured helicopter.
27/29.952(d): Frangible or deformable structural attachments	NOT recommended	
27/29.952(e): Separation of fuel and ignition sources	NOT recommended	
27/29.952(g): Rigid or semirigid fuel tanks	NOT recommended	There is ambiguity with the rule and associated Advisory Circular as to what types of fuel tank construction are subject to the rule. Additionally, there is no evidence that the rule would improve post-crash fire and thermal injury prevention.

Table 32. Current Occupant Protection Regulations NOT Recommend for Incorporation (Retrofit) into the Existing Rotorcraft Fleet – CRSS		
Regulation	**Recommendation**	**Notes**
27/29.561(b)(3): Restraint of occupants and items of mass in cabin	NOT recommended	While the regulation would provide some benefit, it would be extremely difficult to incorporate into many previously manufactured helicopters.
27/29.561(c): Restraint of items of mass above and behind cabin	NOT recommended	
27/29.561(d): Restraint of fuel tanks below floor	NOT recommended	Regulation would be extremely difficult to incorporate into previously manufactured helicopters, while providing little if any benefit.
27/29.562(b): Dynamic seat testing	NOT recommended	While the regulation would provide some benefit, it would be extremely difficult to incorporate into many previously manufactured helicopters.
27/29.785(a), (b), (d), (e), (f), (h), (i), (j), (k): Seats, berths, litters, safety belts, and harnesses	NOT Recommended	Recommendation limited to the retrofit of upper torso restraints (shoulder harnesses). The remaining paragraphs would be extremely difficult to incorporate into many previously manufactured helicopters.

CRFS DISCUSSION

Overview

The ROPWG Task 5 CRFS Report concluded the following with regards to the effectiveness of partially-compliant CRFS at preventing post-crash fires and thermal injures:

> *"Among partially-compliant designs that passed a 50-foot drop test (with or without structure) and had a puncture resistance of at least 250 lb (models 1-4), crash performance was essentially identical to that of fully-compliant helicopters. Both groups had no significant post-crash fires or thermal injuries for survivable crashes (Severity 1-3). This is in contrast to non-compliant helicopters that had an 11% rate of post-crash fire due to fuel spillage following survivable crashes."*

Note in particular that the partially-compliant designs referenced above were at least partially non-compliant with the follow regulations:

- 27/29.952(a)(4): In-structure drop test requirements
- 27/29.952(b): Fuel tank load factors
- 27/29.952(c): Flexible fuel hoses and breakaway fittings
- 27/29.952(d): Frangible or deformable structural attachments
- 27/29.952(e): Separation of fuel and ignition sources

Since these sections of the regulations were found to have little or no effect on the prevention of post-crash fires and thermal injuries, and since mandating these requirements for incorporation (retrofit) into previously manufactured helicopters would entail significant cost and weight penalties, the ROPWG is recommending that these regulations NOT be required for retrofit.

Note that 27/29.952(f) and the associated AC guidance address the same topics as 27/29.952(c), (d), and (e), but have a regulatory standard ("as far as practicable") that is more appropriate for incorporation into previously manufactured rotorcraft. As a result, the ROPWG is recommending the incorporation of 27/29.952(f) rather than 27/29.952(c), (d), and (e).

Comparison with ROPWG Task 5 CRFS Report Recommendations for Newly Manufactured, Legacy Helicopters

Note that the requirements recommended in the ROPWG Task 5 CRFS Report for newly manufactured, legacy helicopters also include:

- Requiring that fuel bladders dropped out of structure meet a 370 lb puncture resistance (versus the 250 lb requirement recommended by the ROPWG for retrofit)
- Requiring the installation of flexible fuel lines, breakaway valves, and fully compliant rollover vent valves (not recommended by the ROPWG for retrofit)

The ROPWG estimates that mandating these regulations for retrofit would add approximately $81,000,000 to the combined Part 27/29 non-recurring and unit costs and would add an unknown amount to operator costs, without appreciably improving post-crash fire and thermal injury prevention. The cost would be due to an additional approximately 3,600 helicopters (32% of the U.S. fleet) that would be required to undergo retrofit modifications that are unlikely to yield a significant benefit. This additional burden is determined to be of minimal benefit for reasons as follows:

- The 370 lb puncture resistance requirement would mandate the replacement of fuel bladders currently installed in several thousand previously manufactured helicopters (reference Model 1, 2, and 4 from the ROPWG Task 5 CRFS Report, Table 4). The bladder design for these helicopters meets a minimum 250 lb puncture requirement, but not 370 lb. Also, Models 1 and 2 were drop tested out of structure before 27.952 was adopted. As a result, bladders from Models 1, 2, and 4 do not meet the ROPWG recommendations for newly manufactured, legacy helicopters.
- Accident data over a 30-year time period has shown these bladders/fuel systems to be extremely effective at preventing post-crash fires and thermal injuries following survivable accidents (reference the ROPWG Task 5 CRFS Report). Therefore, requiring replacement of these bladders with nearly identical bladders would greatly increase the cost and burden of this rule while providing little or no added benefit.
- The flexible fuel line, breakaway valve, and fully compliant rollover vent valve requirements would necessitate the modification of several thousand helicopters that partially, but not fully, meet the requirements and intentions of these rules (reference Model 4 from the ROPWG Task 5 CRFS Report, Table 4). Accident data shows that the fuel systems in these helicopters have been extremely effective at preventing post-crash fires and thermal injuries following survivable accidents. Therefore, requiring the addition of flexible fuel lines, breakaway valves, and fully compliant rollover vent valves would greatly increase the cost and burden of this rule while providing little or no benefit.

Comparison with Full Compliance

Requiring full compliance to 27/29.952 would dramatically increase costs (monetary and performance) even further, due primarily to the fuel tank load factor requirements of 27/29.952(b); this requirement would be extremely difficult to incorporate into most previously manufactured airframes due to the extensive structural modifications that would have to be performed in order to react the fuel tank crash loads. As detailed in the ROPWG Task 5 CRFS Report, helicopters that fully comply with 27/29.952(b) were shown to be no more effective at preventing post-crash fires and thermal injuries following survivable accidents than those that meet the primary requirements discussed in this section. As a result, requiring full compliance to 27/29.952 via retrofit would dramatically increase costs for little if any increase in safety.

Additional Discussion

The ROPWG Task 5 CRFS Report, section "Discussion of Recommendations (Table 12)", contains a more detailed discussion of why some of these regulations were not recommended for incorporation into newly manufactured, legacy helicopters. Since incorporating these regulations into previously manufactured helicopters would be even more difficult, but no more effective, the rationale given in the referenced section applies to the present retrofit discussion as well. For convenience, the relevant parts of the referenced discussion are reproduced in Appendix H of the present report.

CRSS DISCUSSION

Overview

The data presented earlier in the "Retrofit Feasibility" and "Cost/Benefit Analysis, CRSS" sections showed that while the following regulations would likely provide some benefit, they would be extremely difficult to incorporate into previously manufactured helicopters:

- 27/29.561(b)(3): Restraint of occupants and items of mass in cabin
- 27/29.561(c): Restraint of items of mass above and behind cabin
- 27/29.562(b): Dynamic seat testing
- 27/29.785(a), (b), (d), (e), (f), (h), (i), (j), (k): Seat, berths, litters, safety belts, and harnesses

Dynamic Seat Considerations

As discussed in the "Retrofit Feasibility" section, the difficulty in incorporating dynamic seats into previously manufactured helicopters is due to the following reasons:

- The vertical dynamic seat test requires a significant volume underneath the seats for stroking/energy absorption, and many previously manufactured helicopters were built without sufficient free space. As a result, complying with this requirement would involve relocating or significantly modifying many critical helicopter system components such as fuel tanks and control systems. This would require redesigning and rebuilding the cabin almost from scratch, and redesigning and remanufacturing several major systems.
- Many small helicopters have integral seats, meaning the seat is a sheet metal box riveted into the cabin, as opposed to the bolt-in seats found in most larger helicopters and airplanes. Modifying these seats would require the disassembly of major portions of the cabin, and significant sheet metal rework.
- Helicopters with existing, non-compliant, bolt-in seats often do not have sufficient floor and/or ceiling strength to fully restrain the seats during dynamic seat tests. As a result, significant structural rework would be required to strengthen the floor and cabin around the seat attachment points.

Due to these difficulties, mandating the incorporation of dynamic seats (27/29.562(b)) into previously manufactured helicopters is not practicable, and is therefore not recommended.

Improved Retention of Occupants and Items of Mass in the Cabin Considerations

As discussed in the "Retrofit Feasibility" section, the difficulty in incorporating improved retention of occupants and items of mass in the cabin into previously manufactured helicopters is due to the following reasons:

- Increasing occupant retention strength is more difficult than simply using stronger bolts to affix the seat belts and/or seats to the floor and ceiling, since the cabin structure around the attachment points needs to be strong enough to withstand the loads imparted during crashes and crash tests. Many older designs do not have sufficient strength in these areas to meet the current requirements, and would, therefore, require significant structural modifications, which is very difficult in previously-manufactured helicopters.
- Strengthening the integral seats found in many small helicopters would require the disassembly of major portions of the cabin, and significant sheet metal rework.

Due to these difficulties, mandating the incorporation of improved retention of occupants and items of mass in the cabin (27/29.561(b)(3)) into previously manufactured helicopters is not practicable, and is therefore not recommended.

Restraint of Items of Mass Above and Behind Cabin Considerations

As discussed in the ROPWG Task 5 CRSS Report, it would be extremely difficult to mandate this rule in newly manufactured, legacy helicopters because it would require extensive redesign and strengthening of structure both in close proximity to the item and, in many cases, distant supporting structures as well. This would result in significant costs in design and fabrication combined with significant weight penalties. These difficulties would be even greater in previously manufactured helicopters, as the strengthening would require significant disassembly and modification of the existing structure.

Table 2 from the ROPWG Task 5 CRSS Report demonstrates that the ranking of this hazard is low (Hazard Ranking #8) and the percentage of life-threatening injuries associated with this hazard is zero.

Since the hazard ranking associated with this regulation is low, and since implementation would be extremely difficult and costly, the ROPWG recommends that this rule NOT be mandated for incorporation (retrofit) into previously manufactured helicopters.

Also, note that in the referenced document, the ROPWG considered a requirement for 27/29.561(c) at reduced g-loads, with the idea that a modest increase in the strength of the structure might be more practicable than full compliance, but still provide significant benefit. The analysis found that (in newly manufactured, legacy helicopters) the weight penalties at reduced g-loads were still excessively high in comparison to the anticipated benefit. This would be true for previously manufactured helicopters as well.

27/29.561(d): Restraint of Fuel Tanks Below Floor

In the ROPWG Task 5 CRFS Report, the working group was unable to find any evidence that failure of under floor tank retention was a significant contributing factor to post-crash fires or blunt force injuries in survivable crashes (see the ROPWG Task 5 CRFS Report). Also, OEMs reported that complying with this section in newly manufactured, legacy helicopters would involve considerable cost and weight penalties. These cost and weight penalties would be even greater for previously manufactured helicopters.

Since the Working Group could not determine that compliance would result in an increase in safety in survivable crashes, and since considerable cost and weight penalties would be incurred, implementation of this rule is NOT recommended for previously manufactured helicopters.

DEVELOPMENT OF RECOMMENDATIONS UNRELATED TO INCORPORATION OF EXISTING ROTORCRAFT OCCUPANT PROTECTION REGULATIONS

OVERVIEW

In its deliberations to develop its Task 6 recommendations, the ROPWG not only considered potential regulatory interventions (those presented in the previous section), but also more novel approaches to improve crash protection in the existing fleet including:

- Educational or incentive approaches
- Promulgation of industry standards
- Recommendations for use of personal protective equipment (PPE)
- Recommendations for new research
- Considerations for Public Rotorcraft
- Improvements to existing rotorcraft occupant protection regulations
- Changes to current law related to aircraft accident investigation
- Means of funding enhanced occupant protection in the existing rotorcraft fleet

The process for forming and evaluating these potential non-regulatory recommendations is discussed in this section.

INTERVENTION STRATEGIES

The ROPWG used a broad approach to develop its Task 6 recommendations to the ARAC/FAA that was derived in part from the Commercial Aviation Safety Team (CAST)/General Aviation Joint Steering Committee (GAJSC) scoring process described in the U.S. Helicopter Safety Team (USHST) Report.[28] Since the CAST process was developed for scoring (prioritizing) interventions to prevent injury in specific accidents, the process had to be somewhat modified to apply to the more general situation being addressed in Task 6, where hazards, not specific accidents, were addressed.

CAST/GAJSC Scoring Process

In the USHST Study, a team of subject matter experts (SMEs) examined a set of fatal helicopter accidents and, for each accident, assigned a "Standard Problem Statement" (SPS) to describe the specific problems underlying the accident (*e.g.*, what things went wrong and contributed to the fatal outcome?) and any contributing factors, if applicable. For each SPS, the SMEs then developed one or more Intervention Strategies (IS's) that might have mitigated injury in each analyzed crash.

After identifying the problems and interventions strategies, the SMEs then scored each standard problem statement on a scale of 0 to 6 for:

- P1: The importance of the SPS in contributing to the particular fatal accident being analyzed
- A: The applicability of the SPS in contributing to all future fatal accidents/fatalities

[28] U.S. Helicopter Safety Team (USHST). Helicopter Safety Enhancements: Loss of Control-Inflight, Unintended Flight in IMC, and Low-Altitude Operations, USHST Report, October 3, 2017.

Each intervention strategy also was scored on a scale of 0 to 6 for:

- P2: In the "perfect" world, how effective will the IS be in eliminating fatal accidents/fatalities related to this SPS?
- C: In the "real" world, how effective will the IS be in eliminating fatal accidents/fatalities related to this SPS (confidence level)?

The P1, A, P2, and C values were input into the mathematical formula, developed by both the CAST and GAJSC, to calculate Overall Effectiveness (OE).[29]

Each Intervention Strategy was further scored for feasibility on a scale of 1 to 3 across six factors (technical, financial, operational, schedule, regulatory, and sociological), which were then averaged. The final score for each IS was the product of the Overall Effectiveness and Feasibility (OE*F). The final scores were used to rank the ISs.

The twenty-five highest ranked IS's were assigned to an individual expert or a team of subject matter experts from the USHST study to develop each into a detailed helicopter safety enhancement or H-SE, which were used to "achieve prioritized, detailed implementation plans".

ROPWG Scoring Process

The ROPWG took a slightly different approach than the USHST in developing its prioritized list of intervention strategies to improve crash safety in existing helicopters. Standard Problem Statements (SPS's) were extracted from the crash hazards identified in CT-85/11, which was a study of all survivable crashes during a 5-year period, published in 1985 (see the ROPWG Task 5 CRFS and CRSS Reports). Each SPS identified a general hazard in survivable crashes as opposed to a hazard identified in a specific crash. Table 33 shows the 11 SPSs derived from CT-85/11 plus two additional SPSs that were added by the ROPWG to cover problems not addressed in CT-85/11.

Table 33 also shows the CT-85/11 hazard ranking and the accumulated Abbreviated Injury Score (AIS) attributed to that crash hazard (SPS). P1 (the relative severity of the SPS in contributing to serious injuries and fatalities) for each SPS was estimated based upon the hazard ranking and cumulative AIS. The cumulative AIS is the summation of all AIS ratings for survivable accidents attributable to a particular hazard and considers injury frequency (number of injured occupants) and injury severity and is only useful for ranking the relative severity of each hazard (SPS).

[29] Ibid.

Table 33. Standard Problem Statements and Derived P1				
Priority	**SPS (Hazard)**	**CT-85/11 Hazard Rank**	**CT-85/11 Cumulative AIS**	**P1**
1	Body exposed to fire when fuel system failed on impact	1	147	6
2	Body received excessive decelerative force when aircraft and seat allowed excessive loading	2	145	6
3	Body struck aircraft structure because design provided inadequate clearance and/or restraint allowed excessive motion	4	87	4
4	Body struck aircraft structure due to lack of upper torso restraint	5	82	4
5	Body struck aircraft structure because restraint was not properly used	7	29	3
6	Body struck aircraft structure when structure collapsed excessively - to include temporary collapse/elasticity	8	22	3
7	Body struck aircraft structure when seat failed	9	12	1
8	Body struck by external object when object entered occupied space	11	12	1
9	Body struck aircraft structure when restraint system failed	12	8	1
10	Body injured during post-crash egress	13	2	1
11	Body injured from internal flying debris/equipment	0	0	1
12	Lack of incentives to prompt cultural change	N/A	N/A	3
13	Lack of FAA oversight of Public Aircraft Operations (PAO)	N/A	N/A	2

For each identified SPS, potential intervention strategies were proposed in a "brainstorming" session of the ROPWG. ROPWG members were not restricted in the number or content of proposed ISs except by the general considerations described above. In fact, members were encouraged to "think outside the box" and explore novel approaches to mitigating hazards beyond typical engineering or regulatory solutions. This process produced a total of 92 ISs, many of which were novel and some were quite impractical. Each proposed IS was then assigned to one of the 13 SPSs (Table 33). ISs related to accident prevention and human factors were generally not considered since the ROPWG was tasked to make recommendations related to occupant protection after a crash has occurred rather than on preventing the crash. When similar strategies were combined and duplications removed, the total number of ISs remaining for scoring and further consideration was 85 (see Appendix C for the complete list).

The scoring factors — A, P2, C and the six feasibility factors — for each of the 85 ISs were then scored in a two-day ROPWG meeting by a vote of voting members of the ROPWG using the method described above. Appendix C shows the scoring results including the Overall Effectiveness and Feasibility (OE*F) for each IS.

The scoring results were used to give the working group a general sense of the perceived merits of each of the proposed ISs. Considering the scoring results, the proposed list of ISs was further narrowed and ranked using a more subjective process. The remaining ISs were divided among four task groups who refined the wording of each remaining IS and recommended elimination of ISs that were clearly impractical based upon expert knowledge and the previously determined scoring results. Each remaining intervention was assigned to one of the following categories:

1. Recommendations for Implementation of Current Occupant Protection Regulations to the Existing Rotorcraft Fleet
2. Recommendations for Educational/Incentive programs to improve the Crash Safety of the Existing U.S. Rotorcraft Fleet
3. Recommendations to Review and Improve Industry Standards
4. Recommendations for Use of Personal Protective Equipment
5. Recommendations for Changes to Enhance/Improve Current Occupant Protection Regulations
6. Recommendations for Research to Improve the Crash Safety of Rotorcraft (FAA, NASA, Private Sector)
7. Recommendations for Public Rotorcraft

A consolidated list and description of these remaining intervention strategies is provided in Appendix D. These ISs were evaluated for practicality and appropriateness based upon knowledge of available technology and a verified need for the proposed intervention. It was agreed that, for many of the proposed ISs, while appearing to be both practical and appropriate, the need for the proposed intervention had not been established from evidence from crash investigations or recent epidemiological studies. For instance, several proposed interventions recommended specific improvements in helicopter restraint or seat design based upon hazards identified in epidemiological studies of military helicopter crashes or automobile crashes. While the results of military and automobile epidemiological studies suggest that the identified problems might also exist in civil helicopters, there have been no recent studies to verify that seat or restraint failures are occurring in survivable crashes of civil helicopters, and if they are occurring, how common they are and how many injuries/fatalities they cause. Consequently, proposed intervention strategies directed toward mitigating hazards of unknown frequency and severity were relegated to category #6 (Recommendation for Research) since further research is clearly needed to establish that the specific failures addressed by these interventions are, in fact, occurring in the field and the extent to which they are occurring.

The final disposition of all IS's was determined by the voting members of the ROPWG at the final meeting of the ROPWG held on June 13-14, 2018. Each of the IS's was assigned to one of four action categories by a majority vote of all ROPWG voting members. These categories were:

1. Highly recommended for implementation as soon as practicable
2. Recommended
3. Requires research
4. Not recommended

When reasonable, similar ISs were combined into a single intervention strategy. This process reduced the number of ISs to the 20 final ROPWG recommendations presented in the next section. While cost-benefit data was available for the ISs related to implementation of current occupant protection regulations into the existing rotorcraft, it was not available for non-regulatory recommendations.

Other Considerations

Target Audience

Not all of the final recommendations were directed toward the FAA and/or the NTSB; the ROPWG also has some general recommendations directed toward industry professional organizations or the insurance industry that, if enacted, would probably contribute significantly to the improvement of overall helicopter crash safety and accident prevention. These recommendations are listed in a separate category because they do not necessarily fall under the direct purview of the FAA and/or the NTSB. However, the FAA can participate in enacting these recommendations by sponsoring conferences or by tasking the ARAC to form a working group to study the issues addressed by these ROPWG recommendations.

General Considerations

As in the previous studies performed by the ROPWG, for Task 6, the decision on whether to recommend promulgation of a particular occupant protection regulation or portion of any regulation or whether to recommend a proposed strategy to mitigate an identified injury hazard was based on several overriding principles:

1. The recommendation must address an injury hazard that has been identified and generally quantified through studies of the crash performance of the U.S. rotorcraft fleet. In other words, the hazard must have been shown to be real and not just theoretical.
2. Adoption of the recommendation must be expected to result in a decrease in serious or fatal injuries to occupants in survivable helicopter crashes.
3. The technology required to implement the proposed mitigation must be readily available except for recommendations that relate to proposals for research or further study.
4. The recommended intervention should be practicable.
5. The proposed regulatory mitigation must be applicable to the entire fleet.

“Practicable” as defined by the FAA “means that within the major constraints of the applicant’s design (e.g., aerodynamic shape, space, volume, major structural relocation, etc.), this standard’s criteria should be met”. The level of practicability is much higher in a new design project than in a retrofit project.

ROPWG TASK 6 RECOMMENDATIONS

OVERVIEW

For clarity, convenience, and emphasis, all ROPWG recommendations are discussed in this section. Since the recommendations for incorporation of fuel bladders and upper torso restraints have already been discussed in this report, they are only summarized in this section.

Note that while the analysis of the recommendations for the incorporation of existing occupant protection regulations into the existing fleet was performed in a prior section, this organization was chosen for the sake of clarity and continuity given the extensive analysis required. This organization should not be interpreted as implying that the non-regulatory recommendations presented in this section are necessarily less critical. **While the occupant protection regulation recommendations are considered extremely important by the ROPWG, the ROPWG considers some of the non-regulatory recommendations to be equally critical**.

Table 34 provides a summary of the ROPWG Task 6 recommendations for improving the crash safety of previously manufactured helicopters. Full descriptions of these recommendations follow the table.

Table 34. Summary of ROPWG Task 6 Recommendations
<u>High Priority Recommendations to the FAA:</u>
1. 27/29.952(a)(1)(2)(3)(5)(6), 27/29.952(f), and 27.963(g)/29.963(b): The FAA should require, in all rotorcraft, the installation (retrofit) of crash resistant fuel bladders that meet the requirements of the 50-foot fuel cell drop test in or out of structure, and that demonstrate a minimum of 250 lb puncture resistance. Note: Some potential exceptions to this rule are discussed in the main body of the report.
2. 27/29.785(c) and (g): The FAA should require installation (retrofit) and proper usage of upper torso restraints (shoulder harnesses) in all rotorcraft seating positions in all rotorcraft. Note: Some potential exceptions to this rule are discussed in the main body of the report.
3. 27/29.785: The FAA should mandate the use of appropriate restraints for all occupants of rotorcraft, regardless of the age of the occupant. “Lap Children” should not be permitted in rotorcraft.
<u>High Priority Recommendations for Legislative Changes:</u>
1. The NTSB and the FAA should seek the authority and funding through whatever means available to increase the scope of their aircraft accident investigations to include determinations of impact conditions, occupant injuries, and injury mechanisms.
2. The FAA should recommend that Congress offer tax credits and/or other financial incentives to all rotorcraft operators for installing critical safety equipment and/or upgrading to helicopter models equipped with critical safety equipment.
<u>Recommendations for Research/Safety Studies:</u>
1. The FAA should conduct a comprehensive injury study, similar to that reported in FAA CT-85/11, to determine impact conditions, injuries sustained by all occupants, and occupant injury mechanisms for a large set of recent rotorcraft accidents.
2. The FAA should conduct a study to determine the need for and the potential effectiveness of supplemental restraint systems.
3. The FAA should study whether adjustable weight energy absorbers and/or energy attenuating seat cushions would provide a practicable and effective means of improving vertical energy attenuation.

4.	The FAA should conduct a study to determine the appropriate capabilities for flight and impact data recording systems to enable collection of flight data as well as impact velocity, acceleration, and condition data.
5.	The FAA should conduct a study to ascertain the extent to which integrating Human Factors processes and education (HRO, Just Culture, HFACS, CRM, etc.) into helicopter operations would reduce accidents and contribute to reduced injury rates in crashes.
Recommended Changes to Current Regulations/Guidance:	
1.	The FAA should change TSO-C80, 27/29.952(g), and 27.963(g)/29.963(b) to require tear and cut resistance as well as the presently required puncture resistance in CRFS flexible bladder constructions. Note that this recommended tear and cut resistance requirement should be limited in applicability to new designs.
2.	The FAA should amend FAR 91.107 (and/or other applicable regulations) to require a passenger briefing on egress procedures in addition to the presently required briefing on the operation of restraint systems.
Recommendations to Industry:	
1.	Helicopter industry professional organizations should encourage the use of Personal Protective Equipment (PPE) by crew and passengers when practicable and when operational conditions indicate a potential benefit.
2.	Helicopter Air Ambulance (HAA) operators should use flame resistant wraps on patients transported
3.	Insurance companies should implement incentive programs for the installation and utilization of safety enhancing equipment.
Recommendations for Near-Term Implementation by the FAA:	
1.	The FAA should work with existing accreditation organizations to define common safety standards.
2.	The FAA and/or insurance industry should establish a standardized safety rating system for rotorcraft and rotorcraft components (e.g. Seat Systems, Fuel Systems) similar to that being used by NHTSA and IIHS for automobiles.
3.	The FAA should develop a centralized information exchange to communicate rotorcraft safety and technology efforts.
Recommendations for Public Rotorcraft:	
1.	Public Rotorcraft associations and the FAA should use education and industry standards to promote voluntary retrofit of Crash Resistant Fuel Systems (CRFS) and Crash Resistant Seat and Structure (CRSS) in helicopters performing Public Rotorcraft operations.
2.	Public Rotorcraft associations and the FAA should use education and industry standards to promote the voluntary use of Personal Protective Equipment (PPE) in helicopters performing Public Rotorcraft operations.

HIGH PRIORITY RECOMMENDATIONS TO THE FAA

27/29.952(a)(1)(2)(3)(5)(6), 27/29.952(f), and 27.963(g)/29.963(b): The FAA Should Require, in all Rotorcraft, the Installation (Retrofit) of Crash Resistant Fuel Bladders that Meet the Requirements of the 50-foot Fuel Cell Drop Test in or out of Structure, and that Demonstrate a Minimum of 250 lb Puncture Resistance

Objective: Prevent thermal injuries and thermal fatalities following survivable accidents by installing fuel bladders that minimize fuel spillage.

Discussion: As previously discussed, the ROPWG strongly recommends that, with few exceptions, all Normal Category (Part 27 and Part 29) helicopters operating in the U.S. be required to have crash resistant fuel bladders that meet the following requirements:

- 27/29.952(a)(1), (a)(2), (a)(3), (a)(5), (a)(6): Fuel tank/bladder 50-foot drop test conducted either in-structure or out of structure at the tester's discretion
- 27/29.952(f): Other CRFS features "as practicable"
- 27.963(g)/29.963(b): Fuel bladder must have a minimum puncture resistance of 250 lb
- The recommended time period for implementation of these requirements is 3-5 years following acceptance of the final rule

In brief, this recommendation is based on the following considerations:

- CT-85/11 identified post-crash fire resulting in thermal injuries as the most significant hazard in survivable helicopter crashes. It is also one of the hazards most easily prevented.
- Crash resistant fuel bladders meeting the requirements detailed above are extremely effective at preventing post-crash fires and thermal injuries following survivable accidents.
- Upgrading the entire existing fleet to include fuel bladders is expected to prevent approximately 143 fatalities due to thermal injury over the lifetime of the current fleet.
    - A large, though unknown, number of severe thermal injuries are also expected to be prevented.
- For Part 27 helicopters, the monetary benefit of the avoided thermal fatalities and thermal injuries is equal to or greater than the total cost of the upgrades.
- For Part 29 helicopters, the monetary benefit of the avoided thermal fatalities and thermal injuries is likely modestly lower than or equal to the total cost of the upgrades.

See the previous section "Recommendations for Incorporation of Existing Rotorcraft Protection Regulations into the Existing Rotorcraft Fleet" for further details regarding this recommendation, including a detailed discussion of feasibility, costs, benefits, and possible exceptions to the rule.

Note that in addition to the analysis presented earlier in this report, this recommendation was also subjected to the scoring process described in the previous section, where it was among the highest scoring interventions (reference Appendix C).

27/29.785 (c) and (g): The FAA Should Require the Installation (Retrofit) of Upper Torso Restraints (Shoulder Harnesses) at All Seating Positions

Objective: Reduce flailing and blunt force injuries by retrofitting upper torso restraints to seats in older helicopters that lack these restraints.

Discussion: The ROPWG strongly recommends that, with few exceptions, all Normal Category (Part 27 and Part 29) helicopters in the U.S. fleet be required to have upper torso restraints (shoulder harnesses) at all seating positions.

In brief, this recommendation is based on the following considerations:

- Upper torso restraint systems that prevent upper torso flailing into fixed objects or deforming structure are absolutely critical to occupant crash survival. Proper upper and lower body restraint is probably the single most important factor in occupant crash survival and without proper restraint, occupants are subject to serious or fatal injury in even minor crashes.
- The installation of a shoulder harness would provide a very significant benefit in many accidents for occupants of those seats where a shoulder harness is added.
- The cost of developing and installing shoulder harness retrofit kits is likely to be fairly small for most helicopter models.

See the previous section “Recommendations for Incorporation of Existing Rotorcraft Protection Regulations into the Existing Rotorcraft Fleet” for further details regarding this recommendation, including a discussion of feasibility, costs, benefits, and possible exceptions to the rule.

Note that in addition to the analysis presented earlier in this report, this recommendation was also subjected to the scoring process described in the previous section, where it scored highly (reference Appendix C).

27/29.785: The FAA Should Require the Availability and Use of Appropriate Restraints for All Occupants of Rotorcraft, Regardless of the Age of the Occupant

Objective: Reduce blunt force injuries to child occupants by requiring all passengers regardless of age to occupy a separate seat and have access to and utilize an approved restraint system appropriate for their age.

Discussion:

Child Safety Seat Exemption in Part 121 Operations

As a general rule, each occupant on board an aircraft must occupy an approved seat or berth with a separate seatbelt that is properly secured. However, the FAA provides exemptions in Parts 91, 121, 125, and 135, for children under 2 years of age, which allow these children to be held in an adult's lap during the entirety of the flight, rather than having their own seat.

In an article on the FAA website called "Flying with Children", the FAA states the following:

> *"Did you know that the safest place for your child on an airplane is in a government-approved child safety restraint system (CRS) or device, not on your lap? Your arms aren't capable of holding your child securely, especially during unexpected turbulence[30]"*

The article goes on to "strongly" urge parents to provide their children with an approved CRS or restraint device. Yet, the exemptions were granted and remain in place.

The justification for these exemptions was announced in an FAA Press Release "FAA Announces Decision on Child Safety Seats" on August 25, 2005.[31] According to this document, FAA analyses showed that, if forced to purchase an extra seat for children under 2 years, some families would choose to drive to their destination instead. Since driving is statistically much more dangerous than Part 121 airline travel, FAA analyses showed that a mandate for children to occupy a separate seat in aircraft would result in another 13 to 42 added family member fatalities in highway accidents over a 10-year period. Therefore, allowing children under two years of age to occupy the same seat as their adult caregiver is actually safer than requiring children to be properly restrained in Part 121 aircraft. The National Highway Traffic Safety Administration (NHTSA) Administrator concurred with the FAA decision saying that, "This is good public policy that is in the best interest of safety for the traveling public". Nevertheless, the FAA continues to urge parents to properly restrain their children while not requiring it.

Differences Between Part 121 Operations and Helicopter Operations

Accident Rate

This may be "effective public policy" for children traveling in Part 121 aircraft, where the accident rate is extremely low, but it does not necessarily make sense in helicopter operations. According to NTSB crash statistics from 2006-2015, the average annual accident rate for Part 121 aircraft was about 0.12/100,000

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[30] https://www.faa.gov/travelers/fly_children/

[31] FAA Press Release. FAA Announces Decision on Child Safety Seats, Release No. AOC 03-05, August 25, 2005. https://www.faa.gov/news/press_releases/news_story.cfm?contentKey=1966&hc_location=ufi

flight hours[32], whereas FAA data reveals that the estimated U.S. Rotorcraft accident rate from 2015 to 2017 was approximately 3.60/100,000 flight hours, or approximately 30 times greater than the Part 121 accident rate.[33,34] As a result of the greater accident rate in helicopters, the FAA analysis referenced above for the Part 121 “lap child exemption” cannot be rationally applied to helicopter operations.

Cabin Interior

Since there is little space in a helicopter, a child that is ejected from his/her parent’s arms is likely to forcefully strike a hard interior surface and receive blunt force injuries as a consequence of the ejection. This occurrence is likely over time, as a parent cannot hold on to a child when abrupt accelerations exceed about 1.5-2.0g, so even a hard landing or severe turbulence can result in the child being ejected from the parent’s arms.

Recommendations from Other Agencies

The NTSB has issued safety recommendations since 1979 asking the FAA to require that children under age 2 be in an appropriately secured child restraint in their own seat on airplanes. In 1999, NTSB Chairman Hart observed,

> *“It is unfortunate that regulations require everything except our smallest children to be secured for airplane takeoffs and landings and during in-air turbulence. We have seen cases in which the lack of a child seat has led to serious or fatal injuries and others where the use of a child seat has prevented such injuries. We should use the technology that is available, the resources at our disposal, and our compassion to prevent the needless injury to or loss of more of our most precious resource - our children”.*[35]

FAA official guidance recognizes the increased risk for lap children. FAA AC 120-87C states that the safest place for young children on an aircraft experiencing turbulence or an emergency is in an approved child restraint system or device, not on an adult’s lap.

The American Academy of Pediatrics also recommends a mandatory federal requirement for restraint use for children on aircraft.[36] This sentiment is echoed by a European Aviation Safety Agency (EASA) study on Child Restraint Systems from 2008, which states in part, “There are recognized concerns that the current regulations and operational practice may not provide such children with the level of impact protection equivalent to that provided to the other passengers.”[37]

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[32] https://www.ntsb.gov

[33] Federal Aviation Administration, Rotorcraft standards Branch (AIR-680), Air-682, Safety Management Section. Monthly Accident Briefing, March 2018.

[34] Federal Aviation Administration. U.S. Helicopter Accidents Decrease. https://www.faa.gov/news/updates/?newsId=87406

[35] National Transportation Safety Board. NTSB Plans International Conference on Child Safety in Aviation. NTSB News Release, December 8, 1999.

[36] American Academy of Pediatrics Committee on Injury and Poison Prevention. Restraint use on aircraft, Pediatrics, 108: 5, November 2001.

[37] Study on Child Restraint Systems, EASA.2007 C.28, November 29, 2008.

A 2006 study by the Australian Transportation Safety Bureau concluded that, "…infants and young children are entitled to the same level of protection, both in flight and during emergency landing situations, that is afforded to adults." [38]

Summary:

Based upon these studies and an overriding concern related to the ethics of permitting lap children in rotorcraft, the ROPWG strongly recommends that the "lap-child exemption" be eliminated for children traveling in rotorcraft, and that all helicopter occupants be required to use an FAA-approved restraint system appropriate for the age and size of the occupant.

Additionally, although the ROPWG is only tasked to make recommendations related to rotorcraft safety, it should be noted that many ROPWG members feel very strongly that the "lap child exemption" should be eliminated for **all aircraft operations**, not just rotorcraft, for the reasons discussed above.

[38] Human Impact Engineering and Britax Childcare Pty Ltd. ATSB Report B2004/0241, February 2006.

HIGH PRIORITY RECOMMENDATIONS FOR LEGISLATIVE CHANGES

<u>The NTSB and the FAA Should Seek the Authority and Funding to Determine Impact Conditions, Occupant Injuries, and Injury Mechanisms in Aircraft Accident Investigations</u>

Objective: Improve the ability of the FAA to draft effective, fact-driven safety and occupant protection regulations by expanding the missions of the NTSB and the FAA to include collecting critical data on aircraft impact conditions, injuries sustained by all occupants, and the mechanisms of injury for injured occupants.

Discussion: The National Transportation Safety Board (NTSB) is an independent Federal agency charged by Congress with investigating every civil aviation accident in the United States and significant accidents in other modes of transportation – railroad, highway, marine, and pipeline. The NTSB is charged with the responsibility to determine the probable cause of accidents and to issue safety recommendations aimed at preventing future accidents. Note that the NTSB can delegate the investigation of certain accidents to the FAA.

Since NTSB investigations are focused on accident prevention, they do not routinely consider the issue of protecting occupants when an accident inevitably occurs. This is particularly true in general aviation accidents (both helicopters and airplanes). Consequently, the NTSB has no requirement to determine aircraft impact conditions or injuries sustained by occupants, or the mechanisms of those injuries.

As a result, NTSB general aviation accident investigation dockets do not usually contain the data required to determine impact conditions, survivability of the crash, non-fatal injuries sustained by occupants, or injury mechanisms, though they do generally contain autopsy reports on licensed pilots involved in the crash. The lack of impact and injury data prevents analysts from accurately determining the survivability of crashes and the causes of injury to the injured occupants. This situation limits the FAA's ability to draft effective occupant protection regulations since it cannot determine how people are injured or whether the injuries sustained were related to material failures of structure or protective equipment such as restraints or seats, or due to misuse of protective equipment or other reasons. It naturally follows that if the FAA does not know how occupants are being injured and under what conditions, it cannot write effective occupant protection regulations.

The National Highway Traffic Safety Administration (NHTSA) provides a model of what data should be collected in crashes through their National Automotive Sampling System-Crashworthiness Data System (NASS-CDS). Data collected through the NASS-CDS has contributed enormously to the drafting of Federal Motor Vehicle Safety Standards (FMVSS), which have been primarily responsible for the vast improvements in automobile crashworthiness over the past few decades. Military aviation crash investigation manuals also provide examples of how to apply these principles and requirements to aviation crashes.

Summary: The NTSB and the FAA should seek the authority and funding through whatever means available to increase the scope of their aircraft accident investigations to include collecting and analyzing impact and injury data. Doing so will better allow the FAA to draft effective, fact-driven safety and occupant protection regulations.

The FAA Should Recommend that Congress Offer Tax Credits and/or Other Financial Incentives to Operators for Installing Critical Safety Equipment and/or Upgrading to Helicopter Models Equipped with Critical Safety Equipment

Objective: Encourage OEMs and operators to voluntarily install critical safety equipment or replace their existing rotorcraft fleets with models equipped with critical safety equipment by granting them financial incentives such as tax reductions or tax rebates.

Discussion: Although mandating compliance with the current occupant protection regulations is the most efficient method of ensuring rapid incorporation of life-saving safety equipment and systems into the current fleet, as discussed above, there are numerous technical and economic reasons why a blanket requirement to install (retrofit) this equipment across the entire fleet will be extremely difficult to implement.

The rotorcraft industry has been generally slow to adopt optional safety enhancing equipment offered by OEMs and suppliers. For instance, Bell Helicopter Textron, Inc. offers fuel system retrofit kits that provide near fully-compliant CRFS in many of their older helicopter models. However, they report that very few of these systems have been purchased. Robinson Helicopter Company similarly reports that a significant portion of older R22 and R44 helicopters that were manufactured before CRFS was introduced on new production helicopters are yet to be retrofitted in spite of the proven effectiveness of these systems and the issuance of a Service Bulletin mandating their installation.

Slow adoption of such equipment can be attributed to many factors, but the primary reason expressed by many owners/operators is the expense of purchasing and installing the new equipment. Aircraft downtime for equipment installation and additional long-term maintenance requirements/costs are commonly cited as reasons for slow adoption as well. Lastly, some operators fear that partially-complaint systems, particularly CRFS, will not be recognized by the FAA, and therefore those operators will be forced to upgrade their fuel systems a second time in the future.

As discussed previously, approximately 80% of the existing helicopter fleet in the U.S. does not comply with current occupant protection regulations since most were certified after the current rules became effective in 1989 and 1994. In order to equip the majority of the fleet with this equipment in a timely manner, the process of improving the crashworthiness of the current fleet needs to be accelerated.

Offering OEMs and owner/operators financial incentives to voluntarily improve the crash safety of their fleets could facilitate this process. The precedence for this type of tax credit includes solar energy, hybrid cars, high efficiency heat pumps, dual pane windows, and in aviation, the installation of ADS-B OUT equipment. In the energy category, these types of credits are significant, often offsetting 25%-40% of acquisition costs, while the ADS-B OUT credit was 10-20% of the total cost. These credits typically expire after a few years in order to encourage early adoption of the targeted improvement. Considering the historical effectiveness of this type of incentive in the energy arena, it is reasonable to expect similar effectiveness in encouraging helicopter operators to adopt life-saving improvements in their aircraft if the incentives are large enough, the program is vigorously promoted, and the targeted audience is sufficiently educated. While the ROPWG recognizes that funds for such incentives are limited, it is the opinion of the ROPWG that the overall societal benefit of improved helicopter crash safety makes the incentives a worthwhile financial investment.

Summary:

The ROPWG recommends that the FAA propose that Congress draft and pass legislation that will offer tax credits and/or other incentives to owners/operators who install and utilize safety-enhancing equipment on existing aircraft and/or who replace their existing fleet with models that incorporate safety-enhancing equipment. This type of credit could be offered for a limited time, and possibly with declining benefit over time in order to encourage early adoption of potentially life-saving enhancements.

RECOMMENDATIONS FOR RESEARCH/SAFETY STUDIES

Comprehensive Epidemiological Study of Civil Helicopter Crashes

Objective: Determine the relative effectiveness and failure modes of the various occupant protection systems in the current U.S. Helicopter fleet.

Discussion: As noted several times in this and previous ROPWG reports, the lack of impact and injury data in NTSB accident dockets made it extremely difficult for the ROPWG to evaluate the effectiveness of various occupant protection standards in helicopters involved in survivable crashes. This was especially problematic when attempting to analyze the effectiveness of components and systems designed to prevent blunt force trauma, such as upper torso restraints, energy absorbing seats, and increased structural strength related to occupant and items of mass retention. Additionally, although the data provided by the Civil Aeromedical Institute (CAMI) allowed a reliable estimation of the benefit provided by CRFS in preventing thermal fatalities, the lack of non-fatal thermal injury data prevented an estimation of the (likely substantial) benefit of preventing non-fatal thermal injuries. While military crashworthiness studies acquire the required data and allow the determination of what crashworthiness features are generally effective, these studies do not allow a precise analysis of the effectiveness of civilian helicopter crashworthiness features, as the differences between civilian and military airframes, operations, and aircrew are very significant.

Without this data, it is very difficult to make rational, data-centered recommendations and policy with regards to occupant protection. As a result, it is likely that current and future occupant protection standards will be either insufficient to provide the protection desired, or overly burdensome (cost, weight, etc.) for the benefit provided.

To help address this problem, the ROPWG has already recommended that the NTSB and the FAA seek the authority and funding through Congress to collect data on accident impact conditions, occupant injuries, and mechanisms of injury (reference "High Priority Recommendations for Legislative Changes" section). While implementing this recommendation will yield valuable data in the future, such data will not be available for many years. Therefore, in the interest of near-term improvements to occupant protection standards, the ROPWG strongly recommends that the FAA commission a comprehensive study of all survivable helicopter crashes, both Part 27 and Part 29, over the most recent 5- to 10-year period. The proposed study should use a methodology similar to the CT-85/11 study that FAA sponsored in 1985 but should focus on the injuries to occupants in survivable crashes and the detailed cause of each injury, particularly in relation to the performance of protective equipment, aircraft structure, and the attachment of high-mass items addressed in the current occupant protection regulations. While such a study will be considerably more difficult given the lack of much relevant data in the accident dockets, the CT-85/11 study showed that through careful analysis, meaningful data can still be generated from many accident dockets.

To acquire the necessary data, the entire NTSB docket of each crash must be perused to collect information on the impact conditions, crash loads, occupant injuries, and the cause of these injuries. In most cases, survivability will have to be determined based on examination of photographs of the scene and of the accident helicopter. In some cases, recorded flight data or other portable Global Positioning System (GPS) devices with accelerometers such as smart phones and video cameras may be available to help determine impact velocity and orientation of the aircraft at impact. Furthermore, it may be necessary to directly contact the responsible accident investigator(s) to acquire the necessary data. The exact period of the study will have to be determined based on the number of crash investigation dockets with sufficient data to constitute a meaningful sample for analysis.

The study should determine how actual survivable impact velocity and conditions compare to load standards/requirements expressed in the occupant protection regulations, and how well helicopters meeting the current occupant protection standards perform in crashes relative to the helicopters that are either non-compliant or partially compliant. The study should also identify specific failure modes of protective equipment such as seats and restraints and determine whether these failures contributed to or caused injuries.

The final product should provide sufficient data for analysts and rulemakers to determine the effectiveness of current occupant protection standards and identify specific areas where the standards need to be improved, and/or where new technology should be introduced to allow maximum survival without serious injury in survivable helicopter crashes.

Study to Determine the Need for and Potential Effectiveness of Supplemental Restraint Systems

Objective: Conduct a follow-on study to determine whether supplemental restraint systems or modified/improved restraint systems would provide a practicable and effective means of reducing injuries in survivable rotorcraft crashes.

Discussion: Supplemental restraint systems, primarily air bags, have been extremely effective in reducing serious injuries in automobile crashes, as has the introduction of protective technology such as pretensioners, load-limiters, and other advanced technology devices. The effectiveness of these systems in reducing injuries in automobile crashes suggests that similar systems may be highly effective if adapted to civil helicopters. Therefore, based on the findings of the proposed comprehensive injury study detailed above, the ROPWG recommends that a supplemental restraint study be performed to examine whether the introduction of supplemental restraints (air bags, deployable barriers), pretensioners, load-limiters, 4- or 5-point restraint systems, and other novel seat and restraint system technologies into helicopters would be practicable and effective in further reducing injuries in survivable helicopter crashes.

Study Energy Absorbing Seats and Cushions

Objective: Conduct a follow-on study to determine whether adjustable weight energy absorbers and/or energy attenuating seat cushions would provide a practicable and effective means of improving vertical energy attenuation for the range of anthropometry of occupants expected to occupy these seats during survivable rotorcraft crashes.

Discussion: Military helicopter flight crewmembers encompass a wide-range of anthropometry. The weight of flight crewmembers may range from as low as less than 100 lb to over 250 lb. Since the force level at which an energy absorbing seat strokes is dependent upon mass and acceleration, peak forces will vary considerably for different weight occupants exposed to the same crash pulse. In order to protect the range of occupants occupying energy attenuating seats and optimize the force experienced by these personnel, the military has developed seats with adjustable weight settings for some of its energy attenuating seats. These seats have been reported to perform well in preventing spinal injuries, particularly for low-weight occupants who are at increased risk for spinal injury in seats that are optimized to protect occupants weighing 170 lb.

The comprehensive crash injury study recommended above will identify spinal injuries and the crash conditions under which they occur. If a significant portion of injuries occur due to inadequate vertical force attenuation, the ROPWG recommends that a further study be commissioned to determine whether adjustable weight attenuators would provide a practicable means of increasing protection for the range of people occupying those seats. It should also be determined whether energy attenuating seat cushions would be a practicable means of affording increased vertical force energy attenuation in non-energy attenuating seats. The results of these studies will be used to provide the data necessary to optimize the requirements of 27/29.562.

Study Installation and Use of Flight and Impact Data Recording Systems

Objective: Conduct a study to determine the appropriate capabilities for flight and impact data recording systems to enable collection of flight data as well as impact velocity and acceleration data. Impact data is needed to assist with determining appropriate regulatory safety standards and to help evaluate aircraft/equipment performance, while flight data is useful for determining the probable cause and contributing factors of accidents in rotorcraft.

Discussion: One of the challenges the ROPWG faced when attempting to determine the relative effectiveness and failure modes of the various occupant protection systems in the current U.S. Helicopter fleet was the lack of available data regarding actual impact velocity and accelerations. While traditional Flight Data Recorder systems (FDR) and Cockpit Voice Recorders (CVR) have been used in large airplanes for some time, they may not provide this data, and even when they do, they are far too large and heavy for practical use in small aircraft. Recently, however, Lightweight Aircraft Recording Systems (LARS), and similar Helicopter Flight Data Monitoring systems (HFDM), have been designed at a cost and weight practical for use in all small aircraft.

Regulatory and investigative agencies have recently recommended installation of such small, lightweight systems as a safety enhancement for helicopter operations. Such systems have even been required for specific operations such as Helicopter Air Ambulance (HAA). Furthermore, many portable GPS-enabled systems such as smart phones, which are often carried onboard aircraft, can provide useful information to estimate actual impact velocity and conditions.

This study will explore various systems and potential parameters for a small, lightweight data recording system that will enable the collection of the impact velocity and acceleration data necessary for the evaluation of aircraft/equipment performance and its effectiveness at preventing occupant injuries. The study should further evaluate costs and applicability to various helicopter models as well as provide recommendations for which segments of the fleet should be required to have a data recorder, and what the capabilities of a proposed data recorder should be for each segment of the fleet. Ideally, the study should identify a basic design that would be sufficiently lightweight, small, and affordable to be required for the entire helicopter fleet.

Additionally, while outside the scope of this report, a small, lightweight cockpit and airframe data recorder could also be of great benefit in determining the probable cause and contributing factors in helicopter accidents, as has been the case for decades in larger aircraft equipped with these devices. Since it may be impractical to have two separate data recording devices (one focused on impact data, and one focused on causal data like cockpit audio, video, and control system inputs), the study should also include considerations of these other aspects of accident investigation. The end product could then help in the determination of accurate causes of accidents (thereby helping prevent future similar accidents), while also providing impact data essential for incorporating effective occupant protection features for future accidents that will inevitably occur.

Note that it is assumed in this recommendation that in order to produce a small, lightweight, affordable data recorder, some features of traditional FDRs and CVRs would have to be omitted, such as protection from extreme impacts and intense fires, submersion underwater, homing beacons, etc. While this will prevent the devices from providing data following a small minority of accidents, the ROPWG feels that this is an acceptable compromise in order to get useful data from the majority accidents.

Study Integration Principles/Culture that Address Human Factors into Helicopter Operations

Objective: Conduct a study to ascertain the extent to which integrating Human Factors processes and education (HRO, Just Culture, HFACS, CRM, etc.) into helicopter operations would reduce accidents and contribute to reduced injury rates in crashes.

Discussion: The success of technology and improvements to technology, many of which are recommended in this report, depend upon the human-machine interface and the appropriate use of the technology by humans. The complexity of the variables that impact how humans interact with technology is an essential part of the conversation on safety improvements. Further, the culture within which humans operate is a critical factor in the success of safety improvements as well as risk mitigation strategies. Adopting a combination of models to provide a framework to optimally address the human-machine interface and overall culture will help to ensure the success of the safety initiatives presented in this report. The suggested models are:

1. High Reliability Organization (HRO)
2. Just Culture
3. Shared Accountability/Shappell & Wiegmann's Human Factors Analysis & Classification System (HFACS)
4. Crew Resource Management (applied organizationally)

These models are described in the following text.

High Reliability Organization (HRO)

High reliability organizations are those that consistently experience no serious or catastrophic accidents despite operating in complex, high-risk domains. The guiding principles of an HRO are:

- Preoccupation with failure (recognize the latent organizational weaknesses or flaws)
- Reluctance to simplify (understand complexity)
- Sensitivity to operations (ability to see the big picture, situational awareness)
- Deference to expertise (expertise is sought regardless of hierarchy)
- Commitment to resilience (capacity to detect, mitigate, and recover from errors)

Just Culture

A "Just Culture" provides a culture of learning, rather than punishment, and creates a model of shared accountability between individuals, who are responsible for their behavior and choices within an organization; and the organization, which is responsible for designing and improving workplace systems. Personal accountability is essential, but to focus exclusively on individual error does not expose the systemic conditions that may have placed the individual in the optimal position to err. Systemic conditions must be addressed in order to truly mitigate future risk.

Shared Accountability

Shared accountability between an individual and a system is difficult to ascertain without a framework such as the Human Factors Analysis and Classification System (HFACS) model to help identify underlying causal and/or contributing system issues. The HFACS model was developed by Dr. Scott Shappell and Dr. Douglas Wiegmann. This model, based upon James Reason's Swiss Cheese Model, was developed to help identify contributing/causal factors to incidents and accidents from a systems perspective. It provides both retrospective as well as prospective/predictive opportunities to manage human performance and to identify system issues that contribute to mishaps. Many of the issues identified by the HFACS model can be addressed by human factors engineering, applying engineering controls and forcing functions, and by employing the principles of Crew Resource Management (CRM).

The aviation industry has historically been punitive in nature, particularly towards pilots, when it comes to incidents and accidents. This creates an environment in which operators may be reluctant to report problems they identify, or near-misses/close calls. The non-reporting of close calls does not allow existing or latent issues to be addressed before a serious mishap or catastrophe occurs. Additionally, in a suboptimal culture, safety concerns may be reported by frontline staff but ignored or dismissed by leadership.

Crew Resource Management (CRM)

CRM is a method to help achieve safe and efficient flight operations by teaching and practicing strategies related to threat and error management, information processing, communication, stress/fatigue, decision-making and judgment, workload and time management, team building, situational awareness, and complacency. The principles of CRM can be extrapolated beyond the cockpit to the organization as a whole to help achieve safe and efficient operations in general.

Purpose of Study

The ROPWG recommends that a study be conducted to measure the empirical benefits derived by operational users in selected (but high exposure) providers that perform Utility, Emergency Medical Services, and tour operations. The study should evaluate incident and accident experiences between organizations that employ these human factor processes against those that do not, and should examine the investment each of these operator populations make in training and material outlays.

Based upon this data, the study should evaluate the correlation between human factors investments and real benefits derived from their use. Based upon the strength of the correlation, the FAA should consider the next logical step in requiring these processes be integrated in various helicopter operations with broader application to be considered afterward.

RECOMMENDED CHANGES TO CURRENT REGULATIONS/GUIDANCE

<u>Change TSO-C80 and 27/29.952 to Require Tear and Cut Resistance as well as Puncture Resistance Standards for Fuel Bladders</u>

Objective: Ensure the crash resistance of future fuel bladders by requiring they meet specific standards for tear and cut resistance in addition to those already required for puncture resistance. This requirement would apply to newly certificated helicopters only and should not be applied to existing fuel systems.

Discussion: Fuel bladder tear and cut resistance has been shown to be an important property for crash resistant fuel bladders. While most or all fuel bladders currently used in civil helicopters likely have sufficient tear and cut resistance despite the lack of a specific requirement, this is not guaranteed with the current requirements, as the standards refer only to puncture resistance (27.963(g) and 29.963(b)). Tear and cut resistance criteria are additionally required to ensure that fuel bladders complying with this subpart will, in fact, provide the desired survivable crash resistance. Therefore, the ROPWG recommends that subparagraphs 14 CFR §§ 27.952(g) and 29.952(g) be revised to include a requirement for tear and cut resistance.

In establishing this position, reference is made to TR 79-22E Aircraft Crash Survival Design Guide (ACSDG)[39] and to the recommendations for rotorcraft fuel tank design reported by Robertson and Turnbow.[40] The Robertson and Turnbow report recommendations released in 1966 were incorporated into the original (1967) and subsequent versions of the ACSDG (TR-79-22E and TR 89-D-22E). These recommendations were based upon significant crash testing as well as helicopter crash investigations.

The ACSDG states that the key issues in designing an effective crashworthy fuel tank are “cut, tear, and impact resistance”, however, “tank shape, flexural modulus of the material, reinforcement orientation, and loading rate sensitivity” are also involved. The ACSDG notes that the cut and tear resistance test requirements in MIL-T-27422B have proven to be effective in actual crashes of military helicopters.

When the host container yields in a survivable crash, a flexible bladder having sufficient puncture resistance, tear resistance and tensile strength to withstand the crash loads and avoid catastrophic failure is essential to preclude post-crash fire. TR 89-D-22E states in paragraph 4.3.1.3, Tank Materials:

> *“Elongation can be obtained by tank deformation or material stretch. The amount of fuel tank elongation actually required is unknown. It is known, however, that fuel tanks lacking the ability to elongate are either fairly strong (heavy) or brittle. Both types are easily ruptured in moderate crashes. On the other hand, crash-resistant fuel tank studies have shown that light tanks that can readily rearrange their shape (deform/elongate), at*

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[39] U.S. Army. ROTORCRAFT CRASH SURVIVAL DESIGN GUIDE, Volume V – Rotorcraft Post Crash Survival, Prepared for Applied Technology Laboratory, U.S. Army Research and Technology Laboratories (AVRADCOM), Fort Eustis, Virginia 23604, USARTL-TR-79-22E, Simula Inc., 2223 South 48th Street, Tempe, Arizona 85282, January 1980, Final Report.

[40] Robertson, S.H., and Turnbow, J.W., ROTORCRAFT FUEL TANK DESIGN CRITERIA, Aviation Safety Engineering and Research of Flight Safety Foundation; USAAVLABS Technical Report 66-24, U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, March 1966, AD 631610.

the same time exhibiting a high degree of cut and tear resistance, can hold their contents during upper-limit survivable crashes."

Tanks constructed with the material properties that meet MIL-DTL-27422B and later revisions have resulted in zero deaths from post-crash fires in survivable military rotorcraft crashes. These same requirements, at about half of the MIL-SPEC values, have been incorporated into Advisory Circulars 27-1B and 29-2C, but are not regulatory. The FAA selected lower chisel drop height and constant rate tear requirement of 200 ft-lb since civil rotorcraft fly different missions and have been demonstrated to have lower average vertical crash velocities than military rotorcraft based on statistical data (DOT/FAA/CT-85/11, § 2.2.3[41] vs. TR 79-22B, § 3.2).

In consideration of the information above, the ROPWG recommends that the FAA implement rulemaking for flexible fuel bladders used in CRFS as detailed below:

1. **Change the TSO-C80 material requirement for flexible fuel liners by adding the following requirements:**

    a. Test bladders per MIL-DTL-27422F, Detail Specification: Tank, Fuel, Crash-Resistant, Ballistic-Tolerant Rotorcraft, dated February 2014 except with the following values:
        i. Constant rate tear – A cut is made in the sample and pulled apart at 20 inches per minute. Must withstand no less than 200 ft-lb.
        ii. Impact penetration – 5-lb chisel dropped from 8 ft onto a construction sample, must not leak when 5 psi is applied to the construction.
        iii. Impact tear – 5-lb chisel dropped from 8 ft onto the edge of the construction with a v-notch cut into the sample. The resulting tear cannot propagate to longer than 1 inch.

    b. Change TSO-C80 to indicate that these requirements are intended for the construction properties of the flexible fuel liner and are to be present over the entire surface of the liner.

2. **Rewrite §§ 27.952 (g) and 29.952 (g) to require demonstration of tear and cut resistance to the proposed requirements of TSO-C80 above, taking the following into consideration:**

    a. §§ 27.952(g) and 29.952(g) currently state the following:

        "Rigid or semirigid fuel tanks. Rigid or semirigid fuel tank or bladder walls must be impact and tear resistant."

    The wording of this regulation is highly non-specific and does not provide guidance on how to measure impact or tear resistance. Impact resistance requirements are specified in 27/29.952(a), but there is no specific requirement in the regulations on tear resistance. However, guidance is provided in AC 27-1B and AC 29-2C.

[41] DOT/FAA/CT-85/11, *Analysis of Rotorcraft Crash Dynamics for Development of Improved Crashworthiness Design Criteria*, June 1985.

b. FAA AC 27-1B, § 27.952, Amdt. 27-30, paragraph d(19) currently states:

> "*Section 27.952(g) also requires that all fuel tank designs (regardless of the materials utilized and whether or not a flexible liner of any type is used) ... tested to the criteria of paragraph d(18)(iv) of AC § 27.952, or equivalent.*"

Paragraph d(18)(iv) provides specific test requirements and values for constant rate tear, impact penetration and impact tear.

c. The crashworthiness of tanks can be assured through compliance with appropriate impact and tear resistance standards. However, the current regulations do not specify a test requirement for tear resistance. Advisory Circulars provide guidance for tear resistance testing, but ACs are not regulatory.

Note that the recommended tear and cut resistance requirement should not apply to fuel bladders that were previously installed and that otherwise meet the ROPWG recommendation for successfully passing a drop test and meeting the 250 lb puncture resistance requirement. Rather, the tear and cut resistance requirement would be limited in applicability to new rotorcraft type designs, and possibly newly-certified CRFS retrofit kits (OEM or STC). There is no intention on the part of the ROPWG to require the replacement of previously-installed fuel bladders, nor to require the revision of previously-approved fuel bladder designs that otherwise meet the ROPWG recommendations.

Amend 14 CFR 91.107 to Require Briefing on Egress in Addition to Briefing on the Operation of Restraint Systems

Objective: Ensure that each person on board is briefed on how to egress the helicopter in an emergency by amending 14 CFR 91.107 (and/or other appropriate regulations) to include the requirement that the pilot in command ensure that each person on board is briefed on proper emergency egress procedures including operation of his/her restraint harness, operation of doors, and other pertinent procedures.

Discussion: The required content of a pre-flight passenger safety briefing is specified in 14 CFR 91.107: "Use of safety belts, shoulder harnesses, and child restraint systems". This regulation only requires pilots to brief passengers on the use of a safety harness but not other aspects of emergency egress. 91.107(a)(1) states the following:

> *No pilot may take off a U.S.-registered civil aircraft (except a free balloon that incorporates a basket or gondola, or an airship type certificated before November 2, 1987) unless the pilot in command of that aircraft ensures that each person on board is briefed on how to fasten and unfasten that person's safety belt and, if installed, shoulder harness.*

While it is extremely important that occupants of aircraft fully understand how to secure and remove their restraint systems, in an emergency landing in a helicopter, it is equally important that passengers be thoroughly familiar with how to egress the aircraft after they have released their restraints. This is due to the limited exposure the general public has to helicopters, and the wide variety of helicopter doors that may be encountered. Passengers of rotorcraft should be thoroughly briefed on emergency egress procedures, door location and operation, and egress precautions such as avoiding contact with the main and tail rotor systems and egress following an emergency landing. Since helicopters rarely have flight attendants to assist them in an evacuation, passengers frequently must rely on themselves to successfully escape after an emergency landing or ditching. The quality of their preflight briefing and demonstrations are vital to prepare a passenger for an unexpected emergency.

Additionally, due to the importance and complexity of a thorough preflight briefing for successful passenger egress in an emergency, pilots involved in “for hire” operations should be required to undergo egress training tailored to each model rotorcraft they operate, to include regular refresher training. This training should include instruction on how to provide an effective preflight briefing.

RECOMMENDATIONS TO INDUSTRY

Helicopter Industry Professional Organizations Should Encourage the Use of Personal Protective Equipment (PPE) by Crew and Passengers When Practicable and When Operational Conditions Indicate a Potential Benefit

Objective: Reduce injuries to occupants exposed to post-crash fires and potential head trauma through increased use of flame resistant clothing and military specification flight helmets.

Discussion:

Thermal Injuries

Post-crash fires in rotorcraft have been identified as one of the most significant hazards resulting in occupant injuries and fatalities. While the ROPWG CRFS recommendations detailed above would nearly eliminate post-crash fires following survivable accidents, numerous post-crash fires will likely occur before all helicopters are retrofitted with appropriate CRFS, and a rare fire may occur even after the incorporation of effective CRFS, particularly in marginally survivable crashes or brush fires ignited by the heat of the engine or other components. As a result, it is prudent to investigate means of lessening the injuries caused by a post-crash fire should one occur.

While fabrics used in street clothing, particularly those containing polyester, are often flammable and increase the severity of burn injuries by melting into the skin, some fabrics are engineered to undergo charring instead, thereby lessening the severity of thermal injuries. DuPont brand “Nomex” fabrics are the most commonly recognized, and have been used in military flight suits since the 1970’s. Proper use of flame resistant clothing and other PPE such as flight gloves and flame resistant shoes/boots have been proven to reduce burn injuries, at a cost of less than $800 at current retail prices. This technology is well proven, widely used in military aviation and other industries such as automobile racing, and is commercially available and economical. Considering the effectiveness of fire resistant clothing in preventing burn injuries, helicopter professional organizations should advocate the use of flame resistant clothing by flight crew and passengers when practical and when operational conditions dictate.

Head Trauma

Blunt impact injury to the head has also been identified as one of the most common and severe types of injuries sustained by occupants in survivable helicopter crashes. While numerous studies have documented the effectiveness of helmets in preventing injury in military helicopter crashes and motorcycle and bicycle crashes, flight helmets are unfortunately not as widely used in helicopter flight operations as the ROPWG believes they should be.[42,43,44] Reasons offered for failure to utilize military standard flight helmets in civil helicopter operations include that they are perceived as being too expensive, too uncomfortable, too heavy, and using helmets may send a message to potential passengers that helicopter flight is dangerous. Considering their effectiveness in preventing blunt force

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[42] Singleton, M.D. Differential protective effects of motorcycle helmets against head injury. Traffic Inj. Prev., 18(4): 387-392, 2017.

[43] Crowley, J.S. Should helicopter frequent flyers wear head protection? A study of helmet effectiveness. J. Occup. Med., 33(7): 766-769, 1991

[44] McEntire, B.J. U.S. Army aircrew helmets: head injury mitigation technology (Reprint). U.S. Army Aeromedical Research Laboratory, USAARL Report No. 98-12, 1998.

trauma to the head and their reasonable cost (approximately $1,000 at current retail prices), the ROPWG recommends that helicopter professional organizations advocate the use of helmets by crew and passengers when practical and when operational conditions indicate.

Helicopter Air Ambulance (HAA) Operators Should Use Flame Resistant Wraps on Patients Transported

Objective: Protect HAA patients from thermal injuries due to post-crash fires by revising HAA accreditation standards to require the use of flame resistant coverings for HAA patients. Standard implementation should progress from "encourage" to "recommend" to "require" over the course of revision updates and as flame resistant wraps become more readily available.

Discussion: Most helicopter air ambulance (HAA) accreditation organizations (e.g., the Commission for Accreditation of Medical Transport Systems (CAMTS) and the National Accreditation Alliance Medical Transport Applications (NAAMTA)) have standards related to the use of flame resistant uniforms for HAA pilots and medical crew. The use of flame resistant uniforms is intended to offer rotorcraft crewmembers an additional layer of protection from thermal injury during egress from a rotorcraft accident or incident that involves potential exposure to fire.

Patient protection from thermal injury is not a current standard in HAA. While there is scant evidence to illustrate a trend of patient thermal injury during HAA accidents and incidents, it seems intuitive that efforts to protect pilots and medical crew should also extend to patients being transported. Any threat to the pilot and medical team that warrants aircraft evacuation is also likely a threat to a patient. The most expeditious way to provide patients with a degree of fire protection in a crash is likely for HAA operators to routinely carry flame resistant sheets or wraps to cover patients prior to loading aboard an HAA. This is a relatively inexpensive and practical method to provide patients post-crash fire protection in the event they need to be evacuated from a disabled helicopter. Therefore, the ROPWG recommends that HAA accreditation standards be updated to require the use of flame resistant coverings for HAA patients.

Insurance Companies Should Implement Incentive Programs for the Installation and Utilization of Safety Enhancing Equipment

Objective: Motivate owners/operators to install and utilize safety enhancing equipment on existing rotorcraft and/or replace their existing fleet with compliant models by encouraging insurance companies to offer incentive programs, such as rebates or premium discounts, for such equipment.

Discussion: The rotorcraft industry has been generally slow to adopt optional safety enhancing equipment offered by OEMs and suppliers. Slow adoption of such equipment can be attributed to many factors, but the primary reason expressed by many owners/operators is the expense of purchasing and installing the new equipment.

Insurers in the automotive industry have proven the value of offering rebates and/or premium discounts to drivers who operate vehicles equipped with modern crash avoidance features. Generally speaking, the aviation insurance community has been slower to adopt this incentive tactic; however, there are a few successful examples of such rebates or premium discounts for fixed wing and rotorcraft operators who opt to install safety enhancing equipment such as a Runway Overrun Protection System (ROPS).

This general concept has proven to be beneficial for both the insurers/brokers and owner/operators, as the safety upgrades are made more affordable, and are therefore more quickly adopted by the owner/operator. As a result, risk/liability is reduced for the insurer/broker, and most importantly, injuries and fatalities due to accidents are potentially reduced.

In consideration of the discussion above, the ROPWG recommends that insurers evaluate the costs associated with injuries and fatalities that could have been avoided with implementation of CRFS, crashworthy seats and structures, and other occupant protection enhancements. Based on this evaluation, the insurers should offer realistic incentive programs such as rebates or premium discounts to encourage owners and operators to install and utilize safety enhancing equipment on existing aircraft, and/or replace their existing fleet with models equipped with safety enhancing equipment.

RECOMMENDATIONS FOR NEAR-TERM IMPLEMENTATION BY THE FAA

The FAA Should Work with Existing Accreditation Systems to Define Common Safety Standards

Objective: Develop universal helicopter auditing standards to more efficiently improve helicopter safety.

Discussion: The helicopter industry has been increasingly utilizing accreditation groups to audit their operations and move toward a "common" safety standard. Due to the variety of tasks accomplished by helicopters, it is difficult to write a common standard for all helicopter operations, resulting in specialized audits for specific sectors of the industry. Development of an all-inclusive standard would provide industry auditors with common terms and taxonomy to develop comprehensive audits that would recognize common aspects of the industry as a whole. This action would create a cadre of auditors educated and trained to inspect all aspects of the industry. A coordinated and aligned approach may provide greater audit fidelity and offer potential improvements in safety for the flying public.

Every instance of an "audited" operation that suffers an untoward occurrence calls the auditing process into question. For the flying public, confidence in the ability of the helicopter industry to effectively monitor its processes and procedures is undermined by any highly publicized accident. The loss of confidence exposes the industry to unfair criticism and unwanted assistance from legislators and regulators.

Accreditation bodies such as Helicopter Association International (HAI), International Standard for Business Aircraft Operations (ISBAO), Commission for Accreditation of Medical Transport Systems (CAMTS), National Accreditation Alliance Medical Transport Applications (NAAMTA), European Aeromedical Institute (EURAMI), Management Advisory Council (MAC), Airborne Public Safety Accreditation Commission (APSAC), and other rotorcraft industry accreditation bodies should be encouraged by the FAA to form an organization or network to create a common core of safety, technological, and cultural improvements that can be incorporated throughout the rotorcraft industry. The organization should be able to mitigate the natural competition between auditing bodies to produce a standard that is essentially free from industry segment weighting. This universal standard should include all segments of the industry with tailored requirements for unique operations. It should be designed so that any auditor could effectively use it without additional specialized training. The standard should be designed to produce easily developed and interpreted metrics to facilitate common understanding.

The FAA and/or Insurance Industry Should Establish a Standardized Safety Rating System for Rotorcraft and Rotorcraft Components (e.g. Seat Systems, Fuel Systems)

Objective: Encourage owners/operators to utilize rotorcraft and on-board safety equipment designed and certified to a higher level of safety, by developing a safety rating system designed to help educate owners and operators on the certification status and relative safety of different makes/models of helicopters and individual items of safety equipment.

Discussion: The rotorcraft industry has been generally slow to adopt optional safety enhancing equipment offered by OEMs and suppliers. Slow adoption of such equipment can be attributed to many factors, but the primary reason expressed by many owners/operators is the expense of purchasing and installing the new equipment. Aircraft downtime for equipment installation and additional long-term maintenance requirements/costs are commonly cited as reasons for slow adoption as well. Also contributing to the slow adoption of safety enhancing equipment is a general lack of understanding of technology, regulations, and/or available options, and in some cases, a lack of perceived value of such equipment. The present recommendation addresses this last factor.

The National Highway Traffic Safety Administration has established a safety rating system, the New Car Assessment Program (NCAP) 5-Star Safety Ratings Program, to provide consumers with information about the crash protection and rollover safety of new vehicles beyond what is required by Federal law. One star is the lowest rating; five stars is the highest. A greater number of stars indicates a safer vehicle.

This rating system has helped educate consumers about the relative safety of available makes and models of new automobiles. Manufacturers who design their models to a higher standard of safety and receive the highest safety ratings have a competitive advantage over manufacturers of comparable models that receive a lower safety rating. The present recommendation is to develop a safety rating system for rotorcraft components and aircraft that is similar to that for cars, with the anticipation that the rotorcraft industry would see positive results similar to those experienced by the automotive industry.

The ROPWG specifically recommends the following:

1. The FAA should proactively coordinate with industry, insurers, and operators (as appropriate) to develop standardized criteria for models of existing rotorcraft that increase aircraft crash safety through component enhancements that are known to reduce exposure to injury risk in rotorcraft. This would be a component of the conceptually proposed Safety Technology and Awareness Refinement (STAR) Program for rotorcraft that would recognize different levels of safety.

   This proposed initiative could be based upon NHTSA's 5-Star Safety Rating System. A certain aircraft model or upgraded model would be awarded a star rating based on its estimated overall crash safety. Helicopters with advanced crashworthiness features such as various elements of CRFS and CRSS would be rated higher than those that do not have these features. The base helicopter model would receive a certain rating, but this rating could be upgraded when operators install additional crash safety features.

2. Additionally, the FAA could coordinate with insurance companies to encourage them to use this rating system for policy and premium review, and encourage the insurance companies to

promote the Star system through education and advertisement. That is, the insurance companies should require that all STAR awarded aircraft carry this rating on company advertising and marketing literature.

The FAA Should Develop a Centralized Information Exchange to Communicate Rotorcraft Safety and Technology Efforts

Objective: Improve safety awareness and knowledge of the availability of crash protective equipment and its effectiveness for the rotorcraft user community through an FAA established information website (Rotorcraft Information Exchange) that can serve as a hub of communication and information exchange.

Discussion: Rotorcraft operators, owners, regulators (FAA, DOT), and manufacturers are not always aware of the improved technologies, products, and education programs that may benefit the rotorcraft industry. This is partly because independent or small developers may communicate their advances to a small subset of the industry, either through a trade venue, industry periodical, or association news release. While the automotive industry (in regard to crash safety) has multiple pathways in sharing information relative to safety, statistics, and technologies, there does not appear to be a consolidated information exchange available where information regarding survivability technologies for rotorcraft can be explored.

If advances in rotorcraft safety were more widely known, other individuals and organizations might be able to use the resultant technology to develop better products that serve to increase awareness of and reduce the severity of accidents.

A centralized information exchange (called the Rotorcraft Information Exchange) would be of significant benefit to all parties who have a stake in rotorcraft design, technologies, operation, and crashworthiness. Such information could span a broad spectrum that may include:

- Aircraft safety “side-by-side” comparisons (e.g. Consumer Reports-like reports) and outreach programs
- Statistical information
- Technology advances
- New and future products announcements
- Press releases

The enhanced communication provided by this exchange could provide a low-cost benefit to the community as a whole and should be considered by the FAA as a subject of an ARAC assigned effort and subsequent working group. If a working group is formed, it is suggested that the working group:

- Establish the scope of content of the proposed “Rotorcraft Information Exchange”.
- Select subject areas for the exchange such as crashworthiness, fuel system technologies, advancements in restraint systems, improved crash statistics, improved seating systems or other areas.
- Establish the recommended web host requirements after exploring entities such as the DOT, the FAA, or industry groups.

If the information exchange is successful, the FAA and the DOT should evaluate the exchange for its overall potential as a template for other categories of aircraft and modes of transportation that can additionally benefit.

RECOMMENDATIONS FOR PUBLIC ROTORCRAFT

The ROPWG recognizes that by public law (Title 49 of the United Sates Code, 40102(a) (41) and 40125; AC00-1.1A), the FAA has no regulatory authority over Public Aircraft[45], and as a result, the FAA cannot mandate that Public Rotorcraft incorporate the most significant crash hazard interventions recommended in this report. Nevertheless, some members of the ROPWG felt it important to make several recommendations for voluntary action by Public Rotorcraft operators and associations. Considering the generally higher risk operations performed by Public Rotorcraft, the ROPWG recommends that all Public Rotorcraft operators be educated on the benefits of crash resistant fuel bladders, energy attenuating crew seats, and the benefits of all crewmembers being provided with and using Personal Protective Equipment (PPE) commensurate with the risk of the operation. These recommendations are discussed in detail below. Note that Public Rotorcraft operations comprise approximately 10% of helicopter operations in the U.S.

Public Rotorcraft Associations and the FAA Should Use Education and Industry Standards to Promote the Voluntary Retrofit of Crash Resistant Fuel Systems (CRFS) and Crash Resistant Seat and Structure (CRSS) in Helicopters Performing Public Rotorcraft Operations

Objective: Increase the number of helicopters involved in Public Rotorcraft operations that are equipped with CRFS and CRSS, and thereby reduce the potential for injury and death sustained in crashes of these helicopters.

Discussion: As discussed in this and previous ROPWG reports, the incorporation of CRFS and CRSS in helicopters has been shown to reduce thermal and blunt-force trauma following survivable accidents. Accordingly, the ROPWG strongly recommends the voluntary incorporation of CRFS and CRSS, as they become available, into the current fleet of helicopters performing Public Aircraft operations.

Specifically, industry associations and industry groups whose members operate helicopters performing Public Rotorcraft operations, in conjunction with the FAA, should develop educational materials and programs showing the benefits of, and lending support to, the incorporation of CRFS and CRSS into the current fleet of helicopters performing Public operations. These associations and industry groups should distribute the educational materials via all available media (publications, websites, social media, etc.), and routinely conduct related educational programs at industry conferences and trade shows.

Industry standards, especially when used for accreditation, provide a strong impetus for compliance. Accordingly, the ROPWG also recommends that Public Rotorcraft industry associations and accreditation bodies develop standards that call for the incorporation of CRFS and CRSS into the current fleet of helicopters performing Public Rotorcraft operations. These industry standards should be promoted as Public Rotorcraft operations best practices, and compliance should be mandatory for accreditation of the operator. The entities that set standards should promote the use of best practices and the benefits

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[45] Public Aircraft are aircraft owned, operated or exclusively leased for at least 90 continuous days by the government of a State, the District of Columbia, or a territory or possession of the United States or a political subdivision of one of these government. Due to public law, these aircraft are not required to comply with the FAA regulations discussed in the present report (airworthiness and operational regulations). Further details regarding Public Aircraft can be found in AC 00-1.1A: Public Aircraft Operations (PAO).

of accreditation via all media available to them, and should make the standards readily available to operators of Public Rotorcraft.

With increased awareness through education and inclusion in industry standards, it is expected that incorporation of CRFS and CRSS in helicopters performing Public Rotorcraft operations will increase, thereby reducing the number and severity of injuries and fatalities in future Public Helicopter accidents.

Public Rotorcraft Associations and the FAA Should Use Education and Industry Standards to Promote Voluntary Use of Personal Protective Equipment (PPE) in Helicopters Performing Public Rotorcraft Operations

Objective: Reduce injuries to occupants involved in survivable crashes of helicopters engaged in Public Rotorcraft operations through the use of PPE.

Discussion: By public law (Title 49 of the United Sates Code, 40102(a) (41) and 40125; AC00-1.1A), the FAA has no regulatory authority over Public Aircraft nor has it shown a willingness to assume any authority through a change in the law. Therefore, none of the recommendations presented previously in regards to PPE would apply to helicopters operated solely as Public Rotorcraft, and any recommendations for helicopters operated as Public Rotorcraft must be voluntary in nature. In consideration of this, the ROPWG has developed a separate set of recommendations for Public Rotorcraft.

Note that Public Rotorcraft operations comprise approximately 10% of helicopter operations in the U.S. As discussed in this report, the use of PPE in helicopter operations has been shown to reduce head trauma and thermal injuries in survivable crashes. Accordingly, the ROPWG strongly recommends the voluntary use of personal protective equipment by those involved in Public Rotorcraft operations.

Specifically, industry associations and other groups whose members operate helicopters performing Public Rotorcraft operations, in conjunction with the FAA, should develop educational materials and programs supporting the use of PPE. Recommended PPE should include the use of certified helmets, flame resistant flight suits and gloves, and leather (or other flame resistant material) boots by all crewmembers involved in Public Rotorcraft operations. The industry groups should then distribute these materials via all media available (publications, websites, social media, etc.), and routinely conduct related educational programs at industry conferences and trade shows.

Industry standards, especially when used for accreditation, provide a strong impetus for compliance. Accordingly, the ROPWG also recommends that Public Rotorcraft industry associations and accreditation bodies develop standards for the use of PPE as an industry best practice and as a mandatory requirement for accreditation. The entities that set standards should promote the use of best practices and the benefits of accreditation via all media available to them, and should make the standards readily available to operators of Public Rotorcraft.

Since the use of PPE in Public Rotorcraft operations is a public safety industry best practice, and since it is a required standard for accreditation by the Airborne Public Safety Accreditation Commission (APSAC) across all sets of public safety aviation areas (law enforcement, firefighting and SAR), compliance with this recommendation should not be difficult for the vast majority of public safety helicopter operators.

With increased awareness through education and inclusion in industry standards, it is expected that PPE use in Public Rotorcraft operations will increase, thereby reducing the number and severity of injuries and fatalities in future Public helicopter accidents.

CONCLUSIONS

HIGH PRIORITY RECOMMENDATIONS TO THE FAA

Although the ROPWG made a number of recommendations in several different areas, the ROPWG considers certain recommendations critical to mitigating the problem of inadequate occupant protection in the existing rotorcraft fleet. As discussed in this report, the options available for retrofitting occupant protection features into the entire existing rotorcraft fleet are severely limited due to technical and financial considerations. However, there are three reasonably practicable recommendations that the ROPWG considers critical to improving overall crash safety:

- Require retrofit of crash resistant fuel bladders in all Normal Category rotorcraft with few exceptions.
- Require retrofit of upper torso restraint in all rotorcraft seating positions with few exceptions.
- Require age-appropriate restraints for all rotorcraft occupants (eliminate "lap child exemption").

These changes would ensure that post-crash fires in potentially survivable crashes are absolutely minimized, that upper torso and head injuries due to lack of upper torso restraint are eliminated, and that all occupants involved in crashes have available and will use an effective restraint system. It is the ROPWG's opinion that all of these improvements can be implemented with reasonable cost into the entire rotorcraft fleet, and that once accomplished, the improvements will result in a significant reduction of injuries and fatalities in survivable crashes. **The ROPWG cannot overemphasize the importance of the FAA adopting these recommendations and keeping exceptions to an absolute minimum.**

HIGH PRIORITY RECOMMENDATIONS FOR LEGISLATIVE CHANGES

The ROPWG's recommendation that enhanced accident impact and injury data be collected in all aircraft accidents is also extremely important. The lack of crash and injury data in crash investigation reports by the NTSB and the FAA severely inhibits development of well-defined and well-directed occupant protection standards. The lack of this data was the single most significant impediment to the ROPWG accomplishing its task of recommending effective regulatory measures and other enhancements to improve occupant protection in survivable rotorcraft crashes, since it is impossible to develop effective injury reduction countermeasures if the analyst does not know the survivability of each crash or the injuries and mechanisms of injury of the occupants involved in the crash. If future occupant protection regulations are to be based on sound technical data and verifiable epidemiological studies, it is vitally important that this data be included in future accident reports and crash databases.

For several decades, the NHTSA (National Highway Traffic Safety Administration) has based its Federal Motor Vehicle Safety Standards (FMVSS) on data similar to what we are proposing for aviation, and the enhancements to regulations afforded by accurate crash and injury data have been vital to the dramatic crashworthiness improvements and reductions in death and serious injuries experienced in automobile crashes over the same period of time. While adoption of a requirement to include this data in accident reports will not directly save lives, it will provide the basis for more effective occupant protection regulations that will save lives in the future.

In its research to find reasonable recommendations to improve fleet-wide rotorcraft crash protection, the ROPWG noted that Bell Helicopter Textron, Inc. has had retrofit crash resistant fuel system kits available for much of its legacy fleet for several decades. Even though the installation of these kits would vastly improve post-crash fire prevention in these legacy helicopters, very few of these kits have been sold. Similarly, Robinson Helicopter Company has found that many owners/operators are reluctant to install CRFS retrofit kits for R22 and R44 helicopters, even after the issuance of a Service Bulletin. The main impediment to operators installing the kits from Bell and Robinson appears to be cost, even though many of these kits are offered at discounted prices to encourage operators to take advantage of an extremely effective safety enhancement. Since cost seems to be the main impediment to operators installing essential safety equipment or replacing their fleets with safer helicopters, the ROPWG has proposed that the FAA recommend that Congress enact legislation to provide significant tax or cash rebates to owners/operators who install occupant protection systems into their helicopters. If operators could be urged to install life-saving systems or replace their fleets with helicopters equipped with improved safety systems, lives would certainly be saved over time.

RECOMMENDATIONS FOR RESEARCH/SAFETY STUDIES

As stated previously, NTSB accident reports do not provide data that allow an analyst to determine survivability of a crash, injuries incurred in crashes, or failure modes that contribute to injury. While the ROPWG has recommended that the NTSB and the FAA seek the authority and funding to collect this information for future accidents, such data will not be available for many years. Therefore, in the interest of near-term improvements to occupant protection standards, the ROPWG strongly recommends that the FAA commission a large study similar to FAA study CT-85/11, to be focused on assessing data on impact conditions, injuries received, and injury mechanisms. New, reliable data derived from this new study could be used to assess current crash hazards, determine the effectiveness of current occupant protection standards, and determine which standards need modification or improvement. While such a study will be considerably more difficult given the lack of much relevant data in the accident dockets, the CT-85/11 study showed that through careful analysis, meaningful data can still be generated from many accident dockets.

While performing research for this and previous reports, the ROPWG found that there are numerous potential safety interventions, many of which are used in automobiles, that could be adopted to potentially increase helicopter crashworthiness and occupant protection in crashes. However, it is unknown which interventions used in automobiles would be both practical and effective in helicopters. Specifically, it is unknown whether current restraints are effective or are failing in survivable crashes, whether seats and seat tie-down strength are adequate, to what extent structural failures are contributing to injuries in survivable crashes, and whether a host of other potential failure modes are contributing to injuries. The ROPWG recommends that a study subsequent to that described in the previous paragraph be conducted to study these questions and form the basis for updated regulations. This study could also help determine whether supplemental restraints such as deployable air bags and devices such as pretensioners and load-limiting belt restraints that are commonly used in automobiles, would be practicable and effective in helicopters. Additionally, data from this study could be used to determine whether adjustable seat energy attenuators and/or energy attenuating seat cushions would be practicable and effective in civilian helicopters.

Flight and crash data recorder technology is now sufficiently advanced and inexpensive such that a minimum standard recorder could be mandated for installation in many or all helicopters. The data recorders would help facilitate an accurate determination of the cause of accidents, thereby helping prevent future similar accidents, while also providing impact data essential for incorporating occupant protection features for future accidents that will inevitably occur. The economic impact of such a requirement would most likely be no greater than that for the requirement to install emergency locater transmitters (ELTs). The ROPWG recommends that the FAA commission a study to determine whether small, lightweight flight and crash data recorders should be required in some or all rotorcraft, and also determine the minimum standards for such a device.

The ROPWG also recommends that a study be conducted to evaluate incident and accident experiences between organizations that employ human factor processes against those that do not, and examine the investment each of these operator-populations make in training and material outlays. Based upon this data the study should evaluate the correlation between human factors investments and the real benefits derived from their use.

RECOMMENDED CHANGES TO CURRENT REGULATIONS/GUIDANCE

While the ROPWG believes the current occupant protection standards are extremely effective in preventing serious injuries and fatalities in survivable crashes of rotorcraft, the ROPWG noted several areas where the FAA should consider modifying the current standards to improve their overall effectiveness.

While post-crash fires are one of the greatest hazards in a survivable helicopter crash, crash resistant fuel systems have been shown to be extremely effective at preventing post-crash fires and thermal injuries. Additionally, fuel bladder tear and cut resistance has been shown to be a critical property for the crash resistance of fuel bladders[46]. While most fuel bladders currently used in civil helicopters likely have sufficient tear and cut resistance despite the lack of a specific requirement, this is not guaranteed with the current requirements, as the standards refer only to puncture resistance (27.963(g) and 29.963(b)). To ensure that future fuel bladders provide the desired crash resistance, tear and cut resistance criteria are additionally required. Therefore, the ROPWG recommends that TSO-C80, and subparagraphs 14 CFR §§ 27/29.952(g) and 27.963(g)/29.963(b), be revised to include a requirement for tear and cut resistance in addition to the current requirement for puncture resistance. Note that the recommended tear and cut resistance requirement should be limited in applicability to new rotorcraft type designs, and possibly newly-certified CRFS retrofit kits (OEM or STC); there is no intention to require the replacement of previously-installed fuel bladders, nor to require the revision of previously-approved fuel bladder designs that otherwise meet the ROPWG recommendations.

The ROPWG has also noted that the pre-flight briefing requirements specified in 14 CFR 91.107 and other applicable regulations are inadequate due to the fact that 91.107 only requires that the pilot in command brief passengers on the correct use of the safety belt and shoulder harness, whereas knowledge of other factors such as door operation and the hazard posed by a rotating rotor system are of equal importance in an emergency egress. Therefore, the ROPWG recommends that 91.107 and any other applicable regulations and guidance be broadened so that the mandated preflight briefing is required to include all elements required for a safe emergency egress. Additionally, the ROPWG recommends that the pilots engaged in operations that carry passengers for hire receive regular training

[46] Robertson, S.H., and Turnbow, J.W., ROTORCRAFT FUEL TANK DESIGN CRITERIA, Aviation Safety Engineering and Research of Flight Safety Foundation; USAAVLABS Technical Report 66-24, U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, March 1966, AD 631610.

on proper egress from the specific helicopter models they operate, as well as training in effective passenger briefing techniques.

RECOMMENDATIONS TO INDUSTRY

For many helicopter operations, the ROPWG believes personal protective equipment should be more widely used. Helmets, flight suits, flight gloves and safety boots have proven to be highly effective in protecting occupants from crash hazards and should be available and used in many operations, particularly those that are higher risk. The current retail cost of a complete personal ensemble including a military specification helmet is less than $2,000, which is not a large expense considering their effectiveness in protecting users in a crash. The ROPWG recommends that the FAA and professional associations/organization take a more active role in promoting the use of personal protective equipment when operational conditions suggest a potential benefit from their use.

The ROPWG has noted that although flight crews in HAA operations typically wear flame resistant clothing, there is no provision to protect patients in the rare event of a post-crash fire. Consequently, it is recommended that HAA industry associations and operators consider routine use of flame resistant (Nomex) wraps for their patients.

Finally, the ROPWG recommends that the aviation insurance industry become more actively involved in promoting voluntary crash safety upgrades by operators by granting premium reductions or rebates to customers who provide increased crash protection in their aircraft.

RECOMMENDATION FOR NEAR-TERM IMPLEMENTATION BY THE FAA

The ROPWG recommends that the FAA and/or industry associations develop a helicopter safety rating system similar to the star rating system for automobiles sponsored by the NHTSA and the parallel rating safety system offered by the Insurance Institute for Highway Safety (IIHS). These rating systems have been very effective in encouraging buyers of automobiles to preferentially buy the highest safety rated automobiles. A similar system may be effective if applied to aviation. It might also be useful to apply a safety rating system to separate rotorcraft components such as seating systems and fuel systems.

The ROPWG is also recommending that the FAA establish a working group to consider the merits of establishing an information website (Rotorcraft Information Exchange) for the rotorcraft user community that can serve as a hub of safety communication exchange.

Lastly, the ROPWG recommends that the FAA work with existing accreditation systems to develop universal helicopter auditing standards.

RECOMMENDATIONS FOR PUBLIC ROTORCRAFT

By public law, the FAA has no regulatory authority over Public Rotorcraft, nor is there any other organization with regulatory authority over this segment of the rotorcraft industry. As a consequence, there is no regulatory requirement for Public Rotorcraft to meet the requirements of current FAA occupant protection regulations, nor is there a regulatory requirement for operators of Public Rotorcraft to use PPE when engaged in Public operations.

For these reasons, the ROPWG strongly recommends that Public Rotorcraft industry associations and accreditation bodies, in conjunction with the FAA, develop educational materials and programs showing the benefits of, and lending support to, the incorporation of CRFS and CRSS into the current fleet of helicopters performing Public operations. The ROPWG also strongly recommends that these same organizations develop educational materials and programs supporting the use of PPE. These associations and industry groups should distribute the educational materials via all available media (publications, websites, social media, etc.), and routinely conduct related educational programs at industry conferences and trade shows.

SUMMARY

The ROPWG has carefully considered a wide range of potential interventions that might improve the crash performance of the existing fleet of rotorcraft, most of which do not comply with the current occupant protection regulations. In consideration of the feasibility and financial impact of requiring implementation of these standards into the existing fleet, the ROPWG has been very hesitant in making recommendations to require implementation (retrofit) of all or a portion of current occupant protection standards to the existing fleet of helicopters. The three regulatory changes that have been recommended are considered essential and generally cost effective, and are of the highest priority for FAA adoption:

- Require retrofit of crash resistant fuel bladders in all operational helicopters with few exceptions.
- Require retrofit of upper torso restraint in all rotorcraft seating positions with few exceptions.
- Require age-appropriate restraints for all rotorcraft occupants (eliminate “lap child exemption”).

The ROPWG is making additional recommendations to improve crash data collection in order to improve the effectiveness of future rulemaking, as well as recommending studies that the FAA can commission in the near-term to improve the understanding of injury mechanisms and help guide rulemaking. The remaining recommendations of the ROPWG are intended to improve the safety culture in the industry and to encourage operators and OEMs to provide the highest possible level of crash safety in the rotorcraft they operate.

We hope all these recommendations are carefully considered by the FAA, the NTSB, Congress, and the helicopter industry in general.

ROPWG VOTING MEMBERS STATEMENTS OF NON-CONCURRENCE

While the content of this report, and the ROPWG recommendations in particular, were in general agreed upon by most members, there were some areas where there was a difference of opinion. Individual statements of non-concurrence are included below.

Airbus

Airbus strongly supports the development and industry adoption of any safety enhancing features and equipment such as CRFS. However, Airbus notes that for some older and/or rare aircraft models and specific types of operations, retrofit of fuel systems is simply not feasible due to economic and/or mission payload constraints. Airbus feels strongly that retrofit efforts should be focused on helicopters that conduct commercial and/or passenger carrying operations, as the ROPWG recommended for Public Rotorcraft operations. As stated in the report, the ROPWG concluded that it is unlikely that there is any exception language that will satisfy all affected parties. Therefore, Airbus endorses the recommendation to incorporate CRFS features 27/29.952(a) and (f), and 27.963(g)/29.963(b), but feels the FAA should **strongly recommend**, rather than **require**, installation of crash resistant fuel bladders passing 50-foot drop test in or out of structure and with a minimum 250 lb puncture resistance.

Airbus supports actions such as the FAA's publication of Safety Airworthiness Information Bulletin (SAIB) SW-17-31, which notifies all registered helicopter owners and operators of an available list of helicopters that are equipped or can be retrofit with fuel systems that meet the standards of 14 CFR § 27.952 and discusses how such systems may reduce the risk of post-crash fires and improve occupant survivability in an accident.

Last but not least, Airbus suggests that features of §27/29.952 beyond just those recommended in Table 29 can help to reduce the post-crash fires and strongly recommends the incorporation of all crash resistant fuel system features outlined in §27/29.952 for retrofit fuel systems if practical.

Sikorsky

Sikorsky Aircraft strongly supports the goals of reducing helicopter accident rates and increasing survivability when an accident occurs. With those goals in mind, Sikorsky has reviewed the contents of the ROPWG Task 6 report, but does not concur. Please see the following comments and recommendation:

- The report has not demonstrated the basis of the recommendation to retrofit CRFS into Part 29 aircraft.
- The recommendation for retrofit of CRFS is made with the statement that there should be "few exceptions".
- Sikorsky would rather the ROPWG recommend, not require, CRFS be retrofitted in Part 29 Transport Category aircraft. In lieu of retrofit, OEMs or operators could employ other means acceptable to the Administrator to address fuel system crash resistance, including consideration of qualitative methods and compensating features.

1. As noted in the report, "The preceding analysis of CRFS and CRSS effectiveness was based primarily upon analysis of the crash performance of Part 27 rotorcraft since there were

insufficient numbers of Part 29 rotorcraft crashes to perform an empirical analysis of their CRFS and CRSS performance." The report goes on to say "Nevertheless, ROPWG cautiously recommends that similar rules for Part 29 helicopters be adopted as for Part 27 helicopters, as there was no evidence strongly indicating that a different set of recommendations was more appropriate." Table 20 and Table 21, showing the cost-benefit analysis conducted for CRFS for Part 29 aircraft, provides evidence that the cost greatly outweighs the benefit. Furthermore, per Figure 1, OEMs categorized 75% of the existing Part 29 fleet that did not already have CRFS incorporated as having a "low feasibility" of being able to have bladders retrofit into the aircraft. Having insufficient crash data, a cost-benefit analysis showing the costs outweighing the benefits, and OEM experts stating that the effort would be a major, factory-level installation effort for most of the Part 29 aircraft, is all evidence against a recommendation requiring retro-fitting CRFS into all Part 29 aircraft.

2. The report uses historical accident data from Part 27 aircraft with bladders, but bladders that don't conform to the recommendations, as sufficient proof that retrofit of these aircraft with compliant bladders is not required. "Accident data over a 30-year time period has shown these bladders/fuel systems to be extremely effective at preventing post-crash fires and thermal injuries following survivable accidents (reference ROPWG Task 5 CRFS report). Therefore, requiring replacement of these bladders with nearly identical bladders would greatly increase the cost and burden of this rule while providing little or no added benefit." The same consideration of past safety record of Part 29 aircraft is not applied when the recommendation is made to retrofit bladders into Part 29 aircraft.

APPENDIX A: ROPWG MEMBERSHIP

Name	Company/Representing	Position on ROPWG
Dennis F. Shanahan	Injury Analysis, LLC	Chair
Robert J. Rendzio	Safety Research Corporation of America (SRCA)	Voting Member
Harold (Hal) L. Summers	Helicopter Association International	Voting Member
Jonathan Archer	General Aviation Manufacturers Association (GAMA)	Voting Member
Daniel B. Schwarzbach	Airborne Public Safety Association	Voting Member
Krista Haugen	Survivors Network for Air & Surface Medical Transport	Voting Member
Joan Gregoire	MD Helicopters, Inc.	Voting Member
Rohn Olson	Bell Helicopter Textron, Inc.	Voting Member
Matthew Pallatto	Sikorsky	Voting Member
William Taylor	Enstrom Helicopter Corporation	Voting Member
Pierre Prudhomme-Lacroix	Airbus Helicopters	Voting Member
David Shear	Robinson Helicopter Company	Voting Member
Chris Meinhardt	Air Methods	Voting Member
John Heffernan	Air Evac Lifeteam	Voting Member
John Becker	Papillon Airways Inc	Voting Member
Christopher Hall	PHI Air Medical, LLC	Voting Member
Bill York	Robertson Fuel Systems	Voting Member
Randall D. Fotinakes	Meggitt Polymers & Composites	Voting Member
Marv Richards	BAE Systems	Voting Member
Flavio Iurato	Leonardo Helicopters	Voting Member
Laurent Pinsard	EASA Structures Engineer	Non-Voting Member
Rémi Deletain	EASA Powerplant & Fuel Engineer	Non-Voting Member
Martin R. Crane	FAA Structures Engineer	Non-Voting Member
Michael Smith	Bell Helicopter Textron, Inc.	Consultant

APPENDIX B: U.S. ROTORCRAFT REGISTRATION

Table 35. Distribution of Helicopter Models in U.S. Fleet, Sorted by Part 27/29 and by Manufacturer

Type Certificate Holder	Model	Number U.S. Registered	% of Combined Part 27 & 29 U.S. Fleet	Engine	Certification Basis
Airbus Helicopters	BO105	71	0.66%	TT	27
Airbus Helicopters	EC120	89	0.82%	ST	27
Airbus Helicopters	EC130 B4	142	1.31%	ST	27
Airbus Helicopters	EC130 T2	44	0.41%	ST	27
Airbus Helicopters	EC135	278	2.57%	TT	27
Airbus Helicopters	SE3130 (Alouette II)	16	0.15%	ST	27
Airbus Helicopters	SA315 (Lama)	19	0.18%	ST	27
Airbus Helicopters	SA316 (Alouette III)	6	0.06%	ST	27
Airbus Helicopters	SA318 (Alouette II)	11	0.10%	ST	27
Airbus Helicopters	SA319 (Alouette III)	2	0.02%	ST	27
Airbus Helicopters	SA341 (Gazelle)	27	0.25%	ST	27
Airbus Helicopters	SA342 (Gazelle)	3	0.03%	ST	27
Airbus Helicopters	AS350 D B BA B1 (Astar)	101	0.93%	ST	27
Airbus Helicopters	AS350 B2 B3 (Astar)	735	6.79%	ST	27
Airbus Helicopters	AS350 B3e (Astar)	6	0.06%	ST	27
Airbus Helicopters	AS355 (Twin Star)	45	0.42%	TT	27
Bell	206A (Jet Ranger)	96	0.89%	ST	27
Bell	206B/B3 (Jet Ranger)	614	5.67%	ST	27
Bell	206B3 (S/N 3567 & sub) (Jet Ranger)	297	2.74%	ST	27
Bell	206L/L1 (Long Ranger)	204	1.88%	ST	27
Bell	206L3/L4 (Long Ranger)	365	3.38%	ST	27
Bell	407 (4 blade Long Ranger derivative)	707	6.53%	ST	27

Table 35. Distribution of Helicopter Models in U.S. Fleet, Sorted by Part 27/29 and by Manufacturer					
Type Certificate Holder	**Model**	**Number U.S. Registered**	**% of Combined Part 27 & 29 U.S. Fleet**	**Engine**	**Certification Basis**
Bell	427 (Twin 407 derivative)	27	0.25%	TT	27
Bell	429 (Twin 407 derivative)	78	0.72%	TT	27
Brantly	305	2	0.02%	R	27
Brantly	B-2	82	0.76%	R	27
California Helicopters (Sikorsky)	S-55/H-19/HRS-1 (Various) (Chickasaw)	39	0.36%	R	27
California Helicopters (Sikorsky)	S-58/H-34 (Various)	37	0.34%	R	27
Continental Copters	47G	3	0.03%	R	27
Continental Copters	El Tomcat MK-5	15	0.14%	R	27
Continental Copters	El Tomcat MK-6	5	0.05%	R	27
Enstrom	F-28	171	1.58%	R	27
Enstrom	280	100	0.92%	R	27
Enstrom	480	60	0.55%	ST	27
Fairchild Hiller	FH-1100	21	0.19%	ST	27
Helicopteres Guimbal	Cabri G2	13	0.12%	R	27
Hiller	UH-12/H-23 (Raven)	285	2.63%	R	27
Kaman	K-1200 (K-MAX)	16	0.15%	ST	27
Leonardo (Agusta Westland)	A109E	62	0.57%	TT	27
Leonardo (Agusta Westland)	A109A	43	0.40%	TT	27
Leonardo (Agusta Westland)	A119/AW119MKII	81	0.75%	ST	27
Leonardo (Agusta Westland)	AW109SP/A109S/A109S Trekker	35	0.32%	TT	27
MDHI	369	558	5.16%	ST	27
MDHI	500N	38	0.35%	ST	27
MDHI	600N	26	0.24%	ST	27
MDHI	900	19	0.18%	TT	27
Robinson	R22	1023	9.45%	R	27
Robinson	R44	1577	14.57%	R	27

Table 35. Distribution of Helicopter Models in U.S. Fleet, Sorted by Part 27/29 and by Manufacturer					
Type Certificate Holder	**Model**	**Number U.S. Registered**	**% of Combined Part 27 & 29 U.S. Fleet**	**Engine**	**Certification Basis**
Robinson	R66	212	1.96%	ST	27
Scott's Bell (Bell)	47/H-13	608	5.62%	R	27
Sikorsky	R-4	1	0.01%	R	27
Sikorsky	S-52/HO5-S1	6	0.06%	R	27
Sikorsky (formerly Schweizer, Hughes)	269/300/TH-55	600	5.55%	R	27
Texas Helicopter Corporation	OH-13/M74 (Sioux/Wasp)	16	0.15%	R	27
Airbus Helicopters	BK117 A3 A4 B1 B2 C1	74	0.68%	TT	29
Airbus Helicopters	BK117 C2 D2	102	0.94%	TT	29
Airbus Helicopters	EC155 (Dauphin derivative)	10	0.09%	TT	29
Airbus Helicopters	EC225 (Super Puma)	4	0.04%	TT	29
Airbus Helicopters	SA330 (Puma)	23	0.21%	TT	29
Airbus Helicopters	AS332 (Super Puma)	10	0.09%	TT	29
Airbus Helicopters	AS365 (Dauphin)	33	0.30%	TT	29
Bell	204 (Huey derivative)	3	0.03%	ST	29
Bell	205 (Huey derivative)	41	0.38%	ST	29
Bell	210 (Huey derivative)	4	0.04%	ST	29
Bell	212 (Twin Huey derivative)	65	0.60%	TT	29
Bell	214B (Huey derivative)	9	0.08%	ST	29
Bell	214ST (Twin Huey derivative)	15	0.14%	TT	29
Bell	222	28	0.26%	TT	29
Bell	230	8	0.07%	TT	29
Bell	412 (4 blade Twin Huey derivative)	104	0.96%	TT	29
Bell	430 (Bell 222/230 derivative)	35	0.32%	TT	29

Table 35. Distribution of Helicopter Models in U.S. Fleet, Sorted by Part 27/29 and by Manufacturer					
Type Certificate Holder	**Model**	**Number U.S. Registered**	**% of Combined Part 27 & 29 U.S. Fleet**	**Engine**	**Certification Basis**
Columbia (Boeing Vertol)	107-II (Tandem rotor)	15	0.14%	TT	29
Columbia (Boeing Vertol)	234 (Chinook variant)	7	0.06%	TT	29
Erickson (formerly Sikorsky)	S-64 (Skycrane)	24	0.22%	TT	29
Leonardo (Agusta Westland)	AW139	111	1.03%	TT	29
Leonardo (Agusta Westland)	AW169	0	0.00%	TT	29
Leonardo (Agusta Westland)	AW189	2	0.02%	TT	29
Sikorsky	CH-53 (Sea Stallion)	1	0.01%	TT	29
Sikorsky	S-61/H-3/HSS-2 (Various) (Sea King)	67	0.62%	TT	29
Sikorsky	S-70 (Various) (Black Hawk/Seahawk/etc.)	6	0.06%	TT	29
Sikorsky	S-76	203	1.88%	TT	29
Sikorsky	S-92	79	0.73%	TT	29
	Total	10820	100.00%		

Notes:

1. Data prepared by Lee D. Roskop, FAA Rotorcraft Directorate, Ft. Worth, TX, with additional modifications as follows:
    a. Bell 206 model distribution adjusted to align with estimates provided by Bell Helicopter (total number of Bell 206 in U.S. fleet remained the same)
    b. Restricted Category rotorcraft removed from list.

2. Engine abbreviations are as follows:
    a. R = Reciprocating
    b. ST = Single Turbine
    c. TT = Twin Turbine

Table 36. Distribution of Helicopter Models in U.S. Fleet, Sorted by Number U.S. Registered, Part 27					
Type Certificate Holder	Model	Number U.S. Registered	% of Part 27 U.S. Fleet	Engine	Certification Basis
Robinson	R44	1577	16.20%	R	27
Robinson	R22	1023	10.51%	R	27
Airbus Helicopters	AS350 B2 B3 (Astar)	735	7.55%	ST	27
Bell	407 (4 blade Long Ranger derivative)	707	7.26%	ST	27
Bell	206B/B3 (Jet Ranger)	614	6.30%	ST	27
Scott's Bell (Bell)	47/H-13	608	6.24%	R	27
Sikorsky (formerly Schweizer, Hughes)	269/300/TH-55	600	6.16%	R	27
MDHI	369	558	5.73%	ST	27
Bell	206L3/L4 (Long Ranger)	365	3.75%	ST	27
Bell	206B3 (S/N 3567 & sub) (Jet Ranger)	297	3.05%	ST	27
Hiller	UH-12/H-23 (Raven)	285	2.93%	R	27
Airbus Helicopters	EC135	278	2.86%	TT	27
Robinson	R66	212	2.18%	ST	27
Bell	206L/L1 (Long Ranger)	204	2.09%	ST	27
Enstrom	F-28	171	1.76%	R	27
Airbus Helicopters	EC130 B4	142	1.46%	ST	27
Airbus Helicopters	AS350 D B BA B1 (Astar)	101	1.04%	ST	27
Enstrom	280	100	1.03%	R	27
Bell	206A (Jet Ranger)	96	0.99%	ST	27
Airbus Helicopters	EC120	89	0.91%	ST	27
Brantly	B-2	82	0.84%	R	27
Leonardo (Agusta Westland)	A119/AW119MKII	81	0.83%	ST	27
Bell	429 (Twin 407 derivative)	78	0.80%	TT	27
Airbus Helicopters	BO105	71	0.73%	TT	27

Table 36. Distribution of Helicopter Models in U.S. Fleet, Sorted by Number U.S. Registered, Part 27					
Type Certificate Holder	**Model**	**Number U.S. Registered**	**% of Part 27 U.S. Fleet**	**Engine**	**Certification Basis**
Leonardo (Agusta Westland)	A109E	62	0.64%	TT	27
Enstrom	480	60	0.62%	ST	27
Airbus Helicopters	AS355 (Twin Star)	45	0.46%	TT	27
Airbus Helicopters	EC130 T2	44	0.45%	ST	27
Leonardo (Agusta Westland)	A109A	43	0.44%	TT	27
California Helicopters (Sikorsky)	S-55/H-19/HRS-1 (Various) (Chickasaw)	39	0.40%	R	27
MDHI	500N	38	0.39%	ST	27
California Helicopters (Sikorsky)	S-58/H-34 (Various)	37	0.38%	R	27
Leonardo (Agusta Westland)	AW109SP/A109S/A109S Trekker	35	0.36%	TT	27
Airbus Helicopters	SA341 (Gazelle)	27	0.28%	ST	27
Bell	427 (Twin 407 derivative)	27	0.28%	TT	27
MDHI	600N	26	0.27%	ST	27
Fairchild Hiller	FH-1100	21	0.22%	ST	27
Airbus Helicopters	SA315 (Lama)	19	0.20%	ST	27
MDHI	900	19	0.20%	TT	27
Airbus Helicopters	SE3130 (Alouette II)	16	0.16%	ST	27
Kaman	K-1200 (K-MAX)	16	0.16%	ST	27
Texas Helicopter Corporation	OH-13/M74 (Sioux/Wasp)	16	0.16%	R	27
Continental Copters	El Tomcat MK-5	15	0.15%	R	27
Helicopteres Guimbal	Cabri G2	13	0.13%	R	27
Airbus Helicopters	SA318 (Alouette II)	11	0.11%	ST	27
Airbus Helicopters	SA316 (Alouette III)	6	0.06%	ST	27
Airbus Helicopters	AS350 B3e (Astar)	6	0.06%	ST	27
Sikorsky	S-52/HO5-S1	6	0.06%	R	27

Table 36. Distribution of Helicopter Models in U.S. Fleet, Sorted by Number U.S. Registered, Part 27					
Type Certificate Holder	**Model**	**Number U.S. Registered**	**% of Part 27 U.S. Fleet**	**Engine**	**Certification Basis**
Continental Copters	El Tomcat MK-6	5	0.05%	R	27
Airbus Helicopters	SA342 (Gazelle)	3	0.03%	ST	27
Continental Copters	47G	3	0.03%	R	27
Airbus Helicopters	SA319 (Alouette III)	2	0.02%	ST	27
Brantly	305	2	0.02%	R	27
Sikorsky	R-4	1	0.01%	R	27
	Total	9737	100.00%		

Table 37. Distribution of Helicopter Models in U.S. Fleet, Sorted by Number U.S. Registered, Part 29					
Type Certificate Holder	**Model**	**Number U.S. Registered**	**% of Part 29 U.S. Fleet**	**Engine**	**Certification Basis**
Sikorsky	S-76	203	18.74%	TT	29
Leonardo (Agusta Westland)	AW139	111	10.25%	TT	29
Bell	412 (4 blade Twin Huey derivative)	104	9.60%	TT	29
Airbus Helicopters	BK117 C2 D2	102	9.42%	TT	29
Sikorsky	S-92	79	7.29%	TT	29
Airbus Helicopters	BK117 A3 A4 B1 B2 C1	74	6.83%	TT	29
Sikorsky	S-61/H-3/HSS-2 (Various) (Sea King)	67	6.19%	TT	29
Bell	212 (Twin Huey derivative)	65	6.00%	TT	29
Bell	205 (Huey derivative)	41	3.79%	ST	29
Bell	430 (Bell 222/230 derivative)	35	3.23%	TT	29
Airbus Helicopters	AS365 (Dauphin)	33	3.05%	TT	29
Bell	222	28	2.59%	TT	29
Erickson (formerly Sikorsky)	S-64 (Skycrane)	24	2.22%	TT	29
Airbus Helicopters	SA330 (Puma)	23	2.12%	TT	29
Bell	214ST (Twin Huey derivative)	15	1.39%	TT	29
Columbia (Boeing Vertol)	107-II (Tandem rotor)	15	1.39%	TT	29
Airbus Helicopters	EC155 (Dauphin derivative)	10	0.92%	TT	29
Airbus Helicopters	AS332 (Super Puma)	10	0.92%	TT	29
Bell	214B (Huey derivative)	9	0.83%	ST	29
Bell	230	8	0.74%	TT	29
Columbia (Boeing Vertol)	234 (Chinook variant)	7	0.65%	TT	29
Sikorsky	S-70 (Various) (Black	6	0.55%	TT	29

Table 37. Distribution of Helicopter Models in U.S. Fleet, Sorted by Number U.S. Registered, Part 29					
Type Certificate Holder	**Model**	**Number U.S. Registered**	**% of Part 29 U.S. Fleet**	**Engine**	**Certification Basis**
	Hawk/Seahawk/etc.)				
Airbus Helicopters	EC225 (Super Puma)	4	0.37%	TT	29
Bell	210 (Huey derivative)	4	0.37%	ST	29
Bell	204 (Huey derivative)	3	0.28%	ST	29
Leonardo (Agusta Westland)	AW189	2	0.18%	TT	29
Sikorsky	CH-53 (Sea Stallion)	1	0.09%	TT	29
Leonardo (Agusta Westland)	AW169	0	0.00%	TT	29
	Total	1083	100.00%		

APPENDIX C: INTERVENTION STRATEGY SCORING RESULTS

Table 38. Total Score - OE and Effectiveness				
IS No.	**INTERVENTION**	**Overall Effectiveness**	**Average Feasibility**	**OE x F**
9B	Require installation of Energy Absorbing/Stroking seats in Part 29 aircraft	4.55	2.00	**9.09**
1A	Require installation of partially-compliant CRFS in Part 27 helicopters	3.79	2.14	**8.12**
1B	Require installation of partially-compliant CRFS in Part 29 helicopters	3.79	2.14	**8.12**
9A	Require installation of Energy Absorbing/Stroking seats in Part 27 aircraft	3.64	2.00	**7.27**
3	Require Tear Resistance for Flexible Fuel Liners	3.03	2.29	**6.93**
25A	FAA mandates use of helmets	1.98	2.14	**4.23**
27B	OEM's develop Deployable barrier, restraint or occupant mounted	1.98	2.14	**4.23**
33	Mandate upper torso restraint installation (including retrofit pre-1994) and proper usage	1.98	2.14	**4.23**
9C	FAA require energy absorbing seats that can be easily tuned…	2.00	1.86	**3.71**
4	Require flame resistant clothing be worn by occupants	1.67	2.00	**3.33**
8A	Prohibit sale of non-CRFS replacement fuel tanks	1.67	2.00	**3.33**
27A	Deployable barrier(s), cockpit mounted	1.48	2.00	**2.96**
21E	Replace 3-point restraint with 5-6-7-point restraints	1.48	1.86	**2.75**
21C	Replace all 4-point with 5-6-7-point restraints	1.14	2.29	**2.61**
28	Remove Inertia Reels	0.89	2.57	**2.29**
90A	Reinforce programs that influence human factor cultures	0.76	3.00	**2.29**
27D	Reduce lethality of occupied zone	1.14	2.00	**2.29**
25B	FAA and industry promote use of helmets	0.86	2.57	**2.20**
37	Occupant Training on Proper Use of Restraint Systems	0.86	2.43	**2.08**
86B	Encourage owner/operators to make near term investments in safety enhancements…	0.83	2.43	**2.02**
11	FAA require Replacing soft seat bottom cushions with harder energy absorbing foam…	1.00	2.00	**2.00**
21A	Use low elongation webbing	0.76	2.57	**1.96**
30	Proper Restraint System for Children	0.76	2.57	**1.96**
20	FAA require installation of Landing gear with increased energy absorption capability	1.33	1.43	**1.90**
28A	Add Inertia Reels for Passengers	0.76	2.43	**1.85**
29	Require Pre-Flight Safety Briefing to Include Brace Position and proper use of restraint	0.76	2.43	**1.85**
6A	FAA require Flame Resistant Wraps for all Patients in HAA Operations	0.83	2.14	**1.79**
91	Insurance Incentivize Rotorcraft Community	0.63	2.71	**1.70**
34	Inflatable Lap Belt with Upper Torso Screen (e.g., Part 25 design)	0.76	2.14	**1.63**

Table 38. Total Score - OE and Effectiveness				
IS No.	**INTERVENTION**	**Overall Effectiveness**	**Average Feasibility**	**OE x F**
18	FAA requires Crash Predictor System for Occupant Restraint Haul-Back	1.00	1.57	**1.57**
21B	Use wider straps	0.59	2.57	**1.52**
26	Evaluate use of Pretensioners on Restraint Systems to appropriate agency	0.59	2.29	**1.35**
21D	Replace 3-point restraint with 4-point restraints	0.59	2.14	**1.27**
47	Increase structural strength for large overhead masses…	0.86	1.43	**1.22**
38	Checklist to Include Crew Cross-Check for Properly Donning Restraint System…	0.50	2.43	**1.21**
86A	Offer Tax Credits to encourage owners or operators to improve safety on their rotorcraft	0.50	2.43	**1.21**
92D	Promote Voluntary Retrofit of Crash Resistant Fuel and Seat Systems...	0.44	2.57	**1.14**
6B	Provide Flame Resistant Wraps for All Patients in HAA Operations	0.42	2.57	**1.07**
2	Study Fire Suppression Systems Technology for Existing Rotorcraft	0.42	2.43	**1.01**
88	Work with Industry Groups to encourage constituents to improve safety	0.33	3.00	**1.00**
86D	FAA-published advisory materials aimed and educating and encouraging owners/operators…	0.33	2.71	**0.90**
89	Work with existing accreditation systems to define safety standard levels	0.33	2.71	**0.90**
90B	Reinforce programs that influence human factor cultures	0.33	2.43	**0.81**
86C	OEM-published documents to inform and encourage owners/operators to make safety upgrades…	0.27	2.86	**0.76**
92C	Promote Voluntary Retrofit of Crash Resistant Seat and Structure in Helicopters…	0.27	2.71	**0.72**
19	Study incorporation of external belly-mounted airbags	0.29	2.43	**0.69**
31	Head Restraint Systems (Passengers & Pilots)	0.30	2.29	**0.68**
32A	Perform study of Alternate Geometry Restraint Systems (crisscross belts, integrated vest, etc.)	0.30	2.29	**0.68**
92B	Promote voluntary retrofit of crash resistant fuel systems used in Helicopters Performing Public Missions	0.27	2.43	**0.65**
86E	Use Placards to inform operators/passengers when a rotorcraft does not meet latest safety standards	0.19	2.43	**0.46**
48	Research improved EA Landing Gear	0.20	2.29	**0.46**
49	Ballistic Parachutes	0.25	1.71	**0.43**
50	Increase seat retention strength…	0.19	2.14	**0.40**
87	Establish a Standardized Safety Rating System for Rotorcraft components...	0.08	2.71	**0.23**
92A	Mandate the Use of Personal Protective Equipment (PPE)…	0.11	2.00	**0.22**
71	Replace restraint system after specified fielded-time	0.07	2.71	**0.20**
72	Require more detailed inspection of restraint systems	0.07	2.71	**0.20**
82	Provide personal air canisters for all occupants during overwater operations	0.08	2.29	**0.19**

Table 38. Total Score - OE and Effectiveness				
IS No.	**INTERVENTION**	**Overall Effectiveness**	**Average Feasibility**	**OE x F**
64	Use of helmets with visor down	0.07	2.43	**0.18**
50A	Modify seat attachment points to allow localized relative floor motion/twisting	0.07	2.29	**0.17**
83	Secure objects within cabin and cockpit per § 27/29.561(b)	0.07	2.00	**0.15**
84	Equipment mfg. and customizing companies provide means to secure equipment	0.04	2.71	**0.10**
81	FAA require egress training for flight crew and preflight egress briefing for all occupants	0.04	2.57	**0.10**
51	Evaluate use of load-limiters at Seat Attach Points	0.04	2.29	**0.08**
52	Investigate New Materials for Seat Construction	0.04	2.14	**0.08**
85	Provide better definition of what proper securing of loose equipment	0.03	2.86	**0.08**
55	Unload the Seat of Auxiliary Equipment	0.03	2.71	**0.08**
74	Proper restraint system geometry	0.03	2.43	**0.07**
63	Reorient aft-facing seats to forward-facing if feasible	0.03	2.14	**0.06**
70	Reinforce cabin to prevent contact between occupants and cabin structure/external objects during crash…	0.04	1.43	**0.05**
5	Training for Passengers on Appropriate/Safe Clothing	0.00	0	**0.00**
7	Research/require anti-misting fuel (e.g., Part 25 crash demo)	0.00	0	**0.00**
27C	Nets	0.00	0	**0.00**
45	External deployable energy absorber	0.00	0	**0.00**
53	Internal Airbag to Redistribute Loads	0.00	0	**0.00**
54	Netting System to Redistribute Loads	0.00	0	**0.00**
56	Training to Passengers What to Do If Seat Fails	0.00	0	**0.00**
59	Attach Restraint System to Airframe Structure and Use Straps Guides Affixed to Stroking Seat…	0.00	0	**0.00**
60	Provide seat structural redundant load paths…	0.00	0	**0.00**
61	Backup seat retention strap (chicken strap)	0.00	0	**0.00**
62	Minimize Dynamic Overshoot via Usage of Pretensioners	0.00	0	**0.00**
68	Installation of nets as protective barriers in side windows…	0.00	0	**0.00**
75	Use increased strength restraints straps	0.00	0	**0.00**
75A	Remove Inertia Reels	0.00	0	**0.00**
80	Wear protective equipment including helmets and gloves	0.00	0	**0.00**

APPENDIX D: INTERVENTION DESCRIPTIONS

Appendix D presents the descriptions of the potential intervention strategies remaining for consideration for recommendation by the ROPWG after the scoring process was completed. In the final process, many of these ISs were combined and some were removed from consideration, primarily for technical reasons. The Process the ROPWG followed is described in the main body of the report at "Intervention Strategies".

Note that the strategies in this appendix were considerably modified and refined in developing the final ROPWG Task 6 recommendations; they are included here only for reference to document the deliberation process of the working group. The potential strategies/recommendations listed in this appendix are NOT recommended by the ROPWG unless they also appear in the main body of this report. In instances where the strategies/recommendations in the main body of the report differ from those in this appendix, the text in the main body takes precedence.

1. Recommendations for Implementation of Current Occupant Protection Regulations to the Existing Rotorcraft Fleet

IS 33: Mandate Upper Torso Restraint Installation (Including Retrofit Pre-1992) and Proper Usage

Objective: Eliminate injuries resulting from the lack of upper torso restraint by ensuring upper torso harnesses are installed in and used in all Rotorcraft within 4 years of the date of notice publication. (Note: 14 CFR 91.107 already mandates use of shoulder harnesses *if they are installed in the Rotorcraft.*)

Discussion: Crash injury accident statistics indicate that the lack of upper torso restraint (also called a shoulder belt) harnesses significantly increases the probability of injury and fatality. Upper torso restraint systems dramatically reduce the head strike envelope for all occupants and additionally minimize the potential for crewmember impalement on the cyclic. While an upper torso restraint provides increased occupant restraint from deceleration in the longitudinal and sideward directions, it also protects the occupant in vertical impacts by helping keep the occupant's spine aligned with the principal loading direction. Adequate restraint in a crash enhances the occupant's ability to safely egress the rotorcraft by minimizing the potential of injury or debilitating injury during the crash sequence.

On September 16, 1991, mandatory compliance with 14 CFR §§ 27.2 Amdt 27-28 or 29.2 Amdt 29-32 was required within 1 year for all rotorcraft manufactured after September 16, 1992. These airworthiness standards *required that each occupant's seat* [be] *equipped with a safety belt and shoulder harness that meets* specified safety requirements. In FR-1989-12-08/Vol. 45, No. 235, page 50688, it states:

> *"Installation and use of a shoulder harness that restrains the occupant from potential secondary impact, and that properly supports the upper torso for the vertical impact loads, when used in conjunction with a safety belt that is designed to the minor crash condition airworthiness standards, should enhance safety of the occupants in 52 to 68 percent of rotorcraft impacts."*

The FAA should initiate rulemaking to amend 14 CFR Parts 91, 121, 133, 135, and 137 requiring operators to show compliance with 14 CFR §§ 27.2(a), (b), (c) or 14 CFR §§ 29.2(a), (b), (c). OEMs and PMA organizations should develop retrofit kits and obtain STCs for installing upper torso restraints (shoulder belts) at all seats that meet 14 CFR §§ 27.2(a), (b), (c) Amdt 27-37, 27.561(b)(3) Amdt 27-25, and 27.785(c) Amdt 27-35; or 14 CFR §§ 29.2(a), (b), (c) Amdt 29-32, 29.561(b)(3) Amdt 29-38, and 29.785(c) Amdt 29-42.

The ROPWG recommends that the FAA be given 24 months to develop guidance and requirements and an additional 24 months be provided for OEMs to obtain STCs. All rotorcraft operating 4 years after the date of final rule publication shall show compliance with the requirement to have an upper torso restraint (shoulder belt) installed at all seats that meets applicable airworthiness standards.

IS 8A: Prohibit sale of non-CRFS fuel tanks when CRFS alternatives are readily available

Objective: Encourage the FAA to prohibit installation of non-crashworthy fuel system replacement parts when a retrofit, improved CRFS fuel kit is available.

Discussion: Some helicopter OEMs have made progressive improvements in the crashworthiness of their fuel systems over time. These improvements range from adding vent system protection, adding flexible fuel lines, and developing complete STCd fuel system replacements to meet the current FAA 1994 requirements, incorporating more robust crash resistant bladders in place of light construction bladders and adding crash resistant bladders to systems that were originally designed without bladders. In some cases, the OEMs have made available service bulletin modification kits or have developed STCs that bring the older design up to or closer to the 1994 CRFS requirements. Making older non-compliant fuel system replacements parts unavailable when newer compliant/or nearer compliant replacement parts are available should result in quicker fielding of improved fuel systems in the existing rotorcraft fleet, and therefore, increase overall crash survivability in the modified fleet.

IS 86E: Install aircraft placards to inform operators/passengers when a rotorcraft does not meet current Occupant Protection regulations

Objective: Create new regulations requiring the installation of passenger warning placarding when current rotorcraft safety regulations are not met. Review the existing fleet certification basis(s) and determine which rotorcraft would require which placards. An example placard is shown below:

> **PASSENGER WARNING**
> This aircraft does not meet the FAA's current regulations for fuel system crash resistance

Discussion: Placards can be used to inform the operators/passengers in cases where the rotorcraft has not been certified to current FAA crashworthiness standards for occupant protection. Placards will quickly inform the operators and passengers that current safety standards have not be met, allowing people to make a more informed decision on what aircraft they choose to operate or fly in. Placarding may also increase the rate that affected rotorcraft are upgraded and/or encourage operators to upgrade their fleets to helicopters that are compliant.

Media coverage of recent rotorcraft accidents with post-crash fires have informed the public that a large percentage of the existing rotorcraft fleet does not meet current FAA standards for CRFS. These recent accidents and increased public awareness have resulted in NTSB recommendations to the FAA and in the FAA exploring potential approaches to increasing the level of occupant protection in rotorcraft that do not comply with current standards. The FAA has published a Special Airworthiness Information Bulletin (SAIB), SW 17-31, to inform operators on which rotorcraft meet current standards for CRFS. This awareness within the operator community has been a positive step allowing operators easy access to safety information that can be difficult for some to find. Public awareness can be another positive step, creating the possibility of consumer driven-change.

The FAA currently requires the use of passenger warning placards on Experimental/Restricted/Light Sport Aircraft (LSA) category aircraft to inform passengers that these aircraft do not meet the safety standards for standard aircraft. Placards that inform passengers when current FAA safety standards are not met are relevant and important to informing the public. Public reaction to recent media concerning the “grandfathering” of new production rotorcraft to safety regulations that date back prior to 1994 has been one of surprise and disbelief. Public experience with automotive safety enhancements timelines has driven a public expectation of continuous safety improvements.

2. Recommendations for Educational/Incentive programs to improve the Crash Safety of the Existing U.S. Rotorcraft Fleet

IS-90A: Promote principles/culture that address Human Factors: High Reliability Organizations, Just Culture, "HFACS," and Crew Resource Management across industry

Objective: Conduct a study to ascertain the extent to which integrating Human Factors processes and education (HRO, Just Culture, HFACS, CRM, etc.) into helicopter operations would reduce accidents and contribute to reduced injury rates in crashes.

Discussion: A study should be conducted to measure the empirical benefits derived by operational users in selected (but high exposure) providers that perform utility, emergency medical services, and tour operations. The study should evaluate incident and accident experiences between organizations that employ these human factor processes against those that do not, as well as examining the investment each of these operator populations make in training and material outlays.

Based upon this data the study should evaluate the correlation between human factors investments and real benefits derived from their use. Based upon the strength of the correlation the FAA should consider the next logical step in requiring these processes be integrated in various helicopter operations with broader application to be considered afterward.

The success of technology and improvements to technology, many of which are recommended in this report, depend upon the human-machine interface and the appropriate use of the technology by humans. The complexity of the variables that impact how humans interact with technology is an essential part of the conversation on safety improvements. Further, the culture within which humans operate is a critical factor in the success of safety improvements as well as risk mitigation strategies. Adopting a combination of models to provide a framework to optimally address the human-machine interface and overall culture will help to ensure the success of the safety initiatives presented in this report. The suggested models are:

1. High Reliability Organization (HRO)
2. Just Culture
3. Shappell & Wiegmann's Human Factors Analysis & Classification System (HFACS)
4. Crew Resource Management (applied organizationally)

The rotorcraft industry would benefit in following the principles of High Reliability Organizations (HROs) as an overarching framework. High reliability organizations are those that consistently experience no serious or catastrophic accidents despite operating in complex, high-risk domains. The guiding principles of an HRO are:

1. Preoccupation with failure (recognize the latent organizational weaknesses or flaws)
2. Reluctance to simplify (understand complexity)
3. Sensitivity to operations (ability to see the big picture, situational awareness)
4. Deference to expertise (expertise is sought regardless of hierarchy)
5. Commitment to resilience (capacity to detect, mitigate, and recover from errors)

A "Just Culture" provides a culture of learning, rather than punishment, and creates a model of shared accountability between individuals, who are responsible for their behavior and choices within an organization; and the organization, which is responsible for designing and improving workplace systems. Personal accountability is essential, but to focus exclusively on individual error does not solve for the systemic conditions that may have placed the individual in the optimal position to err. Systemic conditions must be addressed in order to truly mitigate future risk.

Shared accountability between an individual and a system is difficult to ascertain without a framework such as the HFACS model to help identify underlying causal and/or contributing system issues. The Human Factors Analysis and Classification System (HFACS) model was developed by Dr. Scott Shappell and Dr. Douglas Wiegmann. This model, based upon James Reason's Swiss Cheese Model, was developed to help identify contributing/causal factors to incidents and accidents from a systems perspective. It provides both retrospective as well as prospective/predictive opportunities to manage human performance and to identify system issues that contribute to mishaps. Many of the issues identified by the HFACS model can be addressed by human factors engineering, applying engineering controls and forcing functions, and employing the principles of Crew Resource Management (CRM).

CRM is a method to help achieve safe and efficient flight operations by teaching and practicing strategies related to threat and error management, information processing, communication, stress/fatigue, decision-making and judgment, workload and time management, team building, situational awareness, and complacency. The principles of CRM can be extrapolated beyond the cockpit to the organization as a whole to help achieve safe and efficient operations in general.

The aviation industry has historically been punitive in nature, particularly towards pilots, when it comes to incidents and accidents. This creates an environment in which operators may be reluctant to report problems they identify, or near-misses/close calls. The non-reporting of close calls does not allow for existing or latent issues to be addressed before a serious mishap or catastrophe occurs. Additionally, in a suboptimal culture, safety concerns may be reported by frontline staff but ignored or dismissed by leadership.

The combination of the HRO principles, Just Culture, HFACS, and CRM creates an optimal environment for proactive and predictive risk management, including incident/accident prevention as well as prevention and/or mitigation of injuries should an accident occur. Governing/regulatory bodies, accrediting/licensing bodies, aviation organizations, trade organizations, and industry should teach/learn, put into practice the principles of HROs, Just Culture, HFACS, and CRM across the industry. Refresher courses should be recommended at periodic intervals.

IS 86D: FAA-published advisory materials aimed at educating and encouraging owners/operators to improve safety on their rotorcraft

Objective: Increase safety awareness of technologies and programs available (or impending) that increase safety of rotorcraft.

Discussion: Many existing rotorcraft owners and operators may not be aware of the improved technologies, products, and programs that are available which may both increase aircraft safety and are supported by incentive programs. This effort establishes a means to communicate these programs across rotorcraft pilot and operator communities.

Historical mishap experience indicates that safety enhancements available to rotorcraft could have reduced the severity of accidents that had actually occurred. These enhancements are as simplistic as improved restraint systems or the integration of crash resistant fuel systems. Unfortunately, these improvements are not well communicated to the community to include articulating their safety benefit(s) and where applicable, cost incentives when integrated.

This program establishes an information communication process that informs the community of emerging technologies, newly emerging enhancement programs available, and finally, their expected positive safety value.

The FAA should publish advisory material that clearly defines the safety standards that are being met for all certified helicopters. For instance, Special Airworthiness Information Bulletin (SAIB) 17-31 was published in 2017 that specifically addressed fuel systems. This effort (or one similar) can be expanded to address other safety enhancements to rotorcraft that are available. This effort can additionally be mirrored in other publications issued by the FAA or be shared both via its web site and through periodicals germane to rotorcraft.

IS 29 and 38: Modify Checklists to ensure proper restraint system use and egress from rotorcraft.

Objective: Ensure that all passengers carried onboard aircraft (regardless of the operations being conducted) be given a detailed pre-mission briefing on the restraint systems, its use, positive aspects in preventing injuries, and proper egress from the aircraft.

Discussion: The proper wearing of the restraint system is key to maximizing their positive impact on preventing blunt force trauma to both crewmembers and passengers. Failing to properly wear or have the restraint system properly adjusted may result in unnecessary and avoidable injury. There is little empirical data that indicates failure of the restraint system was a contributing factor in injuries during accidents but blunt force trauma to the upper torso and head is evident in almost all accidents, both survivable and non-survivable. This intervention is related to ensuring both passenger and crew are aware of the proper use, fitting and benefits of the restraint system.

The FAA should study the merits of this Intervention being incorporated, at the very least, into an awareness education campaign with consideration for incorporation into the Flight Standards Information System (FSIMS) that require checklist changes during the conduct of flight.

The orientation of this Checklist modification would be to include:

1. Briefing. That all passengers be briefed on the use of the restraint systems installed to include how to properly secure and adjust the seat belt and shoulder harness.
2. Positioning during incident. Provide an overview of proper positioning in the event of an incident.
3. Egress. Provide instruction on how to disconnect from the restraint system and how to properly exit the aircraft safely.

IS 86B: Encourage owner/operators to make near term investments in safety enhancements for existing aircraft by making the enhancements more affordable.

Objective: Encourage owner/operators to make near term investments in safety enhancements for existing aircraft by OEMs and third-party vendors by making the enhancements more affordable.

Discussion: In general, the industry has been slow to adopt optional safety enhancing equipment offered by OEMs. Slow adoption of such equipment can be attributed to many factors, but the primary reason expressed by many owners/operators is the expense. Aircraft downtime for equipment installation and additional long-term maintenance requirements/costs are commonly cited as reasons for slow adoption as well.

In mature markets with educated end users who see the value such equipment brings to the safety of the operations (e.g. Oil & Gas), the expense of such equipment can often be justified and accepted as a new standard. However, for operators in extremely competitive markets with generally uniformed customers who may not recognize the value of optional safety enhancements (e.g. Air Tour), the expense of optional safety enhancing equipment can be much more difficult to justify. In such markets, early adopters of safety enhancing equipment are put at a competitive disadvantage by taking on such an expense when others who opt to continue to operate equipment with a lower standard of safety can charge fairly equivalent rates and operate more profitably.

The situation is equally challenging for OEMs who want to invest in technology/equipment to continuously improve the safety of their product lines - new production and in-service aircraft. Slow adoption (low demand) of safety enhancing technology for the reasons mentioned above often makes the business case for development of such technology/equipment difficult for OEMs to justify.

Several OEMs and third-party vendors have developed a wide array of safety enhancing equipment such as crash resistant fuel system and crashworthy seat retrofit kits. This development was done by these OEMs and third parties in good faith to provide safety upgrade options for the fleet, and in some cases, to protect themselves against liability.

The price of OEM/vendor equipment is often set based on a standard calculation of factors to include non-recurring costs, recurring costs, anticipated kit/unit demand #, and profit margin. Unfortunately, in many cases the anticipated demand for “optional” safety enhancing equipment has been grossly overestimated by OEMs. Therefore, OEMs and third parties often end up taking a loss on such development efforts. In some cases, components of safety equipment kits simply expire past their respective shelf lives.

OEMs recognize the challenges owners/operators face with the expense of “optional” equipment. To help alleviate this challenge, some OEMs have offered such equipment at-cost or at a significantly reduced price to help generate demand. This has proven to be a fairly successful way to boost demand, supporting proliferation of safety enhancing equipment in the fleet.

IS 87: Establish a Standardized Safety Rating System for Rotorcraft components (e.g. Seat Systems, Fuel Systems)

Objective: Develop a safety rating system designed to clarify the certification status and relative safety of different makes/models of aircraft and equipment; this should encourage owners/operators to opt for aircraft and equipment designed and certified to a higher level of safety.

Discussion: The rotorcraft industry has been generally slow to adopt optional safety enhancing equipment offered by OEMs. Slow adoption of such equipment can be attributed to many factors, but the primary reason expressed by many owners/operators is the expense. Aircraft downtime for equipment installation and additional long-term maintenance requirements/costs are commonly cited as reasons for slow adoption as well.

Also contributing to the slow adoption of safety enhancing equipment is a general lack of understanding (technology, regulations, and/or available options), and in some cases, a lack of perceived value of such equipment.

Regulators and insurers have partnered to establish an effective safety rating system in the automotive industry. This rating system has helped to educate consumers about the safety standard of available makes and models. The rating system also offers a competitive edge to manufacturers who design and test their models to a higher standard of safety.

There are two entities involved with taking this action. The first is the Federal Aviation Administration (FAA) while the second is the Insurance industry.

1. The FAA should take the lead and collaboratively coordinate with industry, insurers, and operators (as appropriate) to develop a standardized criterion for recognizing owners and operators of existing aircraft who increase aircraft safety through material enhancements to their aircraft that are known to reduce exposure to injury risk as well as reducing the extent of injuries. This would be a component of the conceptually proposed Safety Technology and Awareness Refinement (STAR) Program for rotorcraft that would recognize levels of recognition in achieving certain installation parameters. That is, for certain installations and upgrades to the fuel system, seats and restraint systems the aircraft would be awarded a given number of Stars. This proposed initiative could be based upon five stars and if meeting certain criteria of material enhancement (or meeting standards) an operator may claim that they are a Four/Five Star operator. Such significance could be applied to insurance costs where the higher the level (STAR Level) achieved could inherently result in lower premiums. This initiative is proposed to cover all aircraft that include:

    - Aircraft manufactured after 1992 that are used in Part 91 operations and,
    - All aircraft (regardless of age) used in Parts 135, 136, and all "EMS" operations.

    Additionally, the FAA should consider low cost changes and changes that provide the most gain in safety relative to historical accident costs/human losses. Examples of this may be flexible fuel bladders and improved occupant restraint systems. Installation of these items may result in an award of points that relate to a specific STAR award.

2. Insurance companies should use this rating system for policy and premium review annually and furthermore reinforce the process with education and advertisement. That is, the insurance companies should require that all STAR awarded aircraft carry this rating on company literature and be briefed during the passenger briefings before carriage of passengers whether for hire or not.

IS 86A: Offer Tax Credits to encourage owners/operators to install and utilize safety enhancing equipment on the existing rotorcraft fleet or replace existing helicopters with compliant models

Objective: Encourage owner/operators to install and utilize safety enhancing equipment on existing aircraft and/or to replace existing fleet with compliant models.

Discussion: The rotorcraft industry has been generally slow to adopt optional safety enhancing equipment offered by OEMs or other suppliers. Slow adoption of such equipment can be attributed to many factors, but the primary reason expressed by many owners/operators is the expense of purchasing and installing the new equipment. Aircraft downtime for equipment installation and additional long-term maintenance requirements/costs are commonly cited as reasons for slow adoption as well.

The U.S. Government recently offered significant rebates to early adopters of ADS-B OUT equipment (10%-20% of total cost). The tax credit precedence here is solar energy, hybrid cars, high efficiency heat pumps, dual pane windows, etc. In the energy category, these types of credits are significant, often offsetting 25%-40% of acquisition costs and they almost always expire, specifically to encourage early implementation.

Offer tax credits to owners/operators who install and utilize safety enhancing equipment on existing aircraft and/or to replace existing fleet with compliant models. Offer tax credits in the form of fixed dollar deductions, or even better, offer tax credits based on hours flown. Thus, making flying compliant aircraft cheaper than flying non-compliant models would be a smart business decision. This type of credit could be offered for a limited time, and possibly with declining benefit as time went on. This idea rewards early adopters with the most possible financial benefit.

IS 88: Industry Outreach to Promote Safety Enhancing Equipment

Objective: Conduct industry outreach to educate stakeholders about the need to develop, install, and utilize safety enhancing equipment.

Discussion: The rotorcraft industry has been generally slow to adopt optional safety enhancing equipment offered by OEMs. Slow adoption of such equipment can be attributed to many factors, but the primary reason expressed by many owners/operators is the expense. Aircraft downtime for equipment installation and additional long-term maintenance requirements/costs are commonly cited as reasons for slow adoption as well. Also contributing to the slow adoption of safety enhancing equipment is a general lack of understanding (technology, regulations, and/or available options), and in some cases, a lack of perceived value of such equipment.

The automotive industry has shown that industry outreach can be an effective way to educate owners/operators and passengers about the value and availability of various safety features. Furthermore, outreach can be an effective way to educate people about how to properly utilize such equipment for maximum value.

Educate rotorcraft stakeholders about the lack of occupant protection equipment required by the FAA. Educate stakeholders about the need to develop and install safety equipment. Engage stakeholders in an effort to encourage their constituents to act in implementing technologies (i.e., CRFS and CRSS) and cultural competencies that can improve safety.

Outreach should begin with a core group, and expand as able to additional stakeholders. The core group may include working group members such as International Helicopter Safety Team (IHST), GAMA, HAI, and Airborne Public Safety Association (APSA), as well as Aircraft Owners and Pilots Association (AOPA), Area Airspace Management System (AAMS), Air Medical Operators Association (AMOA), National Emergency Medical Services Pilots Association (NEMSPA), and then expand to other related constituencies.

The core group is charged with setting the tone and direction. Core group to circulate ARAC-accepted ROPWG reports with initial groups as a means of beginning information awareness. Core Group to catalogue and share how other industries (i.e., automobile manufacturing, auto racing and others) have implemented technology or culture to improve safety. Stakeholders to press OEMs to develop kits to upgrade to FAA standards.

IS 91: Insurance Incentive Programs for Safety Upgrades and/or Fleet Replacement

Objective: Encourage owners/operators to install and utilize safety enhancing equipment on existing aircraft and/or replace existing fleet with compliant models.

Discussion: The rotorcraft industry has been generally slow to adopt optional safety enhancing equipment offered by OEMs. Slow adoption of such equipment can be attributed to many factors, but the primary reason expressed by many owners/operators is the expense. Aircraft downtime for equipment installation and additional long-term maintenance requirements/costs are commonly cited as reasons for slow adoption as well.

Insurers in the automotive industry have proven the value of offering rebates and or premium discounts to drivers who operate vehicles equipped with modern safety equipment such as side-impact airbags, etc. Generally speaking, the aviation insurance community has been slower to adopt this clever incentive tactic; however, there are a few successful examples of such rebates or premium discounts for fixed wing and rotorcraft operators who opt to install safety enhancing equipment (e.g. Runway Overrun Protection System (ROPS)). This general concept has proven to be a win-win for the insurers/brokers and owner/operators, as the safety upgrades are made affordable to and are therefore more quickly adopted by the owner/operator. Risk/liability is managed from the insurer/broker perspective. Most importantly, injuries/fatalities due to accidents are minimized.

Evaluate the costs associated with injuries/fatalities that could have been reduced or eliminated with implementation of CRFS, and crashworthy seats and structures.

Offer incentive programs such as rebates or premium discounts to encourage owners/operators to install and utilize safety enhancing equipment on existing aircraft and/or replace existing fleet with compliant models.

IS 84: Equipment manufacturing and customization companies provide a means to secure equipment

Note: The narrative description of this intervention strategy is not available.

3. Recommendations to Review and Improve Industry Standards

IS-89: Work with existing accreditation systems to define safety standard levels.

Objective: Develop Universal Helicopter Auditing Standards

Discussion: The helicopter industry has been moving to the use of accreditation groups to audit their operations to a "common" safety standard. An issue is that due to the variety of tasks accomplished by helicopters, it is difficult to write a common standard for all helicopter operations, resulting in specialized audits for specific sectors of the industry. Development of an all-inclusive standard would provide industry auditors with common terms and taxonomy to build comprehensive audits for the industry. This single action would increase the number of auditors empowered to inspect different parts of the industry. This would in turn reduce the number of "specialized" audits and auditors, which has created an inbred system that weakens the audit process and calls the validity of some audits into question. The current system needs improvement to provide greater audit fidelity and safety for the flying public.

Every occasion of an "audited" operation that suffers an untoward occurrence calls the auditing process into question. For the flying public, confidence in the ability of the helicopter industry to effectively monitor its processes and procedures is undermined. The loss of confidence exposes the industry to unfair criticism and unwanted assistance from legislators and regulators.

Accreditation bodies such as HAI, ISBAO, CAMTS, NAAMTA, EURAMI, MAC, APSAC and other rotorcraft industry accreditation bodies should form an organization or network to create a common core of safety technological and cultural improvements that can be incorporated throughout the rotorcraft industry. The organization needs to be able to mitigate the natural competition between auditing bodies to produce a standard that is essentially free from industry segment weighting. This universal standard should include all segments with tailored requirements for unique operations. It should be designed so that any auditor could effectively use it without specialized training. The standard should be designed to produce easily developed and interpreted metrics to facilitate common understanding.

4. Recommendations for Use of Personal Protective Equipment

IS 4: Require flame resistant protective clothing to be worn by all occupants

Objective: Reduce burn injuries to occupants exposed to post-crash fires using proven flame resistant clothing made with fabrics such as Nomex.

Discussion: Post-crash fires in rotorcraft have been identified as a significant factor in occupant/operator injuries and fatalities. Flame resistant clothing is widely available that can reduce burn injuries. DuPont brand "Nomex" fabrics being the most commonly recognized. Nomex fabric is inherently flame resistant (FR) as opposed to fabrics that have been treated with flame retardant. Treated fabrics (common for aircraft interior applications) generally lose some of their capability during the life of the fabric. The fabrics used in clothing are often flammable and can increase the severity of burn injuries by melting into the skin. Proper use of flame resistant clothing has been proven to reduce burn injuries. Requiring all rotorcraft occupants to wear flame resistant flight suits would likely reduce fatalities and the severity of burn injuries in cases were post-crash fires exist and the occupant is able to egress the aircraft or be quickly removed from the aircraft by other occupants/crew/first responders. Flame resistant gloves are also commonly in use and would further protect occupants in post-crash fires

Flame resistant flight suits and gloves are commercially available. The most common type of suit is the CWV 27/P and is in use by all US Military flight crews. These suits retail for under $200. Flame resistant gloves are also available for under $50.

Requiring that all occupants wear flame resistant clothing would have significant operator impacts. The most obvious is the financial impact of procuring the clothing for all crew and passengers. Tour operators may be the most affected. A significant selection of clothing would need to be made available by the operator to fit various sized occupants. Beyond that, many consumers may resist wearing the clothing, and it may help create the impression that traveling by helicopter is significantly riskier than traveling on the airlines. Creative marketing can likely overcome these concerns, but there would certainly be an effect.

Flame resistant flight suits have been in use by military flight crews since the 1970's. The CWV 27/P flight suit is well defined in MIL-C-83414 initially released in 1969. Similar suits are used in almost all sanctioned automobile racing and are typically required by the sanctioning bodies even at entry levels of racing at the amateur level. Flame resistant clothing technology is well proven, widely used, and commercially available, and economical.

Require (FAA Regulation) or encourage (FAA or Industry Safety Groups) the use of Flame resistant clothing for all rotorcraft occupants. Another option is to only require Flame resistant clothing to be worn in rotorcraft that do not meet the current (1994) CRFS standards contained in FAR 27/293952. Yet another option would be to only require this for required crew – those that are exposed to the post-crash fire risk on a daily basis versus the tour consumer who will likely only be in a rotorcraft a hand full of times in a lifetime.

The FAA should add regulations requiring that all occupants of Part 27 and 29 rotorcraft wear Flame Resistant (FR) protective clothing.

IS-82: Provide personal air canisters for all occupants during overwater operations

Objective: Increase post-crash/ditching survival rate through the adoption of available commercial off-the-shelf (COTS) assistive breathing devices.

Discussion: During the 1980s, the USAF developed a breathing device that used small bottle(s) filled with atmospheric pressure air and a normal regulator to provide 2-3 minutes of breathable air at the water's surface. This would provide extra time past the first held breath to safely egress a submerged helicopter. The extra two minutes of air have been demonstrated to provide time decompression in an unexpected immersion to allow crewmembers to exit the aircraft in a relatively relaxed manner. The Helicopter Emergency Escape Device (HEED) has found universal acceptance and use throughout the Department of Defense helicopter fleet. A growing number of commercial suppliers manufacture the devices and they are readily available on the commercial market. Use of the HEED is easily taught even to non-swimmers and the small size of the unit makes it easily adaptable as a piece of worn flight equipment.

The device was developed after the loss of a USAF CH-53 crew in a relatively survivable accident off Okinawa in the 1980s. Since its adoption, there have been many documented successful post-crash egresses from military helicopters and an increase in the overall post-crash survival rate.

Recommend that:

1. FAA develop work group to review available devices and develop standard for such devices.
2. FAA recommend use of approved devices in overwater operations for affected groups 91, 135, private overwater.
3. FAA encourage participation through outreach and training by Federal Aviation Administration Safety Team (FAASTeams).

IS 25A, 25B and 64: Educate users of the benefits of using helmets and visors.

Objective: Encourage helmet use by industry for all crew and passengers involved in higher risk mission profiles and have the FAA provide regulations on the use of helmets for crew when operating in uncontrolled landing areas and low-level airspace.

Discussion: What flights should be recommended or mandated that helmets be utilized by Passengers and/or crew? A risk analysis on mission profile might help to determine when the use of helmets should be required or recommended. Corporate transport from airport to airport would have a lower risk profile than low level flight, prolonged out of ground effect hovering, or other higher risk, off airport operations.

A one size fits all approach on this intervention could be problematic as we are holding one sector of the industry to a higher standard. Point to point transportation in a helicopter is no different than in a small fixed wing aircraft, giving the public the impression that rotary wing flight is more dangerous than fixed wing. Helmets and visors need to be properly fitted to be effective. An improperly fitted helmet could cause injury to the user. Helmets have a recurring certification requirement.

A portion of the Helicopter industry currently uses helmets for crew and passengers. It has been proven to be effective in preventing injuries and saving lives.

Operators with follow on regulation from the FAA should develop a program to have all flight crews wear approved flight helmets that meet requirements for higher risk mission profiles. Operators should also voluntarily offer passengers the use of a helmet for higher risk mission profiles.

IS-71 and 72: Operators include daily inspections and Maintenance of seatbelts and restraint systems.

Objective: Immediately and voluntarily incorporate seatbelt inspections as part of daily maintenance inspections for rotorcraft.

Discussion: Among other aircraft inspection documents, AC20-106 addresses Aircraft Inspection for the General Aviation Aircraft Owner. TSO-C22g also covers specific manufacturing, performance and marking of seat belt used in aircraft. AWB 25-2 Issue 1 - Inspection and replacement of seat belts and harnesses - makes recommendations for removal and destruction of aircraft seatbelts after 10 years of service, as well as recommendations for inspection of safety belts during the 10-year period.

A rotorcraft pilot's shoulder harness failed unexpectedly during a crash. Testing on the failed webbing revealed that the shoulder harness strength had reduced to less than 20 percent of its original strength. The difficulty is, that while seat belt webbing may appear to be free of detrimental fraying, fading from exposure to ultraviolet light, and chemical contamination, the only way of ensuring that seat belt webbing is safe to use, is to test the webbing to destruction. This, of course, renders the belt assembly unusable. To overcome this problem, some rotorcraft manufacturers have implemented a 10-year service life on seat belts and shoulder harnesses.

This intervention is meant to prevent seat belt failure by increasing frequency of inspection, and (if necessary) replacement of aircraft safety belts. The FAA should update guidance on seatbelt inspections and develop rule requiring a "life limit" based on OEM reliability data from date of manufacture. The FAA should also specify replacement of a seatbelt found to demonstrate signs of wear.

IS-6B: Use of flame resistant wraps for patients on HAA Aircraft

Objective: To revise HAA accreditation standards to begin a progressive transition to requiring the use of flame resistant coverings for HAA patients. Standard implementation should progress from "encourage" to "recommend" to "require" over the course of revision updates.

Discussion: Most HAA accreditation standards (e.g., the Commission for Accreditation of Medical Transport Systems (CAMTS) and the National Accreditation Alliance Medical Transport Applications

(NAAMTA)) have standards relative to the use of flame resistant uniforms for HAA pilots and medical crew. The use of flame resistant uniforms is intended to offer rotorcraft occupants an additional layer of protection from thermal injuries during egress from a rotorcraft accident or incident that involves potential exposure to fire.

Patient protection from thermal injuries is not a current standard in HAA operations. While there is scant evidence to illustrate a trend of patient thermal injuries during an HAA accident or incident, it seems intuitive that efforts to protect pilots and medical crew should also extend to patients being transported; any threat to the pilot and medical team that warrants aircraft evacuation is likely a threat to a patient.

This intervention is meant to incorporate a potential protective barrier to thermal injuries to HAA patients. CAMTS (and other HAA accreditation bodies) should incorporate patient thermal injury preventative measures into future accreditation standards. An initial step would be the inclusion of flame resistant wraps for HAA patients in the next anticipated standards revision.

5. Recommendations for Changes to Enhance/Improve Current Occupant Protection Regulations

IS 30: Mandate proper restraint system for children on rotorcraft

Objective: Ensure proper restraint of child occupants in rotorcraft by revising policies and procedures so that all passengers regardless of age occupy a seat and have access to and utilize approved restraints appropriate for age.

Discussion: According to a research article from the American Academy of Pediatrics, "Children younger than 2 years are the only occupants who, under current federal regulation, are not required to be restrained or secured on aircraft during takeoff, landing, and conditions of turbulence; even items such as coffee pots must be secured." ("Restraint Use on Aircraft," American Academy of Pediatrics Committee on Injury and Poison Prevention. Pediatrics, 108:5, November 2001)

Children under age two are allowed to be held on an adult's lap and are not required to be properly secured in an appropriate child restraint in their own seat. This is in contrast to the auto industry where all children are required to be secured in a properly fitted seat/restraint system. It is contrary to the laws of physics that an adult would be able to effectively maintain a secure hold on a lap-child during severe turbulence and survivable accidents. Preventable deaths and injuries of unrestrained children under the age of two have occurred in commercial aviation. (NTSB Safety Recommendation, A-10-121-123, 8/11/2010)

The NTSB has issued safety recommendations since 1979 asking the FAA to require that children under age 2 be in an appropriately secured child restraint in their own seat on airplanes. In 1999, NTSB Chairman Hart observed, "It is unfortunate that regulations require everything except our smallest children to be secured for airplane takeoffs and landings and during in-air turbulence. We have seen cases in which the lack of a child seat has led to serious or fatal injuries and others where the use of a child seat has prevented such injuries. We should use the technology that is available, the resources at our disposal, and our compassion to prevent the needless injury to or loss of more of our most precious resource - our children." (NTSB News Release, "NTSB Plans International Conference on Child Safety in Aviation," December 8, 1999. Even FAA official guidance states that the safest place for young children on an aircraft experiencing turbulence or an emergency is in an approved child restraint system or device, not on an adult's lap. However, this is not mandated. (FAA AC 120-87C)

The American Academy of Pediatrics recommends a mandatory federal requirement for restraint use for children on aircraft. (American Academy of Pediatrics Committee on Injury and Poison Prevention. Restraint use on aircraft, Pediatrics, 108: 5, November 2001).

According to an EASA Study on Child Restraint Systems from 2008, "There are recognized concerns that the current regulations and operational practice may not provide such children with the level of impact protection equivalent to that provided to the other passengers." (Study on Child Restraint Systems, EASA.2007 C.28, November 29, 2008)

A 2006 study by the Australian Transportation Safety Bureau stated that, "… infants and young children are entitled to the same level of protection, both in flight and during emergency landing situations, that is afforded to adults." (Human Impact Engineering and Britax Childcare Pty Ltd. ATSB Report B2004/0241, February 2006)

The FAA should mandate that children of all ages be properly restrained when occupying a rotorcraft by removing all FAA rules and guidance that allow children under the age of 2 not to be properly restrained in an individual seat (e.g. 91.107 (a)(3)(i), 135.128 (a)(1).

IS 81: Require egress training for flight crew in "for hire" operations.

Objective: Require that pilots involved in rotorcraft "For Hire" operations have annual training on proper egress procedures under all emergency conditions including ditching.

Discussion: In order for flight crews to properly brief passengers on safety aspects of the aircraft to include emergency egress, they must be highly literate on the subject themselves. Standardization is critical in "For-Hire" operations since many of these operations involve carriage of "naïve" passengers.

The recent ditching of a tour helicopter in the East River highlights the need for pilots engaged in passenger flights to give an encompassing pre-flight briefing to passengers on the execution of egress from the aircraft in a variety of emergency conditions. To provide a thorough briefing to passengers requires that the pilots be thoroughly trained on proper egress procedures. This training should be recurrent on an annual basis.

IS 3: Require Tear and Cut Resistance in CRFS Flexible Bladder Constructions

Objective: Ensure the crash resistance of fuel bladders by requiring them to meet specific standards for tear resistance in addition to the already required puncture resistance standards.

Discussion: The ROPWG recommends that subparagraphs 14 CFR §§ 27.952(g) and 29.952(g) be revised to provide assurance that fuel bladders meeting this subpart will, in fact, provide the desired survivable crash resistance. In establishing this position, reference is made to TR 79-22E Aircraft Crash Survival Design Guide[47] and to the recommendations for rotorcraft fuel tank design reported by Robertson and Turnbow.[48] The Robertson and Turnbow report recommendations released in 1966 were incorporated into the original (1967) and subsequent versions of the Aircraft Crash Survival Design Guide (TR-79-22E and TR 89-D-22E). These recommendations were based upon significant crash testing as well as helicopter crash investigations.

FAA Advisory Circular 27-1B § 27.952 at Amdt. 27-30, paragraph d.(18)(i) states:

> *"Flexible liners are exempt from the requirements of § 27.952(g) since an unsupported flexible liner can resist only pure tension loads ... the rigid shell structure required by § 27.967(a)(3) that surrounds the flexible liner (membrane) carries the crash-induced*

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[47] U.S. Army. ROTORCRAFT CRASH SURVIVAL DESIGN GUIDE, Volume V – Rotorcraft Post Crash Survival, Prepared for Applied Technology Laboratory, U.S. Army Research and Technology Laboratories (AVRADCOM), Fort Eustis, Virginia 23604, USARTL-TR-79-22E, Simula Inc., 2223 South 48th Street, Tempe, Arizona 85282, January 1980, Final Report.

[48] Robertson, S.H., and Turnbow, J.W., ROTORCRAFT FUEL TANK DESIGN CRITERIA, Aviation Safety Engineering and Research of Flight Safety Foundation; USAAVLABS Technical Report 66-24, U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, March 1966, AD 631610.

impact and tear loads; whereas, the flexible liner is only significantly loaded in tension if the shell structure is penetrated by a sharp object on impact."

This was interpreted as implying that only a puncture resistance requirement is necessary to produce an effective fuel cell liner, which further prompted the change in FAA requirements for puncture resistance to increase from 15 lb to 370 lb. Unfortunately, the underlying assumption can be erroneous because survivable crashes often exhibit loads that cause catastrophic failure of the host container. When the host container yields in a survivable crash, a flexible bladder having sufficient puncture resistance, tear resistance and tensile strength to withstand the crash loads and avoid catastrophic failure is essential to preclude post-crash fire. TR 89-D-22E states in paragraph 4.3.1.3, Tank Materials:

"Elongation can be obtained by tank deformation or material stretch. The amount of fuel tank elongation actually required is unknown. It is known, however, that fuel tanks lacking the ability to elongate are either fairly strong (heavy) or brittle. Both types are easily ruptured in moderate crashes. On the other hand, crash-resistant fuel tank studies have shown that light tanks that can readily rearrange their shape (deform/elongate), at the same time exhibiting a high degree of cut and tear resistance, can hold their contents during upper-limit survivable crashes."

Material properties testing that meets the requirements of MIL-DTL-27422B and later revisions has resulted in zero deaths from post-crash fires in survivable military rotorcraft crashes. These same requirements, at about half of the MIL spec values, have been incorporated into Advisory Circulars 27-1b and 29-2c, but these standards are not regulatory. The FAA selected a lower chisel drop height and a constant rate tear requirement of 200 ft-lb since civil rotorcraft fly different missions and have been demonstrated to have lower average crash velocities than military rotorcraft based on statistical studies (DOT/FAA/CT-85/11, § 2.2.3[49] vs. TR 79-22B, § 3.2).

The FAA should implement rule making for flexible fuel bladders used in CRFS as noted below:

1. Change the TSO-C80 material requirement for flexible fuel liners to the following:
   a. Test per MIL-DTL-27422F, Detail Specification: Tank, Fuel, Crash-Resistant, Ballistic-Tolerant Rotorcraft, dated February 2014 except with the following values:
      i. Constant rate tear – A cut is made in the sample and pulled apart at 20 inches per minute. Must withstand no less than 200 ft-lb.
      ii. Impact penetration – 5-lb chisel dropped from 8 ft onto a construction sample, must not leak when 5 psi is applied to the construction.
      iii. Impact tear – 5-lb chisel dropped from 8 ft onto the edge of the construction with a v-notch cut into the sample. The resulting tear cannot propagate to longer than 1 inch.
   b. Change TSO-C80 to indicate that these requirements are intended for the construction properties of the flexible fuel liner and are to be present over the entire surface of the liner.

2. FAA AC 27-1B, § 27.952 Amdt. 27-30 paragraph d. (19) states:

[49] DOT/FAA/CT-85/11, *Analysis of Rotorcraft Crash Dynamics for Development of Improved Crashworthiness Design Criteria*, June 1985.

"*Section 27.952(g) also requires that all fuel tank designs (regardless of the materials utilized and whether or not a flexible liner of any type is used) ... tested to the criteria of paragraph d.(18)(iv) of AC § 27.952, or equivalent.*"

Due to the ambiguity of the current wording, paragraphs §§ 27.952 (g) and 29.952 (g) need to be re-written to require demonstration of tear and cut resistance for all fuel containment by performance of the MIL-DTL-27422 testing at values specified in TSO-C80, flexible crash resistant liner material property requirements.

IS XX: Change NTSB Charter to require NTSB to include impact data, injury and injury mechanism data in aircraft accident investigations

Objective: Ensure that impact and injury data is collected during the course of general aviation crash investigations.

Discussion: The NTSB is currently responsible for determining "probable cause" of each accident it investigates or delegates to the FAA for investigation. The NTSB has no requirement to determine aircraft impact conditions or injuries sustained by occupants or the mechanisms of those injuries. Consequently, NTSB accident investigation dockets do not usually contain the data required to determine impact conditions, survivability of the crash, injuries or injury mechanisms. The lack of impact and injury data prohibits analysts from determining survivability of crashes or how occupants were injured. This situation limits the FAA's ability to draft effective occupant protection regulations since they cannot determine how people were injured or whether the injuries sustained were related to material failures of structure or protective equipment such as restraints or seats or due to misuse of protective equipment. If you do not know how occupants are being injured and under what conditions, you cannot write effective occupant protection regulations.

The NTSB is an independent Federal agency charged by Congress with investigating every civil aviation accident in the United States and significant accidents in other modes of transportation – railroad, highway, marine and pipeline. The NTSB determines the probable cause of the accidents and issues safety recommendations aimed at preventing future accidents. Since NTSB investigations are focused on accident prevention, they do not consider the issue of protecting occupants when an accident inevitably occurs.

The FAA should work with the NTSB and Congress to expand NTSB or FAA responsibilities to include determination of impact conditions and injury/injury mechanism for each accident investigated. The National Highway Traffic Safety Administration (NHTSA) provides an example of what data should be collected in crashes through the National Automotive Sampling System-Crashworthiness Data System. Military crash investigation manuals also provide examples of how to apply these principles and requirements to aviation crashes.

6. Recommendations for Research to Improve the Crash Safety of Rotorcraft (FAA, NASA, Private Sector)

IS 26 and 18: Evaluate use of Pretensioners and Haul-Backs in Restraint Systems

Objective: Conduct a study to determine if the use of pretensioners or haul-back devices in rotorcraft restraint systems would be feasible and effective.

Discussion: Pretensioners are devices that take slack out of the restraint system. They can be used in the lap belt, the upper torso restraint, or both. Haul-backs are devices that use the restraint system to position (or “pre-position”) the occupant in the seat to better enable him/her to survive the impending impact. While there are differences in philosophy and intent between the two devices, the technology is similar and many of the effects overlap, so they are combined into one discussion.

Pretensioners reduce slack in the restraint system in the early stages of an impact. Reducing the slack tends to reduce injuries for the following reasons:

- It helps to pre-position the occupant for the impact.
- It tends to reduce or eliminate submarining of the lap belt.
- It tends to increase the loading in the restraint webbing, which couples the occupant to the structure, improving the ride down.
- It reduces occupant relative motion within the vehicle, which reduces contact with objects in the vehicle.
- It reduces the unrestrained motion of the occupant, which reduces the peak loads experienced when they “reach the end of the slack.”

There are several factors by which the pretensioner actually reduces the slack:

- It takes up slack in the harness from routing over clothing, etc.
- It reduces the spool out of the webbing on the retractor reel.
- It improves the lock up of the inertial reel.

Pretensioners have been used in automobile restraints for over 40 years. They are typically designed to limit the loading in the strap during pretensioning so it is well below any injury threshold for occupants up to 50 years old and significantly below the loads that will be generated later in the impact. The automobile technology is well understood, but there would be some adaptations required for rotorcraft.

Haul-backs pull the occupant back into the seat and against the seat back, positioning the upper torso in a supported, vertical position, which is better for survival in a vertical impact. Because they are intended to physically move the body as opposed to simply remove slack, haul-backs generate significantly higher loads than pretensioners. These higher loads can cause thoracic injuries. Susceptibility to this type of injury increases as the occupant ages. Risk of injury notwithstanding, the haul-back device has all of the same advantages as the pretensioner.

Numerous studies and accident data have shown that pretensioners reduce injuries. In automobiles, Head Injury Criterion (HIC) is reduced by 26% and chest acceleration and chest compression are also reduced. It is expected that much of the technology could be adapted from the automobile industry.

Haul-backs were developed for ejection seats for military aircraft. The average age of the military aviator population is younger then the civilian rotorcraft population, so thoracic injury from high restraint strap loads is a larger concern.

The FAA in conjunction with industry groups such as ASTM or SAE should establish a program to study the development and use of pretensioners and/or haul-back devices in rotorcraft. The FAA could significantly promote this initiative by funding and supporting the research. Assuming the study determines pretensioner use is feasible and beneficial, the FAA should oversee the development of guidance for their use, including installation and performance parameters.

Seat manufacturers and aircraft OEMs will be most directly affected by this recommendation, if adopted. It should be funded by the FAA, but the FAA, seat and airframe OEMs and an industry group such as SEA or ASTM should be involved.

IS 31: Develop Head Restraint Systems for Passengers and Pilots

Objective: Research head restraint technology and the potential for its use in rotorcraft.

Discussion: Crash injury data indicates that neck and head injuries are a significant cause of death and serious injury in rotorcraft accidents. The auto racing industry has spent considerable time and effort in reducing this type of injury in racecars. The primary form of injury reduction, after implementation of helmets, involves some sort of head restraint system such as the HANS device.

While these systems are effective, by definition they limit head motion, which would be expected to interfere with the normal motion required by the flight crew for normal operations. In addition, to date all of these systems rely on a helmet as part of the system, so these could only be implemented where a traditional helmet was used. Additional research might produce a restraint that reduces head and neck injury while still allowing adequate movement for normal operation. This research could leverage technology developed in the auto racing industry and work toward a system that is practical in a rotorcraft.

Head restraint systems were developed for auto racing in the late-1980's, but were not put into use until the mid-1990's. They did not see widespread use until the early 2000's when various racing associations began to make them mandatory. At the present time, they are mandated by most of the major auto racing associations and generally accepted as effective in saving lives of drivers.

There are obvious differences between the typical impact of a racecar and a rotorcraft. The typical racecar's primary impact is in the horizontal plane (longitudinal and/or lateral) while the rotorcraft's initial impact is typically vertical. However, in both cases, motion of the head relative to the torso exposes the occupant to the risk of injuries, either from contact of the head with objects within cockpit or from inertially-induced injuries (neck injuries, basilar skull fractures). Reducing the head motion is expected to reduce head and neck injuries.

This intervention would encourage the study of alternative head restraint and protection technologies to develop a system that is practical for rotorcraft use, both by flight crew and passengers.

The present state of the technology is not applicable to aviation, especially to rotorcraft. As such, this is a research project and would need funding and sponsorship. While OEMs or private industry could support development, the market is small and it is unlikely that there would be a business case for any private entity to undertake this task. The FAA, perhaps combined with the military, would need to take the lead in organizing and funding this effort. Seat and airframe OEMs, the military, and academia could be enlisted to participate in this study. The technology will need to allow sufficient head motion for the flight crew to perform their duties. Once the technology reaches an appropriate level of development, the FAA will need to develop standards and guidance for its implementation. The FAA could rely on industry groups such as SAE for support in developing the standards and guidance.

IS 52: Investigate New Materials for Seat Construction

Objective: Study modernizing requirements for STC processes while simultaneously evaluating technologies currently available that could cost effectively increase seat contributions in absorbing vertical forces sustained in mishaps.

Discussion: Seat construction, to include the materials used in seats, has evolved over the last 60 years. Yet in many instances today, seats are manufactured to the original design specification under which the aircraft was certificated. There are two issues profoundly affected. The first is technological stagnation of seat design improvement because the aircraft requires a Supplement to its original type certificate (STC). Unfortunately, manufacturers are reluctant to make costly fiscal investments where the return on their non-recurring engineering costs (to older aircraft) are in doubt. Secondly, materials used in seat design and construction have progressed significantly in the previous six decades making seat improvements a reality given the correct environment of inducement and incentive.

Historical mishap experience indicates that for every fatal accident there are 3 non-fatal spinal injuries as a result of unwarranted compression that could have been prevented had better seat design been incorporated that was contemporary to the technology available.

The FAA should establish three studies:

1. STC Study. The first study would study the Supplemental Type Certificate (STC) Process with emphasis on rotorcraft seat construction. This study would evaluate methods on how to fast-track approval processes, reduce unwarranted administrative costs, and evaluate methods that can reduce the time required to obtain an STC.
2. Incentive Programs. The second study would evaluate how costs borne by the STC developer for seats can be ameliorated through incentive programs or grants.
3. Seat Construction. The third study would evaluate actual construction of seats available today that provide attenuation of vertical forces and at the more economical level, evaluate cost effective energy absorbing materials (e.g. materials used in cushions) that can be leveraged from other industries and easily adapted to aviation.

IS 49: Ballistic Parachutes

Objective: Improve rotorcraft crash survivability by developing a ballistic parachute system capable of decelerating the aircraft to survivable levels before ground impact while controlling aircraft orientation. The system could be manually deployed or require a means of detecting an imminent crash impact and firing with sufficient time to be effective. This system would have to act for all potential orientations of the aircraft.

Discussion: Ballistic parachutes have been developed and employed as a means of avoiding catastrophic crashes in fixed-wing aircraft. When deployed, the parachute orients the aircraft right side up and reduces the vertical velocity to a survivable level for ground impact. These devices are effective in cases of pilot disorientation, loss of control and catastrophic structural failure.

There is a combination of minimum altitude/airspeed at which the parachute would be completely effective; however, in an uncontrolled impact even a partially deployed parachute will reduce the energy of the impact, thus improving chances of survival. The installation would need to allow for the motion of the rotor blades, a hazard which in not a concern in a fixed-wing scenario.

The ballistic recovery parachute was developed in the 1980's but was not generally used until 1998 when Cirrus Design introduced it in their line of single engine airplanes. The technology is still confined primarily to single engine fixed-wing airplanes. BRS Aerospace, the primary supplier of ballistic parachutes, claims their systems have saved over 350 lives in the past 20 years.

In theory, these systems could be retrofitted to virtually any aircraft. At present, the technology is more applicable to smaller rotorcraft. Because this intervention is proposed as a market driven initiative, private industry would develop these systems based on the market demand.

IS 28 and 28A: Evaluate Inertia Reel Usage; Add Where Needed and Remove Where Not Needed

Objective: Reduce occupant motion by choosing the optimal application of inertial reel installation.

Discussion: A proper fitting fixed restraint system that is adequately tightened can outperform a restraint system with an inertia reel (retractor) since fixed restraints will not pay out as much as systems with inertia reels. However, passengers and pilots tend to want some freedom of movement and will loosen up straps if they are fixed, and in these situations, the restraint with the inertial reel will outperform the fixed restraint by not allowing initial excessive slack in the belt.

Inertia reels have been shown to be effective at minimizing belt slack yet still allowing occupants freedom of motion. All modern automobiles and many DOD systems contain inertia reels and these can be easily incorporated into shoulder restraints if needed.

Some data indicates inertia reels actually increase relative motion during an impact. There is general consensus that improvements are needed in restraint systems and that all aircraft should include an upper torso restraint. The restraint system should be properly designed and integrated into the aircraft and have sufficient strength that meets existing standards. Where practical, considering aircraft installation limitations, the webbing portion should be of a low elongation type, which can then be integrated with an inertia reel. Additionally, a minimum 4-point is preferred, but going beyond that could yield additional benefits. The low stretch webbing with the inertia reel will then limit compression induced payout and limit motion after activation. Inertia reels should only be used in those situations where a clear benefit can be documented and proper usage ensured. These restraint technologies are in existence, and in some instances STC kits already exist, and can be easily incorporated providing there are attachments in the aircraft of sufficient strength.

FAA: Provide guidance on the conversion from fixed-attachment harnesses to inertia reel harnesses for passenger stations and make recommendations for which operations could benefit from either a fixed restraint or an inertia reel restraint system. Evaluate operational requirements to determine those seat places or operations where an inertial reel is not needed, for all others install an inertia reel.

Restraint System Manufacturers: Develop replacement kits and installation instructions.

Operators: Evaluate their operations and determine for which operations a fixed restraint would be superior. Change the harnesses as required.

IS 27A and 27B: Deployable barrier, restraint or occupant mounted

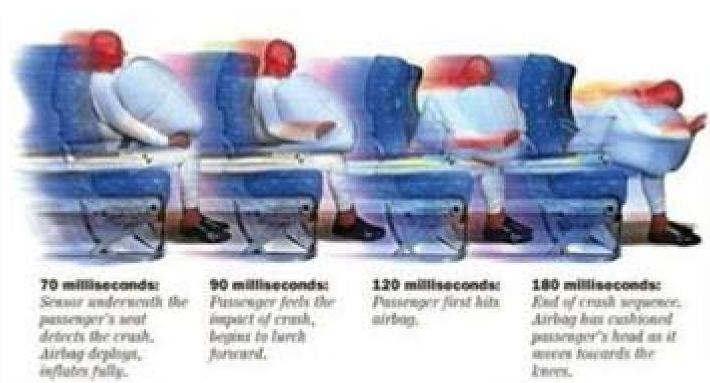
Objective: Provide energy absorbing barriers between occupants and potentially hazardous objects within the occupant strike zones. This is helpful in situations where hazardous objects such as controls cannot be removed from the occupant strike zone or otherwise delethalized.

Discussion: Inflatable systems have been successfully developed for the cockpits of military rotorcraft and for usage in other civil aviation environments. The military developed the Joint Cockpit Air Bag System (JCABS).



https://commons.wikimedia.org/wiki/File:OH-58D_Cockpit_Air_Bag_System_(CABS).jpg
https://www.bydanjohnson.com/now-you-dont-see-it-now-you-do/
http://aviationweek.com/awin/us-army-probing-problems-cockpit-airbags-helicopters
https://www.youtube.com/watch?v=lZfPJG3LXxk

In civil aviation, AmSafe, among others, have developed both wedge bag and barrier bag systems.

http://www.technokontrol.com/en/products/airbags-aircraft.php
https://www.amsafe.com/seatbelt-airbag-system/

https://patents.google.com/patent/US9428132

AmSafe recently received approval for a generic airbag that is not just for a particular model but can be used in all general aviation aircraft. With some modifications this could possibly be adapted to rotorcraft with the certification path already established.

Numerous inflatable systems have been approved for installation in civilian aircraft with the goal of reducing head injuries. SAE is currently working on two industry standards AS 5785 "Component Standard for Airbag Systems Installed in Civil Rotorcraft, Transport Aircraft, and General Aviation Aircraft" and AS 6466 "Installation Performance Standard for Airbag Systems Installed in Civil Rotorcraft, Transport Aircraft, and General Aviation Aircraft."

Suppliers, OEMs and restraint system manufacturers should develop a lightweight, reliable, deployable barrier that does not obstruct the view of the pilot for continued flight operations and that can accommodate a range of passengers. Mounting on the restraint system will reduce integration difficulty and such a system could be used on multiple platforms. Developers should be cognizant of the safety implications of varying occupant sizes including children and out-of-position scenarios. The system would require that the belt be positioned properly. It would be activated with a crash sensor (accelerometer).

Work on integrating these systems should begin immediately. The total time for development is expected to exceed four years. At least two years will be needed for the development work of the airbag systems and integration with the crash sensor for rotorcraft scenarios. This would then be followed by two years of integration work into each airframe and approval by the FAA.

An inflatable system can be incorporated into the rotorcraft to delethalize the cockpit and cabin environment. There are several systems already approved for aviation use that can be adapted. These systems can be developed and certified for use in rotorcraft operations.

Inflatable systems have been shown to be effective in other aviation environments; however, additional development work would be needed here to develop the crash sensor and incorporate the sensor into specific platforms. Care would also be needed to ensure the full expected population is accommodated without creating any additional injury modes.

IS 32A: Alternate Geometry Restraint Systems (Crisscross Belts, Integrated Vest, etc.)

Objective: Improve upper torso restraint in crashes through the introduction of new, innovative restraint designs including crossed belts and integrated vests.

Discussion: Some standard restraint systems can allow excessive motion of the occupant, whether it is because the occupant rolls out of the upper torso restraint, submarines under the pelvic restraint, improperly dons the restraint due to sub-optimal restraint geometry or just due to inadequacy of design. FAA AC 21-34 and SAE AS 8043b describe some restraints that are not as commonly used. The military uses integrated vests for many restraint applications.

Some novel restraint systems have been developed and tested for other vehicle applications, but they produced high Neck injury (Nij) readings since they limit upper torso motion while the head is not restrained resulting in high neck tensions. Current FAA injury criteria do not address neck injury criteria.

It is probable that neck injury criteria could be met during the combined vertical dynamic test pulse specified in FAA 27/29.562, which is representative of a common crash, but Nij may be an issue with the longitudinal dynamic test pulse.

Adding additional restraint attachment points to accommodate novel belt restraints may be difficult and/or will require redesign and recertification of some aircraft. It may also be difficult to get support for out-of-production aircraft.

FAA: Mandate, or at least promote, installation of alternate geometry restraints, and provide guidance for their installation and approval.

Restraint System Manufacturers: Develop alternate geometry restraint systems and the requirements for their installation (attachment locations, loads, etc.)

Restraint System Manufacturers, Airframe OEMs and Industry Groups: Develop installation kits and instructions.

Operators: Install these restraints in their aircraft.

Airframe OEMs and operators to evaluate their upper torso restraints and replace with alternative designs if they are shown to be an improvement.

IS 21A and 21B: Incorporate Methods to Reduce Occupant Relative Motion Through Lower Elongation Webbing

Objective: Reduce relative motion of the occupant within the cockpit/cabin by utilizing restraint systems that reduce the amount of restraint system elongation caused by crash loading by using design features such as material changes, dimensional changes, or geometric changes.

Discussion: If a restraint system is designed to SAE AS 8043B specifications, it could still allow up to 20% elongation at 3000 lb static loading. If the restraint system webbing does not meet this specification, then it is unknown how much elongation will result with the above loading. The amount of elongation of the restraint system is directly proportional to the motion that the occupant experiences during a dynamic event. Reducing the amount of elongation should reduce the flail envelope and lower the likelihood of the occupant striking interior items, which could cause an injury. However, it must also be noted that some elongation in webbing material is beneficial to reduce pelvic and upper torso loads, i.e. a rigid strap is not optimal.

.

The FAA in developing its front row policy (PS ANM-115-05-14) for transport aircraft suggested that head path reducing features may be used to meet compliance with HIC requirements. FAA AC 25.462-1b paragraph 5(d) also describes the use of head path reducing features as a way of reducing HIC. Some head path reducing features include the use of low elongation webbing, y-belts, and possibly even wider straps. Restraint designs with low elongation webbing could significantly reduce occupant movement within the cockpit/cabin. A restraint used should meet the applicable standards of SAE AS 8043b.

Restraint System Manufacturers: Research and identify low elongation materials that are available and suitable for restraint systems and incorporate those into their product lines. Provide information on material elongation in their product specifications.

FAA: Provide guidance on the use of low elongation restraint systems (e.g. recommend its use in retrofit situations, provide areas to be evaluated before it is incorporated, such as possible increase in structural attachment loads, etc.) Provide guidance on the use of "wide-strap" restraint systems (e.g. note their availability and write policy requiring their use when replacing restraints, etc.)

Airframe OEMs and Industry Groups: Determine which types/models of aircraft (including STC installations) would benefit from low elongation restraint systems. There is little benefit to low elongation webbing if the installation has adequate clearance for occupant motion with "normal" restraints.

Operators: Incorporate low elongation restraints into their fleets as appropriate. Wide-strap restraints can also be used to reduce webbing elongation.

Restraint System Manufacturers: Manufacture restraint systems with wider straps and incorporate them into their product lines.

There is general consensus that improvements are needed in restraint systems and all aircraft should include an upper torso restraint. The restraint system should be properly designed and integrated into the aircraft and have sufficient strength to meet existing standards. Where practical considering aircraft installation limitations, the webbing should be of a low elongation type, which can then be integrated with an inertia reel. Additionally, a minimum 4-point restraint is preferred but going beyond that could yield additional benefits. The low stretch webbing with an inertia reel would limit compression-induced payout and limit motion after activation. Inertia reels should only be used in those situations where a clear benefit can be documented and proper usage ensured. These restraint technologies are in existence, and in some instances STC kits already exist, and can be easily incorporated providing there are attachments in the aircraft of sufficient strength.

IS 19: Study Incorporation of External Belly-Mounted Airbags

Objective: Reduce peak vertical acceleration seen by occupants by "gradually" decelerating entire aircraft with external belly-mounted airbags.

Discussion: External airbags have been demonstrated to provide significant energy absorption during a crash with complete system weight (sensor, computer, inflators, airbags, housing) ranging from 1-2% of maximum gross weight. Floor decelerations on the order of 8g have been demonstrated for 36 ft/s impacts. With floor decelerations this low, the energy attenuating stroking seats did not stroke since they typically initiate stroking when loads exceed 12g for civil rotorcraft.


Bell OH-58 Boeing OH-6 Sikorsky UH-60

Lockheed F-111 NASA Orion

2004 Mars Rover

Current airworthiness standards embodied in the emergency landing dynamic condition regulation allows for a performance-based means of attenuating vertical impacts. 14 CFR § 27/29.562(d) states: “An alternate approach that achieves an equivalent or greater level of occupant protection, as required by this section, must be substantiated on a rational basis.”

FAA, industry, academia: Provide funding and support for external airbag research and development. This includes studying the complete system from impending crash sensors, lightweight “cool” inflators, and tough lightweight airbag material.

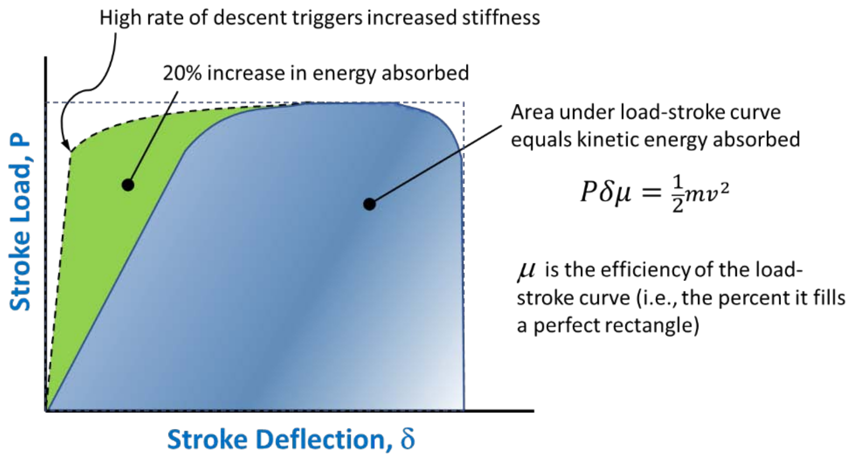
IS 20 and 48: Research Improved Energy Absorbing Landing Gear

Objective: Research opportunities to provide an adaptable stiffness landing gear that stiffens when subjected to high rates of loading yet stays as “soft” as traditional landing gear during normal landing rates.

Discussion: Landing gear, generally the rotorcraft’s first energy-absorbing subsystem to contact the ground, can contribute significantly to the avoidance of damage to the fuselage and equipment in hard landings and to the survival of the occupants in severe survivable crashes. Statistics indicate that the overwhelming majority of rotorcraft crashes occur within ±10° roll and +10°/-5° pitch attitudes. Of course, traditional landing gear can only absorb energy from contact with hard or reasonably hard surfaces, not on water.

Landing gear provide the interface structure that absorbs the kinetic energy of an aircraft during landing operations up to hard landings. The FAA defines *reserve energy* as the energy level a landing gear can absorb without collapsing. The current FAA airworthiness standards for reserve energy in 14 CFR §§ 27.727(c)Amdt. 27-26 and 29.727(c) Amdt 29-30 provides protection for 10.2 ft/s (unless the “*probable sinking speed likely to occur at ground contact in normal power-off landings*” is less but still greater than 8 ft/s). Landing gear with reserve energy velocity of 10.2 ft/s statistically protects 64% of all survivable and potentially survivable crashes according to DOT/FAA/CT-85/11 (Figure 7, page 25).

For high rate of descent events, reduce velocity, ***v***, of whole rotorcraft by increasing the landing gear stiffness without increasing the maximum stroke load, **P**, which would increase loads into the rotorcraft structure beyond what it is designed to handle.



As shown above, this research has the potential for enhancing landing gear energy absorption by approximately 20%. This would increase the reserve energy to 11.2 ft/s with a statistical protection up 3% to 67%.

One research option for improved landing gear is the introduction of external airbags as noted in the following links, which work equally as well on water, soft soil and hard prepared surfaces.

https://vtol.org/store/product/rotorcraft-external-airbag-protection-system-3642.cfm
https://www.researchgate.net/figure/Pre-test-photograph-of-the-F-111-crew-escape-module-with-airbag-attenuation-system_fig15_237133544
http://what-when-how.com/experimental-and-applied-mechanics/a-comparative-analysis-of-two-full-scale-md-500-helicopter-crash-tests-experimental-and-applied-mechanics-part-1/

This is an area for research and not ready for implementation. Hence this activity should be undertaken by the DOT and the FAA to establish research grants to CAMI, universities, OEM's, and Product Manufacturing Authorities (PMA's). All existing and future rotorcraft with reserve energy less than 11.2 ft/s (120% of current reserve energy Minimum Operational Performance Standards (MOPS)) could potentially be affected by favorable results from this research.

IS 74: Proper Restraint System Geometry

Objective: Evaluate all rotorcraft to ensure that their restraint systems meet existing guidelines, both for geometry and strength. During this evaluation, the restraint systems should be inspected for wear and replaced as needed. For those systems that do not meet guidelines, a replacement program should be instituted.

Discussion: It has been noted that in some rotorcraft installations including retrofit installations, the restraint geometry may not be optimal for the range of occupants expected to occupy those seats. The pelvic restraint angles may be too shallow or too steep, allowing excessive loading of the buckle or motion of the pelvis (submarining). If an upper torso harness is also included, its geometry should also allow proper routing across the body so as not to allow upper body flail before the inertia reel locks.

The FAA released AC 21-34 “Shoulder Harness - Safety belt installations in 1993. SAE AS 8043B “Restraint systems for Civil Aircraft” was revised in 2008 and SAE ARP 5526D “Aircraft Seat Design Guidance and Clarifications” was revised in 2015. These documents collectively describe how occupant restraint systems should be integrated with the seats and aircraft and describe the test methodologies for their certification.

Prevent localized/asymmetric loading of webbing in the adjuster that can initiate webbing failure/slippage.

Existing aircraft restraint geometries should be inspected to ensure that they meet the guidelines in guidance and standards documents. If they do not, the repair and or redesign of those restraints should be accomplished in accordance with published information. OEMs and seating system suppliers should ensure the webbing is properly aligned with the adjustor and with the body so as to apply loads to the areas of the body most tolerant to impact loading such as the pelvis and shoulder girdle.

IS 63: Reorient Aft-Facing Seats to Forward-Facing, If Feasible, or Increase Fitting Retention Strength for Aft-Facing Seats

Objective: Help ensure seats are able to withstand survivable crash loads without failure regardless of orientation of the seat.

Discussion: Seat retention is a critical link in the chain of safety necessary for survivability in a crash. Seat retention loads are measured during emergency landing tests in accordance with 14 CFR § 27/29.562. These loads are greater when the seat is oriented aft-facing, since the occupant’s body parts (mass items) are decelerated more rapidly than when oriented forward-facing which allows head, upper torso, and upper arms to extend forward decelerating them over longer time as they load through the restraint system. Decelerating over longer time results in lower peak loads.

Comparison of measured fitting loads during § 27/29.562(b) emergency landing dynamic conditions indicates that the 1.33 factor prescribed in § 27/29.785(f)(2)(i) if applied to the inertial loads of § 27/29.561(b) in general sufficiently accounts for the “dynamic overshoot” loads experienced by forward-facing seats. Unfortunately, this 1.33 factor is approximately 15% lower than the loads required to provide adequate retention strength for aft facing seats.

14 CFR § 27.785 Amdt 27-25 introduced on 12/13/1965 a 1.33 fitting factor for seat fittings consistent with § 29.785(f)(2) Amdt 29-0 (2/1/1965). FAA Advisory Circular 14 CFR § 27/29.785 states, “The inertia forces of § 27/29.561 are ultimate loads and must be multiplied by a factor of 1.33 in determining the ‘strength of attachment’ of each seat to structure and each belt or harness to structure.” This factor of 1.33 is prescribed in 14 CFR § 27/29.785(f)(2)(i). As stated in CFR Notice of Proposed Rulemaking (NPRM), Federal Register: June 9, 1997 (Volume 62, Number 110) [Page 31476], “The 1.33 fitting factor is necessary to ensure that fittings subject to wear and tear under normal use and subject to frequent removal and replacement in the aircraft will retain adequate strength to perform their intended function under crash landing conditions.”

Retain seated occupants in a crash by either re-orienting seats to be forward-facing thus reducing loads from aft-facing seating systems to the airframe structure. Alternatively, increase floor retention strength by using a factor of 1.5 on fittings (in lieu of 1.33) for aft-facing seats.

Forward-facing seats produce lower over-turning moments due, in part, to a lower center of gravity but primarily due to decoupling the occupant from the seat mass, that is, the restraints allow slower deceleration of the occupant's body parts (mass) over a longer time enabling lower peak impulse loads (integral of force time history). Aft-facing seats introduce higher floor loading during forward crash impacts than do forward-facing seats. If the OEM has not accommodated for this increased load with stronger floor or mounting structure under the presumption that the loading is identical for aft-facing and forward-facing arrangements, then the seat should be re-oriented to be forward-facing if possible. Alternatively, the OEM should increase the fitting factor prescribed in § 27/29.785(f)(2)(i) from 1.33 to 1.50 for aft-facing seats.

This should be applied to all Part 27 rotorcraft type certified to an airworthiness standard less than § 27.785, Amdt. 27-25. It also applies to all Parts 27 and 29 rotorcraft with aft-facing seats that employed a 1.33 fitting factor IAW 14 CFR § 27/29.785(f)(2)(i).

The objective is to increase seat retention strength for aft-facing seats using a 14 CFR § 27/29.785(f)(2)(i) fitting factor of 1.5 in lieu of the previously recommended factor of 1.33. Alternatively, re-orient aft-facing seats to be forward-facing.

IS 21C and 21e: Replace All 3 and 4-Point Restraints With 5-Point or greater Restraints

Objective: Reduce occupant upper body motion by better restraining the upper body and providing better pelvic retention, which will also prevent the occupant from "rolling out" of the upper restraint and prevent submarining.

Discussion: Three-point restraint systems can allow the occupant to submarine as well as roll out of the restraint when the initial impact vector is not optimal or when there are multiple impacts. Current 4-point restraints can pull upward on the lap belt as the occupant flails forward, causing the lap belt to ride up over the pelvis, resulting in submarining injuries to the occupant. Industries such as the military and motorsports commonly use 5+Point restraint systems to prevent this risk. 5+point restraints provide a negative g strap, which prevents the lap belt from moving upward, thus preventing submarining and pelvic restraint slippage. The additional belts in a greater than 5-point restraint system provide better restraint of the pelvis and reduce its motion which leads to greater stability and retention of the occupant.

FAA AC 21-34 describes shoulder harness with the addition of the negative g-strap to create a 5-point harness. The military uses these types of multipoint restraints primarily in ejection seats, where there is a need to limit body motion and flail. The motorsports industry has also adopted multi-point, 5 or greater, restraints to better protect drivers in the event of a crash.

<u>FAA</u>: Provide guidance on the use of 5-6-7-point restraint systems (e.g. guidance on design and certification requirements for adding the additional restraint attachment point(s).

<u>Airframe OEMs</u>: Determine which types/models of aircraft can accommodate the additional restraint attachment points and publish acceptable installation data.

Operators: Incorporate 5-6-7-point restraints into their aircraft as appropriate.

Although this modification will reduce/eliminate occupant submarining, adding the additional restraint attachment points may be difficult and/or will require design and certification for some aircraft. It may be difficult to get this support for out-of-production aircraft. 5-6-7-point restraints may be inconvenient or impractical for some types of clothing such as tight skirts or dresses.

There is general consensus that improvements are needed in restraint systems and all aircraft should include an upper torso restraint. The restraint system should be properly designed and integrated into the aircraft and have sufficient strength that meets existing standards. Where practical considering aircraft installation limitations, the webbing portion should be of a low elongation type, which can then be integrated with an inertia reel. Additionally, a minimum 4-point is preferred, but going beyond that could yield additional benefits. The low stretch webbing with the inertia reel will then limit compression induced payout and limit motion after activation. Inertia reels should only be used in those situations where a clear benefit can be documented and proper usage ensured. These restraint technologies are in existence, and in some instances STC kits already exist, and can be easily incorporated providing there are attachments in the aircraft of sufficient strength.

IS 18: Require Crash Predictor System for Occupant Restraint Haul-Back

Objective: Reduce spinal injuries during vertical impacts caused by non-optimal body position at the time of impact through the activation of a haul-back system that will draw the body into a more optimal position in the seat.

Discussion: The FAA should perform research to evaluate the potential benefits of installing haul-back devices in some seats in different helicopters.

IS 55: Reduce the Weight of Seats by Removing Auxiliary Equipment

Note: The narrative description of this intervention strategy is not available.

7. Recommendations for Public Rotorcraft

IS-92A: Through Education, Promote Voluntary Use of Personal Protective Equipment (PPE) for Public Helicopter Operations.

Objective: To increase the use of PPE in Public helicopter operations.

Discussion: By public law (Title 49 of the United Sates Code, 40102(a) (41) and 40125; AC00-1.1A) the FAA has no regulatory authority over Public Aircraft and has not shown a willingness to assume any authority through a change in the law. Therefore, any intervention strategy (IS) pertaining to helicopters operated as Public Aircraft are not feasible from a regulatory standpoint and, therefore, would need to be voluntary in nature.

As the use of PPE for Public Helicopter operations is a public safety industry best practice and is a required standard for accreditation by the Airborne Public Safety Accreditation Commission (APSAC) across all sets of public safety aviation standards (law enforcement, firefighting and SAR), compliance with this intervention strategy (IS) would be easy for the vast majority of public safety helicopters operators.

The use of PPE in helicopter operations has been shown to reduce head and thermal injuries in crashes. The objective of this intervention strategy is to encourage the use of proper personal protective equipment (PPE) during Public Helicopter operations to provide additional protection to Public Rotorcraft crewmembers from head (blunt force trauma) and thermal injuries.

In conjunction with the FAA, Associations and other industry groups, whose members operate helicopters to perform Public Aircraft missions should coordinate with the FAA to develop educational materials and programs supporting the use of personal protection equipment (PPE) to include military certified helmets, flame resistant flight suits and gloves, and leather (or other flame resistant material) boots by all crewmembers involved in Public Rotorcraft operations. They should then distribute these materials via all media (publications, websites, social media, etc.) available to them and conduct these educational programs at industry conferences and trade shows.

This intervention strategy would affect the entire Public Helicopter operator population, estimated to be approximately 10% of helicopter operations in the U.S.

These associations and other industry groups can immediately begin development of these educational materials and programs with information supplied by the FAA and other industry sources. The dissemination of these materials and conduct of these courses could begin immediately following the development of these materials and courses, but in no instance should it take more than one year to implement.

IS-92B & C: Promote Voluntary Retrofit of Crash Resistant Fuel Systems and Crash Resistant Seat and Structure in Helicopters Performing Public Missions Through Education.

Objective: To increase the number of helicopters used in Public Rotorcraft operations that are equipped with CRFS and energy attenuating seats, and thereby reduce the number of injuries and deaths sustained in Public helicopter crashes.

Discussion: By public law (Title 49 of the United Sates Code, 40102(a)(41) and 40125; AC00-1.1A) the FAA has no regulatory authority over Public Aircraft and has not shown a willingness to assume any through a change in the law. Therefore, any intervention strategy (IS) pertaining to helicopters operated as Public Aircraft are not feasible from a regulatory standpoint and, therefore, would need to be voluntary in nature.

The incorporation of crash resistant fuel systems and crash resistant seat and structure in helicopter operations has shown to reduce thermal and blunt force trauma injuries, respectively. Previous ROPWG studies have shown that an appropriate CRFS will eliminate all thermal injuries in survivable crashes and reduce the quantity of thermal injuries in non-survivable crashes. Properly designed energy attenuating seats have been shown in military studies to prevent most serious spinal injuries in survivable crashes.

The objective of this intervention strategy is to encourage and promote voluntary incorporation of crash resistant fuel systems and crash resistant seat and structure as they become available into the current fleet of helicopters performing Public Aircraft missions through education. Both of these crashworthiness features have been shown to be extremely effective and incorporation of them into Public Rotorcraft will provide significant additional protection to rotorcraft crewmembers. Since many Public Rotorcraft are involved in relatively high-risk operations, retrofit of helicopters with these occupant protection features should be a high priority for Public Rotorcraft operators.

Associations and other industry groups whose members operate helicopters that perform Public Aircraft missions in conjunction with the FAA should develop educational materials and programs showing the benefits of and supporting the incorporation of crash resistant fuel systems and crash resistant seat and structure as they become available into the current fleet of helicopters performing public safety missions. These materials should be distributed via all media (publications, websites, social media, etc.) available to them and conduct these educational programs at industry conferences and trade shows.

This intervention strategy would affect the entire Public Aircraft operator population operating helicopters with non-crash resistant fuel and seat systems, estimated to be approximately 10% of U.S. helicopter fleet. Helicopter models that already have CRFS retrofit kits and/or retrofit crash resistant seats available should receive the highest priority for modification since the kits and seats have already been developed.

The targeted associations and other industry groups can immediately begin development of these educational materials and programs with information supplied by the FAA and other industry sources. The dissemination of these materials and conduct of these courses could begin immediately following development, but in no instance should it take more than one year to implement.

IS-92D: Promote Voluntary Retrofit of Crash Resistant Fuel Systems and Crash Resistant Seat and Structure in Helicopters Performing Public Missions Through Incorporation of the Use of These Systems in Industry Standards.

Objective: To increase the number of helicopters involved in Public Rotorcraft operations that are equipped with CRFS and energy attenuating seats, and thereby reduce the number of injuries and deaths sustained in crashes of these helicopters, by incorporation of a requirement for these safety critical systems into industry accreditation and best practice standards.

Discussion: By public law (Title 49 of the United Sates Code, 40102(a) (41) and 40125; AC00-1.1A) the FAA has no regulatory authority over Public Aircraft and has not shown a willingness to assume any through a change in the law. Therefore, any intervention strategy (IS) pertaining to helicopters operated as Public Aircraft are not feasible from a regulatory standpoint and, therefore, would need to be voluntary in nature. Industry standards, especially when used for accreditation, provide a strong impetus for compliance.

The incorporation of crash resistant fuel systems and crash resistant seat and structure into helicopters has been shown to markedly reduce thermal and blunt force trauma injuries in survivable crashes of compliant helicopters. Industry standards, especially when used for accreditation, provide a strong impetus to operators to comply with occupant protection standards.

The objective of this intervention strategy is to encourage and promote voluntary incorporation of crash resistant fuel systems and crash resistant seat and structure as they become available into the current fleet of helicopters performing Public Aircraft missions by recognizing the use of these systems as a Public Aircraft industry best practice.

Public Rotorcraft standard setting organizations should develop standards for the incorporation of crash resistant fuel systems and crash resistant seat and structure into the current fleet of helicopters performing Public Rotorcraft missions as these systems become available. These industry standards should be promoted as Public Helicopter operations best practices and compliance be mandatory for accreditation of the operator. These standards should be made readily available to operators of Public Helicopters. The standard setting entities should promote the use of best practices and the benefits of accreditation via all media available to them (publications, websites, social media, industry conference and trade shows, etc.).

This intervention strategy would affect the entire Public Aircraft operator population operating helicopters with non-crash resistant fuel and seat systems, estimated to be approximately 10% of helicopter in the U.S.

The incorporation of these systems would be mandatory for newly manufactured rotorcraft while this intervention strategy would encourage and promote voluntary incorporation of crash resistant fuel systems and crash resistant seat and structure as they become available into the current fleet of helicopters performing Public Aircraft missions. The requirement to install these systems should be incorporated into industry accreditation standards making them industry best practices.

Entities that develop and promote accreditation standards can immediately begin development of these specific standards and incorporate them into existing standards either as soon as they are developed or at the next scheduled periodic review of the existing standards, but in no instance more than 12 months from development.

APPENDIX E: CRSS RETROFIT BENEFIT CALCULATION

Note: As explained below, the ROPWG feels that this benefit estimate has a great deal of uncertainty due to the lack of available data required for a more precise estimate. Because of this uncertainty, the analysis is presented in this appendix, and the results are not referenced in the main body of this report. However, because the benefit estimation method used here is based on the same method used in previous ROPWG reports, the ROPWG decided to include the analysis in this appendix in case the analysis might prove useful to some readers.

The monetary benefit of incorporating the following CRSS features into the entire U.S. helicopter fleet via retrofit is estimated in this appendix:

- Incorporation of dynamic seats that meet the following criteria:
  - 27/29.562(b)(1): Vertical dynamic seat tests
    - Part 27: Required at 100% of current velocity requirement (26 ft/s) “where practicable”, or 21.7 ft/s otherwise
    - Part 29: Required at 100% of current velocity requirement
  - 27/29.562(b)(2): Horizontal dynamic seat tests required at 100% of current velocity requirement for both Part 27 and 29
  - Note that these criteria are identical to the ROPWG Task 5 recommendations for newly manufactured helicopters, and are identical to the “potential retrofit requirements” discussed in the main body of this report
- Incorporation of improved retention of occupants and items of mass in the cabin that meets the following criteria:
  - 27/29.561(b)(3): Restraint of occupants and items of mass in cabin required at 100% of current g-levels
  - Note that these criteria are identical to the ROPWG Task 5 recommendations for newly manufactured helicopters, and are identical to the “potential retrofit requirements” discussed in the main body of this report

The retrofit benefit calculation is based on data from the ROPWG Task 2 Report, in which the FAA Accident inVestigation and Prevention (AVP) office provided an estimate of the benefit of requiring newly manufactured helicopters to be fully compliant to the subject CRFS and CRSS regulations. In the present analysis, the Task 2 benefit is scaled to account for partial versus full-compliance, and for the number of affected helicopters. Additionally, an estimate is made for the percentage of the benefit due to dynamic seats versus improved retention. Specifically, the benefit is estimated as follows:

1. Reference calculated benefit of full compliance for newly manufactured legacy helicopters (ROPWG Task 2 Report)
2. Scale benefit from #1 to account for “partial compliance” regulations of interest (ROPWG Task 5 CRSS Report)
3. Scale benefit from #2 to account for larger number of helicopters affected by retrofit versus newly manufactured legacy helicopters
4. Estimate percentage of benefit from #3 that is due to dynamic seats versus improved retention

1. Benefit of Full Compliance

The ROPWG Task 2 Report calculated the expected benefit of requiring all newly manufactured, legacy helicopters to fully comply with 27/29.561, 27/29.562, and 27/29.785. This benefit was provided (for all regulations combined) by the FAA AVP, and was determined by estimating the number of injuries and fatalities that would be avoided if all newly-manufactured, legacy Part 27 helicopters were fully compliant with the applicable CRSS regulations, and applying the standard FAA/DOT monetary benefit to each of the injuries and fatalities that would be avoided. The monetary benefit of full compliance from the ROPWG Task 2 Report over a 10-year period was estimated as follows:

Part 27: $113,217,324
Part 29: Benefit estimate not available due to lack of sufficient crash data for Part 29 helicopters

Note that as stated in the ROPWG Task 5 CRSS report, the ROPWG feels that this estimate has a great deal of uncertainty, as it is extremely difficult to evaluate the effectiveness of CRSS features in preventing injury in survivable crashes due to the lack of impact and injury data in NTSB accident dockets, and due to the lack of test data on the effectiveness of the CRSS features in the existing fleet.

2. Scale Benefit From #1 to Account for "Partial Compliance"

In the ROPWG Task 5 CRSS Report, the ROPWG estimated that the "partial compliance" ROPWG CRSS recommendations for newly manufactured, legacy helicopters would be 81% as effective as full compliance for Part 27 helicopters, and 90% as effective for Part 29 helicopters. Therefore, the 10-year monetary benefit expected if all newly manufactured, legacy helicopters met the "partial compliance" requirements is:

Part 27: $113,217,324 * 81% = $91,706,032
Part 29: Benefit estimate is not available due to lack of crash data for Part 29 helicopters

Note that the "partial compliance" ROPWG Task 5 CRSS recommendations are identical to the potential CRSS retrofit requirements analyzed in this report.

3. Scale Benefit From #2 to Account for Larger Number of Affected Helicopters When Performing Retrofit

The benefit calculated in #1 and #2 was limited to injuries and fatalities that would have been prevented over a 10-year period if newly manufactured, legacy helicopters were required to comply with the ROPWG Task 5 CRFS recommendations. The underlying data was formed in the ROPWG Task 2 Report by looking at injuries and fatalities that occurred in the U.S. from 2006 through 2015 and was further limited to helicopters manufactured from 2006 through 2015. Since the present retrofit discussion encompasses the entire U.S. helicopter fleet, the benefit estimate from #2 needs to be scaled to account for the larger number of helicopters affected in a retrofit program versus newly manufactured helicopters only.

The Rotor Roster data from 2015 lists 17,132 total U.S. registered helicopters in the database, 4,204 of which were manufactured between 2006 and 2015 inclusive. Therefore, one can conclude that retrofitting all U.S. registered helicopters versus solely those that are newly manufactured would increase the calculated benefit by a factor of 17,132/4,204 = 4.08.

Therefore, the expected 10-year benefit of mandating the potential CRSS retrofit requirements is:

Part 27: $91,706,032 * 4.08 = $374,160,611
Part 29: Benefit estimate is not available due to a lack of crash data for Part 29 helicopters

As discussed in the main body of this report, the ROPWG feels that a "lifetime" cost and benefit analysis may be more appropriate for the retrofit analysis. Per the analysis in the main body of this report, the corresponding lifetime benefit is calculated as follows:

Part 27 Lifetime Benefit = (25/10) * 10 Year Benefit = $935,401,528
Part 29 Lifetime Benefit not available due to lack of crash data for Part 29 helicopters

Note that the Rotor Roster data from 2015 listed 17,132 total U.S. registered helicopters in the database, versus 11,282 in the database used in the present report (reference Appendix B). The ROPWG does not know the cause of this discrepancy, but since the Rotor Roster data was the only data available that allowed an analysis by year of manufacture, the ROPWG had to assume that the discrepancy was such that the ratio of newer (less than 10 years old) to older helicopters (more than 10 years old) in the Rotor Roster was the same as that for the U.S. fleet.

4. Relative Benefit of Dynamic Seats versus Improved Retention

The benefit calculated above is the total benefit for compliance with both the potential dynamic seat retrofit requirements and the potential improved retention retrofit requirements. Based on anecdotal accident data, the ROPWG estimates that 75% of this benefit would be due to the introduction of dynamic seats, and 25% would be due to improved retention of occupants and items of mass in the cabin:

Part 27, 10-Year Benefit, Dynamic Seats: $374,160,611 * 75% = $280,620,458
Part 27, 10-Year Benefit, Improved Retention: $374,160,611 * 25% = $93,540,153

Part 27, Lifetime Benefit, Dynamic Seats: $280,620,458 * (25/10) = $701,551,145
Part 27, Lifetime Benefit, Improved Retention: $93,540,153 * (25/10) = $233,850,383

Part 29 Benefits not available due to lack of crash data for Part 29 helicopters

APPENDIX F: CAMI MEMORANDUM ON THERMAL INJURIES AND FATALITIES

Federal Aviation Administration

CONCURRENCES
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Memorandum

Date: May 18, 2018

To: Lee Roskop, Safety Management Section, AIR-682

From: Christy Hileman, Autopsy Program Team, AAM-612

Prepared by: Christy Hileman, 405.954.2824

Subject: Post-Crash Fire Rotorcraft Accidents with Thermal Injury Fatalities 01/01/2009 through 12/31/2017

Dear Mr. Roskop,

As per your request, we have looked at the Medical Analysis Tracking Registry (MANTRA) for fatal rotorcraft accidents from 01/01/2009-12/31/2017. A SQL query was prepared and there were 206 accidents that met your initial criteria. After further discussion with you to remove experimental and amateur built rotorcraft, we have removed 29 accidents with a new value of 177 fatal rotorcraft accidents. The following tables explain the data:

Type of Operation	Total Number of Fatal Rotorcraft Accidents
14 CFR 91	126
14 CFR 133	12
14 CFR 135	24
14 CFR 137	13
Outside The U.S.A	2
Total	**177**
Total People on Board	**399**
Total Number of Fatalities	**323**

14 CFR 91 (N=126)	Total Number
People on Board Rotorcraft	274
Number of People Fatal	219
Post-Crash Fire = Yes	55
Post-Crash Fire = No	71
Post-Crash Fire – Undetermined	0
Cause of Death (COD)= Thermal Injuries	28

Thermal Injuries noted but not COD	33
Autopsy Reports Received	142

14 CFR 133 (N=12)	Total Number
People on Board Rotorcraft	19
Number of People Fatal	14
Post-Crash Fire = Yes	2
Post-Crash Fire = No	10
Post-Crash Fire – Undetermined	0
Cause of Death (COD)= Thermal Injuries	0
Thermal Injuries noted but not COD	2
Autopsy Reports Received	9

14 CFR 135 (N=24)	Total Number
People on Board Rotorcraft	83
Number of People Fatal	68
Post-Crash Fire = Yes	9
Post-Crash Fire = No	14
Post-Crash Fire – Undetermined	1
Cause of Death (COD)= Thermal Injuries	2
Thermal Injuries noted but not COD	7
Autopsy Reports Received	43

14 CFR 137 (N=13)	Total Number
People on Board Rotorcraft	15
Number of People Fatal	14
Post-Crash Fire = Yes	5
Post-Crash Fire = No	7
Post-Crash Fire – Undetermined	1
Cause of Death (COD)= Thermal Injuries	3
Thermal Injuries noted but not COD	2
Autopsy Reports Received	12

Outside the U.S.A (N=2)	Total
People on Board Rotorcraft	8
Number of People Fatal	8
Post-Crash Fire = Yes	2
Post-Crash Fire = No	0
Post-Crash Fire – Undetermined	0
Cause of Death (COD)= Thermal Injuries	Unknown
Thermal Injuries noted but not COD	Unknown
Autopsy Reports Received	0

Attachment: Accident List

Please let us know if you have any questions.

Sincerely,

Christy Hileman, MBA, RHIA, CCS
Heather Hunn, RHIA
Ashley Griffin, MS, RHIA, CCS

Autopsy Program Team
Civil Aerospace Medical Institute

APPENDIX G: ANALYSIS OF MODELS WITH FEW UNITS IN SERVICE

The non-recurring costs for developing a retrofit kit are independent of the number of helicopters of that model in the U.S. fleet. Therefore, models with fewer units in service will incur a higher per-unit share of non-recurring costs than models with more units in service. As a result, it may not be economically viable to develop retrofit kits for models with few models in service.

Distribution of Helicopter Models in U.S. Fleet

Table 39 and Table 40 provide a summary of the distribution of helicopters by their frequency in the U.S. fleet. This data was derived from the complete list of models, sorted by frequency, which is included in Appendix B.

Table 39. Distribution of Helicopter Models in U.S. Fleet, Part 27

Units of Particular Model in U.S. Fleet [x]	Number of Models with More than [x] Units in U.S. Fleet	Total Number of Helicopters in This Category	Percentage of Part 27 U.S. Fleet in This Category
1000+	2	2600	26.70%
500-999	6	3822	39.25%
100-499	10	2155	22.13%
50-99	8	619	6.36%
20-49	11	382	3.92%
10-19	8	125	1.28%
1-9	9	34	0.35%
Less than 100	36	1160	11.91%
Less than 50	28	541	5.56%
Less Than 20	17	159	1.63%

Table 40. Distribution of Helicopter Models in U.S. Fleet, Part 29			
Units of Particular Model in U.S. Fleet [x]	**Number of Models with More than [x] Units in U.S. Fleet**	**Total Number of Helicopters in This Category**	**Percentage of Part 29 U.S. Fleet in This Category**
100+	4	520	48.01%
50-99	4	285	26.32%
20-49	6	184	16.99%
10-19	4	50	4.62%
1-9	9	44	4.06%
Less than 100	23	563	51.99%
Less than 50	19	278	25.67%
Less Than 20	13	94	8.68%

Per-Unit Share of Non-Recurring Costs versus Number of Units in Service

Table 41 and Table 42 show the per-unit share of the non-recurring costs for complying with the potential retrofit requirements based upon units in service for Part 27 and Part 29 helicopters.

Table 41. Per-Unit Share of Non-Recurring Costs for Complying with Potential Retrofit Requirements, Part 27

Units in Service	CRFS	CRSS - Dynamic Seats	CRSS - Retention
1	$7,295,909	$8,209,259	$2,031,793
10	$729,591	$820,926	$203,179
20	$364,795	$410,463	$101,590
50	$145,918	$164,185	$40,636
100	$72,959	$82,093	$20,318
500	$14,592	$16,419	$4,064
1000	$7,296	$8,209	$2,032

Table 42. Per-Unit Share of Non-Recurring Costs for Complying with Potential Retrofit Requirements, Part 29

Units in Service	CRFS	CRSS - Dynamic Seats	CRSS - Retention
1	$5,966,667	$4,055,556	$2,444,444
10	$596,667	$405,556	$244,444
20	$298,333	$202,778	$122,222
50	$119,333	$81,111	$48,889
100	$59,667	$40,556	$24,444
500	$11,933	$8,111	$4,889
1000	$5,967	$4,056	$2,444

Total Per-Unit Cost versus Number of Units in Service

Combining the per-unit share of the non-recurring cost (Table 41 and Table 42) with the average unit (installation) cost (Table 4), the average total per-unit cost to develop and install a retrofit kit as a function of the number of units of that model in service can be determined as shown in Table 43 and Table 44.

Table 43. Total Average Per-Unit Cost to Develop and Install Kit to Comply with Potential Retrofit Requirements, Part 27

Units in Service	CRFS	CRSS - Dynamic Seats	CRSS - Retention
1	$7,442,954	$8,538,791	$2,161,661
10	$876,636	$1,150,458	$333,047
20	$511,840	$739,995	$231,458
50	$292,963	$493,717	$170,504
100	$220,004	$411,625	$150,186
500	$161,637	$345,951	$133,932
1000	$154,341	$337,741	$131,900

Note: For reference, the average replacement value of a Part 27 airframe in the U.S. fleet (weighted to account for more numerous models) is $1,240,000.

Table 44. Total Average Per-Unit Cost to Develop and Install Kit to Comply with Potential Retrofit Requirements, Part 29

Units in Service	CRFS	CRSS - Dynamic Seats	CRSS - Retention
1	$6,295,417	$4,361,945	$2,617,232
10	$925,417	$711,945	$417,232
20	$627,083	$509,167	$295,010
50	$448,083	$387,500	$221,677
100	$388,417	$346,945	$197,232
500	$340,683	$314,500	$177,677
1000	$334,717	$310,445	$175,232

Note: For reference, the average replacement value of a Part 27 airframe in the U.S. fleet (weighted to account for more numerous models) is $7,660,000.

APPENDIX H: COPY OF DISCUSSION OF CRFS RECOMMENDATIONS FROM ROPWG TASK 5 CRFS REPORT

The text below is reproduced from the ROPWG Task 5 CRFS Report. It contains a detailed discussion of why some of the CRFS regulations were not recommended for incorporation into newly manufactured, legacy helicopters. Since incorporating these regulations into previously manufactured helicopters would be more difficult, but no more effective, than incorporating just those regulations recommended by the ROPWG, the rationale given in this text applies to the present retrofit discussion as well.

<u>Text Reproduced from ROPWG Task 5 CRFS Report, "Discussion of Recommendations (Table 12)" Section</u>

27/29.952(a): Drop Test Requirements

Dropping the bladder alone is generally considered more severe with respect to pressure loads on the bladder, while dropping with surrounding structure is more critical with respect to puncture and other hazards associated with attachment to structure. Therefore, either approach to drop testing may be critical for a specific bladder installation.

As noted in Table 4 and the associated notes [of the referenced report], as part of the non-required development testing for the CRFS in Models 1 & 2, the CRFS fuel bladders were subjected to a 50-foot drop test per the requirements of 27/29.952(a), except that the test was performed for the bladders alone (i.e., the surrounding structure was not included in the drop). It is clear from the post-crash fire data for these models that these fuel systems are extremely effective at preventing post-crash fires and thermal injuries following survivable accidents.

Therefore, while the surrounding structure may indeed create a puncture hazard, including bladder material puncture resistance and other material properties identified in AC 27-1B/29-2C as part of guidance is an equally effective but less arduous and less expensive means of ensuring bladder crash effectiveness compared to dropping the bladder inside the structure.

Note that mandating 27/29.952(a) Paragraphs 1, 2, 3, 5, and 6, and not requiring paragraph 4, would allow for tests with or without the surrounding structure.

27/29.952(b): Fuel Tank Load Factors

The data in Table 4 and Table 11 [of the referenced report] show that CRFS with fuel tank load factors certified to lower levels than currently required (i.e., those required for the original certification basis) in current partially-compliant helicopters are equally effective at preventing post-crash fires and thermal injuries as CRFS in fully-compliant helicopters. For many helicopter models, increasing the structural retention strength of the fuel tanks would require a significant increase in fuselage strength, with associated weight penalties, research and development costs, and manufacturing costs. This is particularly true for small, legacy rotorcraft that were designed around lower load factors. These penalties and costs, combined with data showing the lack of a measurable benefit, lead to the recommendation that this section not be required for newly manufactured, legacy rotorcraft. Therefore, the load factors required for a particular model during its original certification should remain in effect.

27/29.952(d): Frangible or deformable structural attachments

27/29.952(d) and 27/29.952(f) and their associated AC guidance, both address crash resistant attachments of fuel system components. While these regulations and guidance address very similar topics, the regulatory requirements of 27/29.952(d) include prescriptive details that are impractical for some previously-certified, legacy rotorcraft that have demonstrated adequate post-crash fire protection as reported above. The requirement of, “as far as practicable” in 27/29.952(f) is much more appropriate for a previously-designed airframe, particularly when that airframe has demonstrated adequate post-crash fire protection in survivable crashes. Therefore, it is recommended that compliance with 27/29.952(f) be required, but compliance with 27/29.952(d) is NOT required for newly-manufactured, legacy rotorcraft.

Note that the Model 4 data from Table 4 and Table 6 [of the referenced report] show that this design, while partially-compliant with 27.952(d) but likely compliant with 27.952(f), was extremely effective at preventing post-crash fires following survivable accidents. Similarly, Models 5 and 6, which may not be fully compliant to this section, were also extremely effective at preventing post-crash fires following survivable accidents.

27/29.952(e): Separation of fuel and ignition sources

27/29.952(e) and 27/29.952(f) and their associated guidance both address the separation of fuel and ignition sources. While these regulations and guidance address very similar topics, the regulatory requirements of 27/29.952(e) include prescriptive details that are impractical for some previously-certified, legacy rotorcraft showing adequate post-crash, fuel-fed fire protection. The requirement of “as far as practicable” in 27/29.952(f) is much more appropriate for a previously-designed airframe, particularly when that airframe has demonstrated adequate post-crash fire protection in survivable crashes. Therefore, it is recommended that compliance with 27/29.952(f) be required, but compliance with 27/29.952(e) is NOT required for this group of newly-manufactured, legacy rotorcraft.

While the working group agrees that separation of fuel and potential ignition sources is extremely important in a CRFS, it is clear from the data in Table 3 and Table 10 [of the referenced report] that the existing separations in the studied partially-compliant, legacy models are equally effective in their current configurations to helicopters meeting the requirements of 27/29.952(e). Consequently, the ROPWG does not recommend compliance with this section for newly-manufactured, legacy helicopters.

27/29.952(g): Rigid or semirigid fuel tanks

The rule is explicit that this requirement applies to rigid or semirigid fuel tank or bladder walls and the AC provides definitions of these tanks and further clarifies that flexible liners are excluded. All partially-compliant helicopter models studied for this report rely on flexible liners and therefore 27/29.952(g) is not applicable. This interpretation of the intent of the rule and guidance was confirmed by internal FAA discussions relayed to the working group by the FAA ROPWG representative.

There is, however, material within the Advisory Circular guidance (AC 27-1B/29-2C) for 27/29.952(g) that could lead to the misinterpretation that the tear resistance requirements do apply to flexible liners. It is therefore recommended that the AC guidance be revised to eliminate this ambiguity so that it is clear that this requirement applies to rigid or semirigid fuel tank or bladder walls only and that flexible liners are excluded.

Since this paragraph is not applicable to any of the partially-compliant helicopters in this study, there is no data to support its inclusion or exclusion...

[Task 6 report additional text: Because of the ambiguity regarding the application of this rule, and because of the lack of data as to its effectiveness, the ROPWG is not recommending its mandate for previously manufactured helicopters.]

APPENDIX I: FLIGHT HOUR DATA

This appendix contains U.S. helicopter fleet flight hour data that may serve as a useful reference for readers of this report.

Table 45. Rotorcraft Flight Hours in U.S. Helicopter Fleet			
CALENDAR YEAR	**PISTON**	**TURBINE**	**TOTAL**
Historical*			
2010	794	2,611	3,405
2011E	757	2,654	3,411
2012	731	2,723	3,454
2013	636	2,312	2,949
2014	818	2,424	3,242
2015	798	2,496	3,294
2016E	784	2,565	3,350
Forecast			
2017	777	2,636	3,413
2018	793	2,705	3,497
2019	809	2,773	3,582
2020	828	2,843	3,671
Avg. Annual Growth			
2010-16	-0.2%	-0.3%	-0.3%
2016-17	-0.8%	2.7%	1.9%
2016-26	1.8%	2.3%	2.2%
2016-37	1.7%	2.1%	2.0%
* Source: 2001-2010, 2012-2014, FAA General Aviation and Air Taxi Activity (and Avionics) Surveys.			
****Experimental Light-sport category that was previously shown under Sport Aircraft is moved under Experimental Aircraft category, starting in 2012.**			
Note: An active aircraft is one that has a current registration and was flown at least one hour during the calendar year.			

Table 46. 2016 General Aviation and Part 135 Total Hours Flown by Rotorcraft by Actual Use, U.S. Fleet

AIRCRAFT TYPE	General Aviation Use Total Active	General Aviation Use Personal	General Aviation Use Business w/o crew	General Aviation Use Business w/crew	General Aviation Use Instructional	General Aviation Use Aerial App Ag	General Aviation Use Aerial Obs	General Aviation Use Aerial App Other	General Aviation Use External Load	General Aviation Use Other Work	General Aviation Use Sight See	General Aviation Use Air Med	General Aviation Use Other	On-Demand FAR Part 135 Use Air Taxi	On-Demand FAR Part 135 Use Air Tours	On-Demand FAR Part 135 Use Air Med
Rotorcraft	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Rotorcraft: Total	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Est. Total Hours	**3,128,069**	**105,376**	**33,937**	**74,753**	**619,458**	**129,127**	**619,721**	**61,505**	**150,366**	**55,281**	**64,657**	**22,294**	**119,896**	**234,048**	**305,276**	**532,374**
% Std. Error	**1.1**	**5.1**	**6.7**	**9.6**	**3.2**	**7.0**	**3.6**	**7.0**	**6.7**	**11.2**	**8.0**	**10.6**	**3.3**	**4.0**	**6.8**	**3.1**
Piston	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Est. Total Hours	780,205	71,847	16,053	4,498	444,715	38,011	56,005	3,462	3,195	2,190	52,377	*	14,059	28,152	45,613	0
% Std. Error	3.1	9.0	11.3	35.8	5.0	13.2	10.8	32.4	39.1	23.7	12.1		13.6	13.1	10.3	*
Turbine: Total	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Est. Total Hours	2,347,864	33,529	17,883	70,255	174,743	91,117	563,715	58,043	147,171	53,091	12,281	22,266	105,837	205,896	259,663	532,374
% Std. Error	1.1	5.1	8.8	8.8	4.5	7.8	3.3	6.3	5.9	10.1	11.3	9.3	3.0	3.8	6.9	2.6
1 Eng: Turbine	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Est. Total Hours	1,809,769	29,600	14,089	40,874	143,744	77,908	501,857	49,900	108,735	44,423	11,361	8,699	68,554	144,770	257,955	307,299
% Std. Error	1.3	5.5	9.6	11.9	4.9	7.1	3.2	7.0	7.1	11.1	11.6	13.1	3.7	4.7	6.8	3.4
Multi-Eng: Turbine	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
Est. Total Hours	538,095	3,929	3,794	29,381	30,999	*	61,858	8,143	38,436	8,668	*	13,567	37,283	61,126	*	225,075
% Std. Error	2.4	13.5	21.3	12.9	11.0		15.0	12.6	10.1	23.1	*	13.0	5.2	6.2	*	4.0

APPENDIX J: TABULAR TECHNICAL FEASIBILITY DATA

Table 47. Distribution of Ranked U.S. Fleet with Given CRFS Retrofit Feasibility Ranking

Feasibility	Part 27			Part 29		
	Number of Models	Number of Helicopters	Percent of Fleet with Known Ranking (by number of helicopters)	Number of Models	Number of Helicopters	Percent of Fleet with Known Ranking (by number of helicopters)
1 (Not Feasible)	7	45	0.5%	0	0	0.0%
2 (Low)	9	385	4.1%	14	517	48.7%
3 (Moderate)	11	3158	34.0%	1	4	0.4%
4 (High)	5	1576	17.0%	2	169	15.9%
5 (Already Incorporated)	13	4128	44.4%	9	371	35.0%
Total of Any Known Ranking	45	9292		26	1061	
Total US Registered	54	9737		28	1083	

Table 48. Distribution of Ranked U.S. Fleet with Given CRSS - Dynamic Seats Retrofit Feasibility Ranking						
	Part 27			Part 29		
Feasibility	Number of Models	Number of Helicopters	Percent of Fleet with Known Ranking (by number of helicopters)	Number of Models	Number of Helicopters	Percent of Fleet with Known Ranking (by number of helicopters)
1 (Not Feasible)	9	316	3.4%	0	0	0.0%
2 (Low)	26	8006	86.2%	9	445	41.9%
3 (Moderate)	1	60	0.6%	8	245	23.1%
4 (High)	0	0	0.0%	3	71	6.7%
5 (Already Incorporated)	9	910	9.8%	6	300	28.3%
Total of Any Known Ranking	45	9292		26	1061	
Total US Registered	54	9737		28	1083	

Table 49. Distribution of Ranked U.S. Fleet with Given CRSS - Improved Retention Retrofit Feasibility Ranking

Feasibility	Part 27			Part 29		
	Number of Models	Number of Helicopters	Percent of Fleet with Known Ranking (by number of helicopters)	Number of Models	Number of Helicopters	Percent of Fleet with Known Ranking (by number of helicopters)
1 (Not Feasible)	7	45	0.5%	0	0	0.0%
2 (Low)	17	4113	44.3%	9	445	41.9%
3 (Moderate)	5	1914	20.6%	1	4	0.4%
4 (High)	7	2310	24.9%	11	414	39.0%
5 (Already Incorporated)	9	910	9.8%	5	198	18.7%
Total of Any Known Ranking	45	9292		26	1061	
Total US Registered	54	9737		28	1083	