March 23, 2018

Ms. Lirio Liu
Director, Office of Rulemaking
Federal Aviation Administration
800 Independence Avenue, SW
Washington, DC 20591

RE: Airman Certification Working Group (ACSWG) Recommended Changes; Rotorcraft Occupant Protection Working Group (ROPWG) Task 5 Recommendation Reports

Dear Ms. Liu,

Attached are three documents approved by the Aviation Rulemaking Advisory Committee (ARAC) on March 15, 2018:

- The Airman Certification System Working Group (ACSWG) recommended changes for the Aviation Maintenance Technician Handbook – Airframe (FAA-H-8083-31A) and the AMA sample exam;
- The Rotorcraft Occupant Protection Working Group (ROPWG) Task 5 Final Recommendation Report for Crash Resistant Seats and Structures (CRSS);
- The ROPWG Task 5 Final Recommendation Report for Crash Resistant Fuel Systems (CRFS)

On behalf of the ARAC members, please accept the ACSWG recommended changes to be implemented as soon as possible by the relevant program offices. Please also accept the ROPWG's Final Reports as completion of its Task 5.

Please do not hesitate to contact me with any questions. Thank you very much.

Sincerely yours,

Yvette A. Rose
ARAC Chair

cc: David Oord, ACSWG Chair and ARAC Vice Chair
Dennis Shanagan, ROPWG Chair

ROTORCRAFT OCCUPANT PROTECTION WORKING GROUP (ROPWG)

TASK 5

CRASH RESISTANT SEATS AND STRUCTURE (CRSS) FINAL ANALYSIS REPORT TO THE AVIATION RULEMAKING ADVISORY COMMITTEE (ARAC)

Submitted: January 29, 2018

EXECUTIVE SUMMARY

BACKGROUND

This report contains the Rotorcraft Occupant Protection Working Group (ROPWG) recommendations for incorporating the requirements of all or part of 14 CFR 27/29.561, 27/29.562, and 27/29.785 into newly manufactured rotorcraft that were certified before these regulations went into effect (legacy helicopters). For convenience, this report refers to these regulations collectively as Crash Resistant Seat and Structure (CRSS).

METHODS

Studies of both military and civilian helicopter accidents have demonstrated that next to thermal injuries caused by post-crash, fuel fed fires, blunt force injuries are the most prevalent sources of injury in civil helicopter crashes, and are typically caused by one of the following mechanisms:

- Excessive vertical deceleration (often resulting in severe spinal injuries)
- Excessive flailing caused by inadequate restraint or restraint failure
- Body contact with collapsed structure

While reducing these injuries is a high priority for crash safety, incorporating the CRSS regulations into existing helicopter designs is impeded by a number of technical and economic issues. Indeed, a requirement for full compliance with the CRSS regulations for some helicopters currently in production would be impracticable, and could force OEMs and operators to discontinue the use of those helicopter models due to increased costs and/or decreased performance.

One of the primary issues considered by the ROPWG was whether it was **practicable** to apply the current FAA requirements to this specific group of newly manufactured, legacy helicopters, and in cases where this was not practicable, whether there were any alternative regulations that could provide much of the same benefit with significantly lower cost and weight penalties. For some sections of the CRSS regulations, the ROPWG did not recommend incorporation into this group of helicopters either because implementation was overwhelmingly impracticable or because implementation would lead to little or no benefit.

SUMMARY OF ROPWG RECOMMENDATIONS

The ROPWG recommendations for CRSS regulatory compliance with 27/29.561, 27/29.962, and 27/29.785 for newly manufactured, legacy aircraft are summarized below in Table 1, and discussed in detail in the Recommendations section in the body of this report. These recommendations are based upon the ROPWG technical analysis of pertinent issues including a cost-benefit analysis described in the body of this report. Of particular interest is that ROPWG is recommending a reduced velocity dynamic seat test (27.562(b)(1)) for Part 27 helicopters that have seating positions that cannot reasonably incorporate the stroking distance required by a fully-compliant seat. The complete technical discussion for this recommendation is included in Appendix E and is summarized in the body of this report.

Table 1. CRSS (27/29.561, 27/29.562 and 27/29.785) Regulatory Recommendations for Newly Manufactured, Legacy Helicopters* **Unless otherwise noted, recommendations apply to both Part 27 and Part 29 helicopters.*		
Regulation	**Recommendation**	**Notes**
27/29.561(b)(3): Restraint of occupants and items of mass in cabin	Recommended	The loss of occupant retention and flailing are among the greatest hazards in helicopter crashes, and anecdotal evidence suggests that items of mass in the cabin are a potential hazard as well. Also, the associated cost and weight penalties are relatively small, and no other significant impediments to meeting these requirements were identified.
27/29.561(c): Restraint of items of mass above and behind cabin	NOT Recommended	Items of mass above and behind the cabin are a relatively low priority hazard according to CT-85/11, and no known evidence shows that existing levels of tie-down strength are inadequate. Also, the associated cost and weight penalties would be severe.
27/29.561(d): Restraint of fuel tanks below floor	NOT Recommended	No evidence from crash reports supports the contention that failure of below floor fuel tank retention is a hazard in legacy helicopters. Also, the associated cost and weight penalties would be significant.
27/29.562(b)(1): Dynamic seat testing, Vertical Direction	Part 27: Recommended w/changes	Reduction in spinal injuries is a high priority for occupant protection, but some legacy Part 27 models have insufficient space under certain seats to meet the full requirement, which would lead to the discontinuation of these models. However, seats rated to a 21.7 ft/s vertical impact could be incorporated into nearly all seats in existing helicopters, and would provide 71% of the protection afforded by fully compliant seats. The ROPWG therefore recommends full compliance in those seats where practicable, and a 25 ft/s (21.7 ft/s vertical component) test requirement in only those seating positions where full compliance is not practicable.
	Part 29: Recommended	Reduction in spinal injuries is a high priority for occupant protection. Due to their greater size and near universal incorporation of bolt-in seats, the cost and weight penalties associated with full compliance are relatively small for Part 29 helicopters. There is no known significant impediment to requiring the full regulation for Part 29 helicopters other than a possible small reduction in seating capacity in some models.

27/29.562(b)(2): Dynamic seat testing, Horizontal direction	Recommended	The loss of occupant retention and flailing are among the greatest hazards in helicopter crashes. Also, the associated cost and weight penalties are relatively small, and no other significant impediments to meeting this requirement were identified.
27/29.785: Seats, berths, litters, safety belts, and harnesses	Recommended	While the group found that most aspects of this regulation are also covered by other regulations, compliance with the regulation is recommended as there would be a modest safety benefit, and the associated costs and weight penalties are relatively small. Note that the text of 27/29.785 references 27/29.561 and 27/29.562. Therefore, although no changes are required to the intent of the regulation, revised/additional text may be required to clarify that regulations referenced in the text of 27/29.785 are, as applicable, the modified regulations mandated for newly manufactured, legacy helicopters.
Requirement for full compliance 10 years after approval of new CRSS rules	NOT recommended	Since the cost and weight penalties required for full compliance are due to engineering challenges as opposed to development schedules, delaying full compliance by 7-10 years will not result in appreciably lower costs, weight penalties, or disruptions caused by discontinued models.

CONCLUSIONS

Based upon the data and analyses in this report, we conclude the following:

1. Military and civilian helicopter accident data has shown that the greatest hazards in survivable accidents are:
   a. Thermal injuries from post-crash fires following survivable accidents.
   b. Excessive vertical deceleration.
   c. Head, torso, and extremity contact with cabin structure due to inadequate restraint.
2. The ROPWG determined and reported in its Task 2 Report that full compliance with CRSS regulations is not the optimal regulatory approach for newly manufactured, legacy rotorcraft. The analysis described in this report shows that partial-compliance provides a significant safety benefit while substantially reducing the costs compared to full compliance.
3. Qualitative and quantitative analyses of the ROPWG recommendations indicate that they provide a reasonably cost-effective method of improving crash safety in currently-manufactured, legacy helicopters.
4. There are a number of currently manufactured, legacy Part 27 helicopters where the requirements of 27.562(b)(1) (vertical dynamic seat test) cannot be implemented in some seating positions because providing the necessary stroking distance would reduce the fuel capacity and/or occupant capacity in these models to a level where the OEM or operator would be forced to discontinue that model.
   a. As a compromise, the ROPWG determined that a reduced velocity vertical dynamic seat test could be practicable and effective in these seating positions.
   b. It is estimated that a reduction in the vertical velocity component for the dynamic seat test from 26 ft/s to 21.7 ft/s would provide 71% of the protection against serious spinal injury as full compliance, but with substantially reduced fuel and occupant capacity penalties as a result of much smaller requirements for seat stroking distance.
5. Inadequate restraint of items of mass above and behind the passenger compartment contributes to only a small number of injuries, but full compliance with 27/29.561(c) (restraint of items of mass above and behind cabin) would entail considerable expense and severe weight penalties in currently manufactured, legacy helicopters.
6. The empty weight and fuel capacity/range penalties described in this report could potentially increase the accident rate, particularly for small helicopters with small power margins. As a result:
   a. The reduction in the number and severity of injuries per accident could be offset by an increase in the number of accidents.
   b. Regulatory requirements beyond those recommended by the ROPWG (in particular, requiring full compliance with 27/29.561(c) (restraint of items of mass above and behind cabin) and/or 27.562(b)(1) (vertical dynamic seat test) could be detrimental to safety, and are therefore strongly discouraged.
7. While the ROPWG is aware that the FAA asked for a recommendation on “which Paragraphs of each Section for the existing occupant protection standards cited in the referenced Federal Register Notice can be made effective for newly manufactured rotorcraft”, the ROPWG members believe that the inclusion of an alternative, reduced velocity vertical seat test for certain seating positions is required in order to provide effective CRSS regulations for newly manufactured, legacy helicopters.

8. The ROPWG recommends that the FAA **does not** require full compliance with 27/29.561, 27/29.562, and 27/29.785 after a 10-year period for legacy, newly-manufactured helicopters, for the following reasons:
    a. The analysis of data in this report shows that, in comparison to the partial-compliance recommendations summarized in Table 1, the additional benefits of mandating full compliance would be outweighed by the additional costs, weight penalties, and disruption to the industry.
    b. The requirement for full compliance with 27.562(b)(1) (vertical dynamic seat test) would likely result in the discontinuation of certain helicopter models due to the infeasibility of making the required changes in these models, whereas approximately 70% of the benefit could be achieved with the reduced velocity vertical test at a fraction of the cost/weight/disruption.
    c. The requirement for full compliance with 27/29.561(c) (restraint of items of mass above and behind cabin) would result in substantial weight penalties for many helicopters while providing an uncertain but likely modest benefit.
    d. Since the cost and weight penalties required for full compliance are due to engineering challenges as opposed to development schedules, delaying full compliance by 7-10 years will not mitigate any of these factors.
9. The NTSB database and supporting dockets do not provide sufficient data to conduct an analysis of crash injuries and injury causes in civil aviation crashes. Specifically, they lack data on crash impact parameters, injuries to occupants, and injury causes (mechanisms). Without this information, it is impossible to assess the effectiveness of civil occupant protection regulations in preventing injury to occupants in crashes. Consequently, the regulatory process is driven by anecdotal data, which is inherently unreliable and leads to potentially faulty and inefficient regulations.

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.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

This page intentionally left blank

INTRODUCTION

ROPWG TASKING AND REPORT ORGANIZATION

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. 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. This approach has resulted in a low incorporation rate of occupant protection features into the rotorcraft fleet. At the end of 2014, 16% of the U.S. fleet had complied with the crash resistant fuel system requirements effective 20 years earlier, and 10% had complied with the emergency landing requirements effective 25 years earlier.[1] 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.[2] At the present rate of incorporation of these features 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.

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 formed 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.[3]

The ROPWG was given a number of sequential tasks to accomplish in meeting their obligations. Our first tasking (Tasks 1 and 2) was to provide a cost-benefit analysis of implementing current occupant protection regulations into all newly-manufactured rotorcraft. This report was submitted to ARAC in November 2016, unanimously accepted by ARAC in December 2016, and forwarded to the FAA. On January 25, 2017, the FAA tasked 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, ROPWG was additionally tasked with providing:

---

[1] Federal Register. FAA. Aviation Rulemaking Advisory Committee—New Task. Vol.80 (214), November 5, 2015, Notices.

[2] Roskop, L. Post-crash fires and blunt force fatal injuries in U.S. registered type certificated rotorcraft, CAMI Injury Mechanism Workshop, Presented November, 2015.

[3] Federal Register, op. cit., 2015.

"...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 ROPWG to continue reporting separately on CRFS and CRSS. Also, since there were significant differences in the available accident data for CRSS and CRFS (see next subsection) 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 crash-resistant fuel system (CRFS) standards and crash-resistant seat and structure (CRSS) standards into newly-manufactured, legacy rotorcraft. The current report is the ROPWG final report on its CRSS recommendations for how all or part of the existing 27/29.561, 27/29.562 and 27/29.785 standards should be made effective via §§ 27.2 and 29.2 for newly-manufactured, legacy helicopters. The ROPWG CRFS (27/29.952) final recommendations are documented in a separate report to the ARAC.

RATIONALE FOR DIFFERENCES IN CRFS AND CRSS ANALYSIS

While the NTSB database and individual accident investigation dockets contain sufficient information for analyzing CRFS effectiveness, they do not provide sufficient information for analyzing CRSS effectiveness.

For CRFS, the NTSB reports identify crashes that involve post-crash fires, and in many cases, identify occupants that suffered thermal injuries. Additionally, information and photographs in the dockets for these crashes often allow a determination of the source of the post-crash fire, and a rough determination of impact conditions. Based on these data, the working group was able to make reasonably definitive comparisons between crashes of helicopters with few or no elements of a CRFS, partially-compliant CRFS, and fully-compliant fuel systems (see ROPWG Task 5 CRFS report).

In contrast, the NTSB database does not contain information that allows the determination of the types or causes of blunt force injuries for occupants involved in survivable crashes. For instance, there is no data field to identify loss of retention of a high-mass item and whether such a failure resulted in an injury, or whether a particular crash involved a failure of a seat or restraint system. Furthermore, even dramatic injuries such as paraplegia or quadriplegia caused by spinal injury are not reliably reported in accident dockets. Given this lack of CRSS-related data, the ROPWG was not able to use the NTSB database or associated dockets to compare the effectiveness of CRSS features in different helicopter models, and was forced to take a different approach to analyze CRSS than that used for CRFS.

Fortunately, the current CRSS regulations are based on previous in-depth studies of civilian helicopter crashes, the findings of which are corroborated by similar military epidemiological studies. Since we could obtain no data to suggest otherwise, the ROPWG started its analysis of CRSS with the basic assumptions that the previous civilian CRSS studies remain valid, and that military CRSS effectiveness data can be applied to civilian helicopter accidents. The civil accident distribution data from the previous CRSS studies, in combination with military CRSS effectiveness data, allowed the ROPWG to make a rough estimate of the benefit of most CRSS features.

Due to the uncertainty associated with the magnitude of the CRSS benefit, one of the primary issues considered by the ROPWG was whether it was **practicable** to apply the current FAA requirements to this specific group of newly manufactured, legacy helicopters, and in cases where this was not practicable, whether there were any alternative regulations that could provide much of the same benefit with significantly lower cost and weight penalties. As was the case for CRFS, there were a number of helicopter models where full compliance with the current CRSS regulations would result in discontinuation of some currently manufactured, legacy rotorcraft. The group felt that any recommendations made that would result in a significant disruption to the industry should be justified by a reasonable expectation that the recommended change would result in a significant increase in crash safety. The group also felt that full compliance was often not appropriate if alternatives existed that offered similar protection levels for significantly lower cost and weight penalties. The results of this analysis are provided in the "Recommendations" section of this report.

RELATIVE FREQUENCY AND SEVERITY OF INJURY HAZARDS IN CIVILIAN HELICOPTER CRASHES

OVERVIEW

Although occupant protection regulations were promulgated (principally in 1989 for CRSS and 1994 for CRFS) to reduce specific injury hazards in survivable crashes of rotorcraft, some hazards are more prevalent than others, and some of these hazards have a greater overall effect on injury than others. Therefore, it is useful to identify the various injury mechanisms in survivable helicopter crashes and rate these hazards according to frequency and severity. An understanding of these issues allows a relative prioritization of the importance of different mitigation strategies as expressed in the occupant protection regulations (27/29.561, 27/29.562, 27/29.785, 27/29.952).

In order to define and prioritize injury hazards in survivable helicopter crashes, it is necessary to analyze a set of crashes and determine severity of the crash, injuries to the occupants, and mechanism of each injury. As discussed in the Introduction, since the NTSB does not determine these parameters in its investigation of crashes, anyone wishing to perform this type of analysis must select a defined period of time, collect all the data available for each crash occurring during the study period, and then analyze each crash individually to determine impact parameters, injuries to each occupant, and the probable mechanism of each identified injury.

The most complete study of this kind was commissioned by the FAA and conducted by Simula, which published their results in a report in 1985 (referred to as "CT-85/11" for the remainder of this report).[4] The Simula study team reviewed all crashes of U.S. civil helicopters occurring during the then most recent 5-year period (1974-1978) to determine impact conditions, injuries to the occupants, and mechanisms of injury. Of the 1,351 accidents occurring during the study period, 311 NTSB dockets contained sufficient data for the researchers to make the necessary determinations and, of these crashes, 211 accidents were determined to be survivable or partially survivable.

A rank-ordered listing of crash hazards for the civilian rotorcraft fleet was determined based upon the frequency of each hazard and the severity of injuries produced by each identified mechanism or hazard. Table 2 summarizes these findings and identifies each Simula-determined hazard with the applicable occupant protection regulations. Additionally, Table 2 summarizes the annual frequency data for the occurrence of each hazard as a percentage of all crashes in an average year. Injury severity was rated according to the Abbreviated Injury Scale (AIS), which is discussed following the table.

Note that Simula identified a total of 14 hazards, but only 6 of these hazards were associated with the FAA occupant protection regulations ROPWG was asked to consider. Consequently, Table 2 only lists the applicable hazards. The excluded hazards included wire strike, drowning, failure to use restraint correctly, rotor entered occupied space, object other than rotor entered occupied space, injury during egress and body exposed to chemical agents.

---

[4] Coltman, J.W., Bolukbasi, A.O., Laananen, D.H. 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.

Table 2. Occupant Protection Regulations and Crash Hazards for the Civilian Helicopter Fleet in Survivable Crashes							
Regulation	Hazard	Hazard Ranking	Annual Injury Frequency Attributable to Hazard by Severity of Injury				
			Moderate (AIS 1 or 2)	Severe (AIS 3 or 4)	Life Threatening (AIS 5 or 6)	Total of All Severity Levels	Percent of Total Life-Threatening Injuries
27/29.952 Fuel System Crash Resistance	Body exposed to fire when fuel system failed on impact	1	3.7%	3.1%	7.2%	14.0%	51%
27/29.562(b) Emergency Landing Dynamic Conditions	Body received excessive decelerative force when aircraft and seat allowed excessive loading	2	14.3%	12.7%	0.8%	27.8%	3%
27/29.785 Seats, Berths, Litters, Safety Belts, and Harnesses Also, 27/29.561(b)(3) and 27/29.562	Body struck structure because design provided inadequate clearance and/or restraint allowed excessive motion	4	33.7%	2.0%	1.2%	36.9%	3%
27/29.785(b) Seats, Berths, Litters, Safety Belts, and Harnesses	Body struck aircraft structure due to lack of upper torso restraint	5	15.3%	4.6%	0.8%	20.7%	4%
27/29.561(c) Items of Mass Support Structure Inertial Load Factors	Body struck by aircraft structure when structure collapsed excessively	8	5.1%	0.7%	0.0%	5.8%	0%
27/29.561(b) Emergency Landing Conditions	Body struck structure when seat failed	9	0.7%	0.8%	0.4%	1.9%	21%
27/29.785 Seats, Berths, Litters, Safety Belts, and Harnesses Also, 27/29.561(b)(3) and 27/29.562	Body struck structure when restraint failed	12	0.0%	0.8%	0.0%	0.8%	0%

ABBREVIATED INJURY SCALE (AIS)

CT-85/11 used the Abbreviated Injury Scale (AIS) to describe injury severity. AIS is an anatomically based system that classifies individual injuries by body region on a 6-point ordinal severity scale ranging from AIS 1 (minor) to AIS 6 (maximum/currently untreatable) as follows:

Table 3. Abbreviated Injury Scale (AIS)

Scale Rating	Injury Severity
1	Minor
2	Moderate
3	Serious
4	Severe
5	Critical
6	Maximum

For simplicity and to reduce the number of categories, some analysts combine AIS injuries such as was done by the authors of CT-85/11 as shown below:

Table 4. Simplified Abbreviated Injury Scale

Scale Rating	Injury Severity
AIS 1 and 2	Minor
AIS 3 and 4	Moderate
AIS 5 and 6	Life-Threatening

The AIS provides an objective method to assess the severity of each injury separately based purely on type of injury and anatomical location. It does not use physiological parameters to predict severity. The accuracy of the scale has been verified by numerous studies, and today it is used almost universally by researchers studying traumatic injury.

DISCUSSION OF INJURY HAZARDS

Hazard #1: Post-Crash Fires

The data in Table 2 show that thermal injuries are the largest cause of fatalities in non-CRFS equipped helicopters and that a reduction of post-crash fires should be a major goal of occupant protection regulations.

This finding is supported by U.S. Army studies that show the most effective occupant protection concept developed to date is the crash resistant fuel system. Prior to the introduction of CRFS, up to 42 percent of deaths in survivable crashes of U.S. Army helicopters were attributed to fire.[5,6] Studies performed

[5] Haley, J.L., Jr. Analysis of U.S. Army helicopter accidents to define impact injury problems, Linear acceleration of the impact type, Neuilly-sur-Seine, France, AGARD CP 88-71, pp. 9-l to 9-12, 1971.
[6] Singley, G.T., III. Aircraft occupant crash-impact protection, 22(4): 10-12, Army R, D & A, 1981.

since the institution of CRFS in all Army helicopters have shown that post-crash fires in survivable crashes have been practically eliminated. As reported in the ROPWG Task 5 CRFS Report, the expectation is that fuel-fed post-crash fires will also be practically eliminated in survivable crashes of civil helicopters when CRFS is implemented in the entire civil fleet.

While post-crash fire is the most significant safety hazard in civil helicopter crashes, it should be recognized that subsequent studies have demonstrated that many fatally injured victims in post-crash fire accidents also have potentially fatal blunt force injuries, and that, in some cases, fire may have actually been a contributing factor to the fatality rather than the primary cause of the fatality. An FAA autopsy-based study reported by Roskop (2015) of fatally injured occupants of helicopter crashes demonstrated that 80% of thermally injured victims of crashes involving post-crash fire also had blunt force injuries that contributed to their demise.[7] Similarly, in a study of U.S. Army helicopter crashes reported in the Crash Survival Design Guide (1989), thermal injuries in survivable crashes were practically nonexistent since all Army helicopters in this time period were equipped with advanced CRFS.[8] The Army study showed that with thermal injury practically eliminated, the most common mechanism of injury was that the injured occupant sustained blunt force injury due to impacting or being impacted by structure or interior objects (345 occurrences). The second most common injury mechanism was that the individual was exposed to excessive decelerative forces (71 occurrences). The combination of these studies suggests that the CT-85/11 study may have underestimated the effect of excessive flail of the upper body in survivable crashes due to the number of thermally injured occupants in their dataset.

Hazard #2: Occupant Exposed to Excessive Decelerative Forces

The second ranked injury hazard identified by CT-85/11 was injury from excessive decelerative forces when the aircraft and seat allowed excessive loading. Most of the deceleration injuries were spinal injuries due to excessive vertical acceleration. Vertical loading is the most common loading direction producing decelerative injuries to occupants for two reasons:

- Studies have shown that helicopter crashes tend to occur with higher vertical velocities than in other axes since many ground impacts occur in autorotation with their attendant relatively high rates of descent.
- The bottom of the fuselage of helicopters has very limited space to provide crush and, consequently, little available stopping distance to reduce decelerative loading during a vertical crash compared to crashes in the lateral or longitudinal directions.

Other Hazards

The remaining hazards shown in Table 2 are all related to the body making injurious contact with surrounding structure due primarily to inadequate restraint (Hazards #4 and #5), failure of restraint (Hazard #12) including the seat (Hazard #9) and, much less frequently, due to collapse of structure (Hazard #8).

---

[7] Roskop, L. Post-crash fire and blunt force fatal injuries in U.S. registered, type certificated rotorcraft. FAA, CAMI Injury Workshop, April 2015.

[8] Coltman, J.W., Van Ingen, C., Johnson, N.B., Zimmermann, R.E. Aircraft crash survival design guide, Volume II – Aircraft design crash impact conditions and human tolerance. Aviation Applied Technology Directorate, U.S. Army Aviation Research and Technology Activity (AVSCOM), USAAVSCOM TR 89-D-22B, December 1989.

It is important to recognize that occupant restraint in aircraft is a system comprised of numerous components. Even though CT-85/11 and other similar studies separate failure of adequate restraint in a crash into a number of separate categories, all parts of the system must perform properly in order to prevent occupant flailing into structure and consequent contact injuries. In other words, effective restraint requires proper design and functioning of the entire tie-down chain including the occupant to the seat, the restraint to the seat or structure, and the seat to the floor, since failure or poor design in any single area can lead to excessive flail and/or partial or complete ejection of the occupant resulting in blunt force injuries. Also vital to occupant protection from flailing injuries, is that deformation of structure into occupied spaces must be limited in survivable crashes (Hazard #8).

Note that for post-crash fire, 51% of the injuries were life-threatening, whereas for excessive decelerative force, the frequency of life-threatening injuries was only 3%. Likewise, for Hazard #4 (inadequate clearance or restraint), life-threatening injuries comprised only 3% of the total injuries. While this data rightly suggests that post-crash fires are a major hazard, the reader is cautioned against concluding that the small percentage of life-threatening blunt force injuries from Hazards #2 and #4 (excessive decelerative force, and inadequate clearance or restraint) is evidence that they are not a major hazard. This opinion is based on the fact that, although frequently severe, thermal injuries occur far less frequently than blunt force injuries from flailing or injuries from excessive vertical deceleration, particularly as CRFS becomes more prevalent. It is also important to note that Army crash data shows that most excessive decelerative force injuries are typically spinal injuries potentially preventable with an energy absorbing seat, and many of the victims of spinal injuries were paraplegic, and some, quadriplegic.[9] Although not immediately threatening to life, spinal cord injuries result in a shorter life expectancy and the cost and suffering involved is far greater than that for most blunt force injuries. This observation does not change the hazard ranking of this particular hazard, however, it does reflect on the importance of preventing these types of injury.

APPLICABILITY OF CT-85/11 DATA TO CURRENT ROTORCRAFT FLEET

Although CT-85/11 was written more than 30 years ago, the ROPWG determined that the data in CT-85/11 was useful for the purposes of making recommendations of CRSS features for newly-manufactured rotorcraft. This determination was based on the following factors:

- Roskop demonstrated that the civil rotorcraft fleet has changed relatively little over that time period with respect to incorporation of occupant protection standards with the exception of the introduction of a requirement for shoulder restraint in all seats. This finding is supported by the fact that only 16% of the current rotorcraft fleet complies with current 27/29.952 standards and approximately 10% of the fleet complies with the current 27/29.561, 27/29.562, and 27.785 standards.
- The data in CT-85/11 show that the accident impact velocity distribution varied little with helicopter size. Therefore, changes in the makeup of the helicopter fleet over the last 30 years would not be expected to result in a significantly different impact velocity distribution for helicopters presently manufactured.

---

[9] 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.

EFFECTIVENESS OF CRSS FEATURES

BACKGROUND

As discussed previously, even though some crashworthiness features have been incorporated into the civil helicopter fleet to various degrees over the past several decades, it has been 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. In the current system, to perform injury and/or crash impact studies, prospective researchers must initiate independently financed, prospective studies with NTSB permission to attend crash sites to acquire the necessary data. Since this process is lengthy and expensive for individual researchers, it is unlikely additional detailed studies such as that reported in CT-85/11 will be performed in the near future unless sponsored by a governmental entity. Some manufacturers perform independent crash investigations of their aircraft, but they only investigate crashes of their own aircraft and they rarely publish their findings.

In lieu of independent or FAA sponsored research, one can rely on military crashworthiness studies to acquire applicable data. However, one needs to exercise caution in applying military concepts and designs to civilian applications, as the military operates different helicopters than those used in civil operations, they perform different missions, and their aircrew population consists almost entirely of young, healthy, primarily males under the age of 40. For instance, an excellent example of the difference between military and civil application is energy absorbing seats. While the limit load (stroking force) required for military seats was selected to be 14.5g based upon the military aviator population, subsequent cadaver testing on a greater range of individuals established a recommended limit load for civil seats at 11-12g to account for the general civilian population expected to fly in helicopters[10].

Nevertheless, accident data from military helicopters has proven valuable in developing the occupant protection standards that are the subject of this study. In particular, the U.S. Army has developed and studied numerous pieces of occupant protection equipment, and has developed helicopters that had crashworthiness as one of their primary design goals (UH-60 Black Hawk, AH-64 Apache). CRSS effectiveness data from these and other military helicopters are discussed in this section.

Another source of data relating to the effectiveness of CRSS is the automobile literature. Although automobile structures and crash dynamics are arguably different from helicopter crashes, both modes of transportation involve protecting humans from injury and the human is the same regardless of what type of vehicle he is occupying during a crash.

Regardless of the mode of transportation involved, there are surprisingly few studies documenting the effectiveness of the various crashworthiness concepts, regulations, and equipment that have been adopted. Most studies simply identify and quantify the current hazards in a selected dataset of crashes without analyzing the effectiveness of the crashworthiness features or standards applicable to the aircraft under study compared to earlier aircraft that were certified to different standards.

---

[10] Coltman, J.W. et al. Crashworthy crew seat limit load optimization through dynamic testing. Crashworthy Design of Rotorcraft. Georgia Institute of Technology Center of Excellence for Rotary-Wing Aircraft Technology, Atlanta, GA, 1986.

The two exceptions to this are CRFS and, to a lesser extent, energy attenuating seats. As discussed above, the effectiveness of CRFS has been assessed in numerous studies of military helicopter crashes, showing the overwhelming effectiveness of these systems in preventing fuel-fed, post-crash fires in survivable crashes. The effectiveness of energy attenuating seats has also been assessed in several studies, particularly of the UH-60 Black Hawk showing a marked reduction in spinal injury even in extreme vertical crashes.[11] The following sections provide a review of what has been published concerning the effectiveness of the CRSS concepts covered by the current FAA airworthiness standards.

ENERGY ABSORBING SEATS AND LANDING GEAR

The UH-60 Black Hawk was the first helicopter built with crashworthiness as a primary design objective. It was introduced into the Army in the early 1980's and its crashworthiness features have proven to be extremely effective in preventing injuries in survivable crashes.[12] Most relevant to this discussion, the pilot seats (in combination with the landing gear and structure) were designed to absorb significant energy in a vertical impact, with the goal of protecting occupants from serious injury at vertical impact velocities up to 42 ft/s. At the time of its design, the 42 ft/s requirement was judged to represent the 95th percentile survivable vertical crash pulse for Army helicopter crashes. Studies of crashes of the Black Hawk have demonstrated that pilots are surviving crashes with vertical velocities exceeding 60 ft/s and accelerations at the aircraft floor up to 60g without significant spinal injury.

It is important to recognize that the landing gear of the Black Hawk constitute an important part of the vertical energy attenuating system. The landing gear were designed to prevent fuselage-ground contact for vertical crashes up to 35 ft/s, whereas conventional skid gear in other Army helicopters were designed to prevent fuselage-ground contact only up to 10-15 ft/s. One disadvantage of the Black Hawk system is that its landing gear are both expensive and extremely heavy compared to conventional landing gear. Also, relying on the landing gear to absorb a major portion of the energy of a vertical crash requires that the helicopter crash in a relatively upright orientation and on a relatively hard surface since the stroking of the gear is defeated on soft surfaces such as a water impact or impact into swampy terrain. For these reasons, it is unlikely that a similar system would be adopted for civil applications. However, due to the importance of increasing vertical energy attenuation in most helicopters, some manufacturers are considering novel approaches to the problem such as a vertical energy attenuating system that would combine energy attenuating seats with under-fuselage mounted air bags.

In a study of crashes of another military helicopter, the OH-58 Kiowa, it was shown that 22.5% of occupants of the pilot seats suffered some degree of disability from spinal injury.[13] The authors of the study estimated that if the pilot seats were modified to sustain a 30 ft/s vertical impact without transmitting injurious loads to the occupants, 80% of spinal injuries in survivable accidents would be substantially mitigated. Subsequently, such a seat was designed and implemented in two new versions of the OH-58 - the OH-58D and TH-67 training helicopter. Although there have been insufficient crashes of these helicopters to fully assess the performance of these seats, anecdotally, several crashes of the

---

[11] Shanahan, D.F. Crash experience of U.S. Army Black Hawk helicopters. Aircraft Accidents: Trends in Aerospace Medical Investigation Techniques. Neuilly-sur-Seine, France, AGARD CP 532, pp. 40-1 to 40-9, 1992.
[12] Shanahan, D.F. Crash experience of U.S. Army Black Hawk helicopters. Aircraft Accidents: Trends in Aerospace Medical Investigation Techniques. Neuilly-sur-Seine, France, AGARD CP 532, pp. 40-1 to 40-9, 1992.
[13] Ibid.

TH-67 (which had 14 CFR § 27.562 certified (TSO-c127a) seats installed) have not resulted in spinal injury to occupants.

BELT RESTRAINT SYSTEMS

Belt restraint systems were first used in powered aircraft, apparently not as a means of crash protection, but as a means to keep pilots in their seats in open-cockpit aircraft during aerobatic maneuvers.[14] The first restraints were 2-point, leather restraints with metal buckles, which proved to be very effective in that application. Interestingly, at that time, many pilots believed that it was better to be thrown free of the aircraft in a crash than to be restrained inside, so it was rumored that some pilots would remove their seat belt prior to landing. Subsequent crash experience demonstrated the safety benefits of using belt restraint during all aircraft operations.

When introduced in automobiles, lap belts were useful for lower torso restraint, but did little to prevent upper torso and extremity flailing injuries. Consequently, the 3-point belt was later integrated into most automobiles. Rouhana et al. reported that National Highway Traffic Safety Administration (NHTSA) statistics showed in 2001 that 3-point belt systems were estimated to have saved over 12,000 lives and reduced the severity of injury to thousands of other occupants, primarily by reducing occupant impacts with the interior of the vehicle.[15] Belt use was estimated to be about 75% at that time and, if use were 100%, an additional 9,000 lives would have been saved.

The 3-point, lap-shoulder harness used in automobiles was proven to have some deficiencies. In certain crashes, primarily far-side impacts, the occupant would frequently slip out of the shoulder belt causing him to lose upper torso restraint, which would leave him susceptible to flailing injuries if a subsequent impact occurred. Also, the typical lap-shoulder belt configuration was shown to cause unsymmetrical loads to the thorax resulting in lateral chest displacement and consequent rib fractures and other thoracic injuries.

To solve these problems, 4-point and greater belt systems were developed and applied mostly to racecars and some other special purpose vehicles. These belt systems were very effective. Melvin et al. conducted a study of Indianapolis Racecar crashes and showed that drivers using 5 or 6-point restraints could survive frontal collisions without chest injury at decelerations exceeding 100g and changes of velocity (delta v) up to 72 mph.[16] Prior to this study the limit of human tolerance without serious injury was estimated to be approximately 40g.[17] What the Melvin study demonstrates is that survival in crashes is not particularly limited by human tolerance, but rather by how well the occupant is restrained and protected from intruding structure.

---

[14] Snyder, R.G. Occupant restraint systems: Where we've been, where we are and our current problems. Society of Automotive Engineers, SAE 690243, 1969.

[15] Rouhana et al. Biomechanics of 4-point seat belt systems in frontal impacts. Stapp Car Crash Journal, 47: 367-299, 2003.

[16] Melvin, J.W. et al. Biomechanical analysis of Indy race car crashes. Society of Automotive Engineers, SAE 983161, 1998.

[17] Coltman, J.W. Aircraft crash survival design guide: Volume II – Aircraft design crash impact conditions and human tolerance. Aviation Applied Technology Directorate, U.S. Army Aviation Research and Technology Activity, USAAVSCOM TR 89-D-22B, 1989.

Rouhana et al. conducted a study to compare the effectiveness of a 3-point, pretensioned, load-limited restraint system with a 4-point, V-configuration belt system with a central buckle on the lap belt.[18] They found that the 4-point system shifted loads from the thorax to the clavicles and pelvis, thus reducing the potential for serious injuries such as rib fractures and most intra-thoracic injuries. The 4-point system also eliminated the problem of asymmetrical loading to the chest, and in tests using cadavers in 40 km/h (25 mph) frontal sled impacts, chest compression was reduced to zero as was the incidence of submarining under the lap belt.

Based on these and similar data, it can be concluded that 3-point belt systems are extremely effective in reducing upper body flail with a resulting dramatic reduction in blunt force injuries resulting from body contact with structure. Additionally, the 4-point and higher belt systems provide an incremental increase in safety over the 3-point system, particularly in multiple impact crashes as frequently occur in helicopter accidents. The primary disadvantage of 4-point systems is that they are more difficult to don than a typical 3-point belt system, as they require the attachment of the two shoulder belts to the central buckle rather than the single action involved in donning a standard 3-point lap-shoulder belt system.

Clearly belt restraint systems are essential for preventing blunt force injuries in survivable crashes. Furthermore, U.S. Army data show that after post-crash fires were eliminated as a source of injury in survivable crashes, blunt force injury due to impact of the body with structure due to poor restraint performance or failure of the occupant tie-down chain accounted for approximately 60% of all injuries in survivable Army helicopter crashes.[19] Consequently, it is clear that any improvement that reduces body flail will be potentially important in reducing these types of injuries.

RESTRAINT OF OCCUPANTS AND ITEMS OF MASS IN CABIN

The requirements for restraint of occupants within the cabin as stated in 27/29.561(b)(3) (and indirectly required by 27/29.562(b)(2)) are closely related to the issues of restraint discussed in the preceding section since these regulations address a part of the total tie-down chain for the occupants. As discussed above, blunt force injuries caused by inadequate restraint is probably the most prevalent injury mechanism in survivable helicopter crashes when post-crash fire is practically eliminated by CRFS. This makes effective restraint an essential element of occupant survival regulations. A well-designed belt restraint system will provide occupants little protection if the seat and supporting structures fail because they are not able to withstand the inertial loads induced by a survivable crash. Although we could find no studies to justify the load factors specified in 27/29.561(b), it should be noted that a very well restrained human occupant is capable of withstanding up to 100g impact in the forward direction, while the ultimate load factor required in 27/29.561(b)(3) is 16g, a fraction of human tolerance, particularly considering this is a static load factor.

Although we could find no studies proving that poorly restrained items of mass in the cabin were hazardous in survivable helicopter crashes, anecdotal evidence and common sense suggest that high

---

[18] Rouhana et al. Biomechanics of 4-point seat belt systems in frontal impacts. Stapp Car Crash Journal, 47: 367-299, 2003.
[19] 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.

mass items that break loose in a crash become projectiles and a significant hazard if the items strike an occupant. Therefore, it is reasonable to require that the supporting structure of these items be able to withstand significant inertial loads. Ideally, these load factors would be no less than expected in an upper level survivable crash. This is particularly important in certain operations such as EMS where there are numerous items of mass in the cabin that will become injury hazards if they break free of their supporting structure.

RESTRAINT OF ITEMS OF MASS ABOVE AND BEHIND PASSENGER COMPARTMENT

CT-85/11 identifies structural collapse leading to blunt force injury as the eighth most important ranked hazard. This hazard is related to the inertial load factors specified in 27/29.561(c) although structural collapse also occurs for other reasons such as direct impact to the front or sides of the cabin. No known study delineates the portion of injuries attributed to structural collapse caused by inadequate restraint (support) of high mass items above and behind the passenger compartment versus the portion caused by other mechanisms. Similarly, a study of Army crashes analyzed design deficiencies contributing to injuries in survivable crashes and found that in crashes where a deficiency could be associated with an injury, 16% of the injuries were attributed to "structure collapsed into occupied space".[20]

Based upon these studies, it is evident that structural collapse in survivable crashes of civil helicopters is a potential hazard, but it cannot be determined the extent to which high mass item retention has been involved as a mechanism of injury compared to other potential mechanisms. Therefore, the ROPWG believes that requiring compliance with the load factors specified in 27/29.561(c) would have a relatively low but indeterminate effect on improving crash safety in newly-manufactured, legacy helicopters.

RESTRAINT OF FUEL TANKS BELOW CABIN FLOOR

There is no data in applicable crash studies to suggest that loss of retention of fuel tanks below the floor of civil or military helicopters is a significant hazard. In fact, we were not able to identify any study that mentioned this factor as more than a potential hazard. Considering these factors, requiring compliance with the current inertial load factors specified in 27/29.561(d) is not expected to result in a substantial increase in safety for newly manufactured, legacy helicopters.

COMBINED EFFECT OF CRASHWORTHINESS FEATURES

In the late 1970's and early 1980's, the U.S. Army developed two new helicopters that were designed to meet modern crashworthiness standards, which were later codified in MIL-STD-1290A. The UH-60 Black Hawk and the AH-64 Apache designs incorporated crashworthiness features in all aspects of their designs including the fuel system, the structure, landing gear, and high mass item retention. At least two studies of the effectiveness of the crashworthiness designs of these helicopters have been performed in order to confirm the overall effectiveness of their designs in preventing injury, particularly fatal injury, and compared their performance to more conventionally designed helicopters.

---

[20] 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.

Shanahan analyzed survivable crashes of the UH-60 Black Hawk and compared its performance to the UH-1 Huey, which it ultimately replaced.[21] The mortality rate across all accidents over the study period was calculated for each model by determining the number of fatalities occurring within 5 ft/s increments of vertical velocity and dividing by the total number of occupants exposed to impacts with vertical velocities within the increment. This data was then plotted to graphically show, for each model, the change in mortality as a function of vertical impact velocity. The result is Figure 1, which was extracted from the study.

As shown in Figure 1, the UH-60 Black Hawk is able to provide protection to its occupants in considerably more severe crashes than the conventionally designed UH-1 Huey with a CRFS. While both models demonstrate a threshold velocity above which mortality essentially becomes 100%, this threshold occurs in the UH-1 Huey at a vertical velocity of approximately 40 ft/s, whereas it occurs at a much higher velocity (60 ft/s, more than double the kinetic energy) in the UH-60 Black Hawk. While this data is specific to mortality rates in two models of military helicopters, it is reasonable to conclude that a civil helicopter with similar crashworthiness design features (energy absorbing seats and landing gear and increased structural crashworthiness) would provide comparable protection against spinal injury and blunt force injuries.

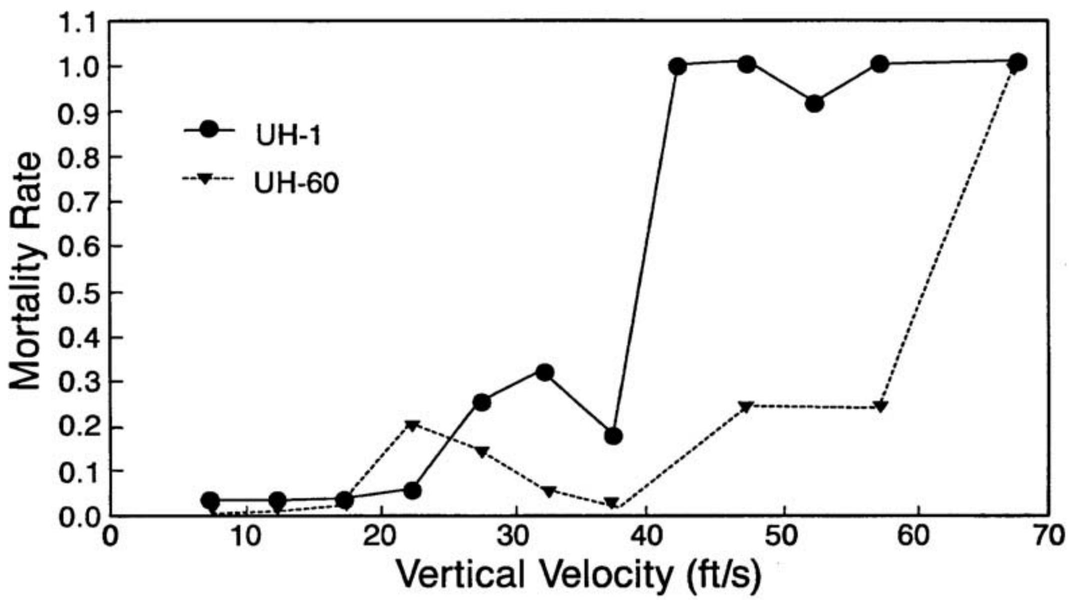

Figure 1: Mortality vs. Vertical Impact Velocity for UH-1 Huey and UH-60 Black Hawk

A similar result was subsequently documented when Crowley compared mortality versus impact vertical velocity for U.S. Army attack helicopters.[22] He compared the conventionally designed AH-1 Cobra with a CRFS to the AH-64 Apache, which, like the Black Hawk, was designed with crashworthiness as a primary design goal. Figure 2 is excerpted from the Crowley report, and shows the same threshold vertical

[21] Shanahan, D.F. Crash experience of U.S. Army Black Hawk helicopters. Aircraft Accidents: Trends in Aerospace Medical Investigation Techniques. Neuilly-sur-Seine, France, AGARD CP 532, pp. 40-1 to 40-9, 1992.

[22] Crowley, J.S. Benefit of crashworthy design in attack helicopters: A comparison of accident fatality rates. RTO HFM Symposium on “Current Aeromedical Issues in Rotary Wing Operations”, San Diego, CA, RTO MP-19, 1998.

velocity phenomenon where mortality essentially becomes 100% as was demonstrated in Figure 1. For the Cobra, this velocity is approximately 35 ft/s and for the Apache, the threshold velocity is approximately 55 ft/s. As was the case for the previous example, Figure 2 demonstrates that the crashworthiness design of the Apache provided a considerably higher degree of protection for occupants compared to the conventionally designed AH-1 Cobra.

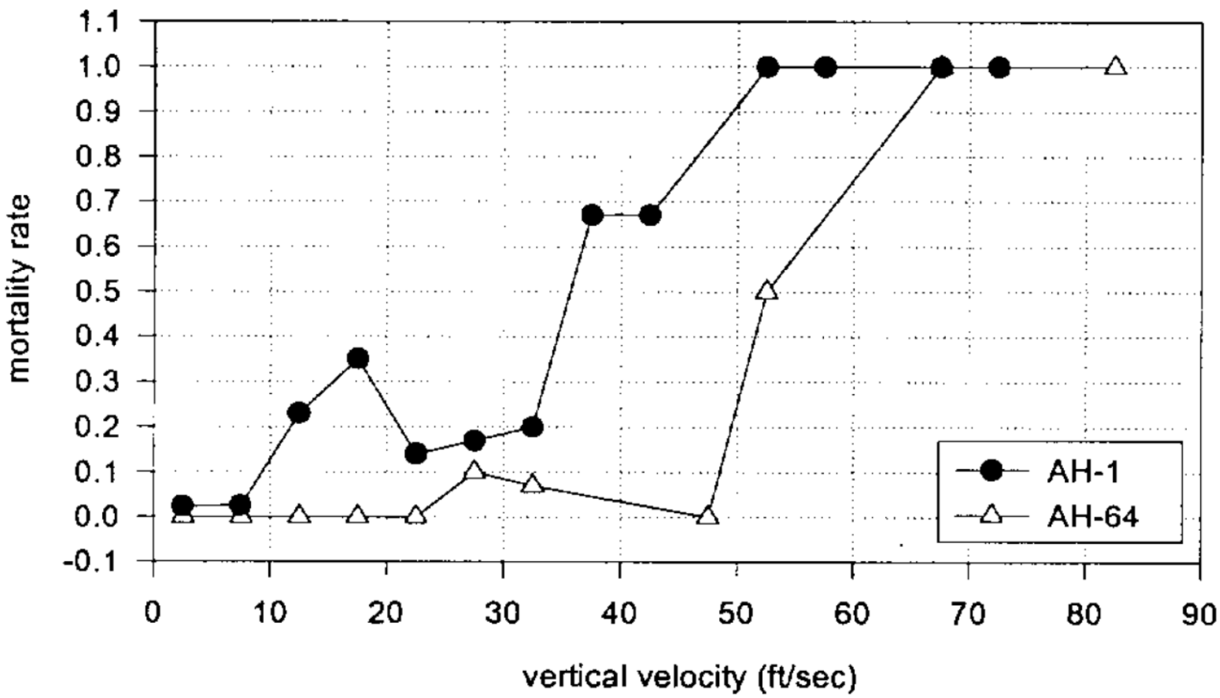

Figure 2: Mortality vs. Vertical Impact Velocity for AH-1 Cobra and AH-64 Apache

The combined analysis of the UH-1 Huey, UH-60 Black Hawk, AH-1 Cobra and AH-64 Apache demonstrate the high degree of effectiveness of implementing existing crashworthiness features into modern helicopters.

REDUCED VELOCITY VERTICAL SEAT TESTS

BACKGROUND

Excessive vertical decelerative forces have been found to be a significant injury hazard in civil and military helicopter accidents. As a result, energy absorbing seats were introduced into civil and military helicopters, and in the case of military helicopters, accident data shows that they have been very effective in reducing serious spinal injury in vertical impacts. It is expected that future analysis of the performance of energy absorbing seats in civil helicopter crashes will show a similar reduction of spinal injuries, but performance data of seats in civil helicopter crashes is not currently available.

For civil helicopters, 27/29.562(b)(1) require that all seats in newly certified type designs pass a dynamic seat test with a test velocity of 30 ft/s when the rotorcraft's longitudinal axis is "canted upward 60^{o} with respect to the impact velocity vector". This results in a vertical velocity component with respect to the seat of 26 ft/s (30 ft/s * cos(30°)). This velocity was selected by the FAA based on the data in CT-85/11, which showed that 95% of all "significant survivable" accidents (survivable and partially-survivable accidents) had vertical impact velocities less than or equal to 26 ft/s. Additionally, the regulation requires that the loads in the lumbar spinal column, shoulder harness, and head injury criteria (HIC) do not exceed values set at the expected threshold for serious injury. The resulting test was intended to ensure that for survivable accidents up to and including the 95th percentile vertical impact velocity, most occupants will not suffer significant spinal injuries.

OBSTACLES TO FULL COMPLIANCE WITH VERTICAL DYNAMIC SEAT TEST

While the reduction of spinal injuries is a high priority for crash safety, the ROPWG determined that there were a number of currently manufactured, legacy Part 27 helicopters where the requirements of 27.562(b)(1) could not be implemented in certain seating positions, because meeting the requirement for vertical energy absorption of the seat requires a minimum stroking distance and this distance was not practicably available.[23] This limitation of available stroke distance occurred in several seating positions in small and medium size helicopter models where the seats are mounted on top of fuel tanks or control system components. The Aircraft Crash Survival Design Guide (CSDG) reported that for the 50th through 95th percentile male occupants, the required stroke distance for a seat with the recommended energy absorber load limit of 12g would be 3.8 – 4.5 inches.[24] Providing this amount of stroking distance would reduce the fuel capacity and/or occupant capacity in these models to a level where the OEM or operator would be forced to discontinue that model.

One example is Bell's 206A/B, 206L-series, and 407-series. As shown in Figure 3, the Bell 206B was stretched to make the 206L, and the 407 was modified from the 206L by adding a 4-bladed rotor system.

---

[23] Rotorcraft Occupant Protection Working Group. Tasks 1 and 2: Cost-benefit analysis report to the Aviation Rulemaking Advisory Committee (ARAC). November 10, 2016.

[24] Coltman, J.W. Aircraft crash survival design guide: Volume II – Aircraft design crash impact conditions and human tolerance. Aviation Applied Technology Directorate, U.S. Army Aviation Research and Technology Activity, USAAVSCOM TR 89-D-22B, 1989.

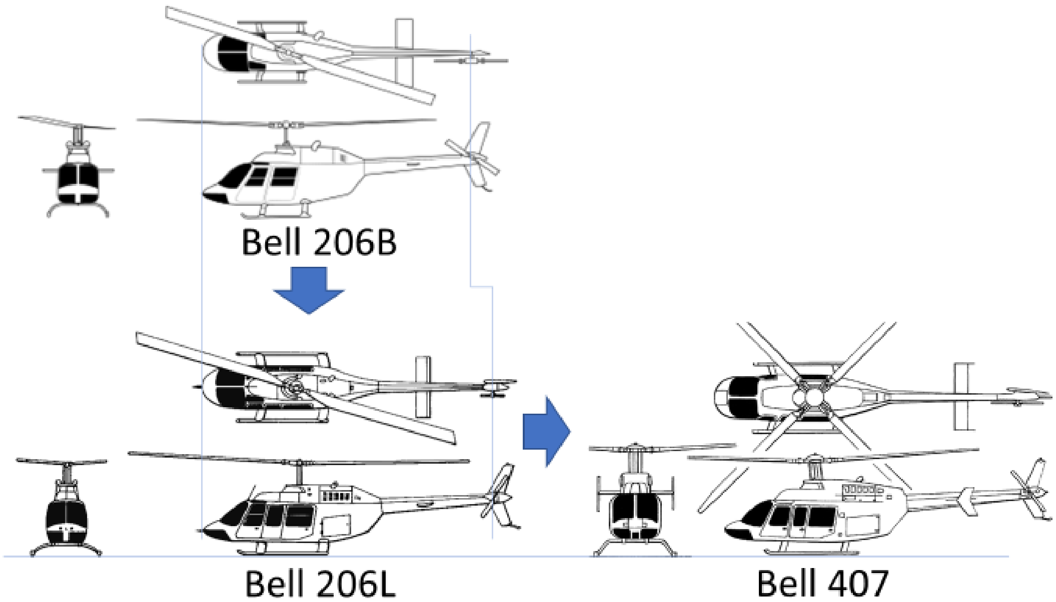

Figure 3: Evolution from the Bell 206B to Bell 206L to Bell 407

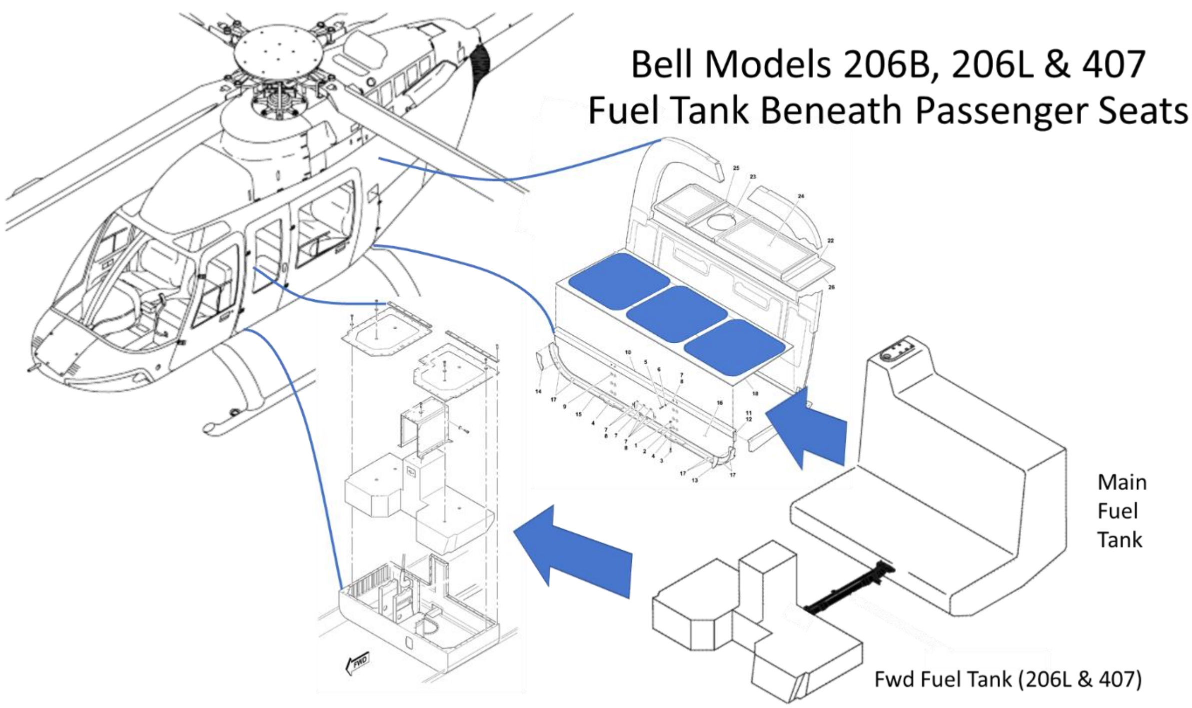

Figure 4: Bell 206/407 Fuel Tank Immediately Below Passenger Seats

This series of rotorcraft has one or more integral fuel tanks immediately below the passenger seats. This configuration, shown in Figure 4, combined with the fixed cabin ceiling height limits the seat stroke distance available. Providing the necessary stroke distance by reducing fuel tank height would result in an economically non-viable reduction in fuel quantity. By reducing the minimum required test pulse velocity, the required seat stroke distance can be reduced to the point where introduction of a stroking seat becomes feasible. Although this illustrates the problem for one particular model helicopter, there are other current production helicopters with similar configurations or with seats mounted above control system components that would also limit seat stroking distance.

Note that these obstacles are only known to exist for some Part 27 helicopters; all currently-produced Part 29 helicopters are believed to have sufficient stroking distance available to meet the requirements of 29.562(b)(1).

REDUCED VELOCITY VERTICAL DYNAMIC SEAT TESTS

In an effort to minimize disruption to the industry that would be caused by a requirement for full compliance with 27.562(b)(1), the ROPWG sought an alternative requirement that could provide much of the benefit of full compliance, but with substantially reduced fuel and occupant capacity penalties.

The ROPWG has determined that a reduced velocity vertical dynamic seat test could meet this objective by virtue of its reduced seat stroking distance compared to a fully-compliant seat. Specifically, as discussed in the Recommendations section of this report, the ROPWG is proposing the following alternative requirement for newly manufactured, legacy Part 27 helicopters:

> *"Where practicable, all seats must meet the requirements of 27.562(b)(1). Where compliance with 27.562(b)(1) is not practicable in certain seats due to existing design constraints, those seats may instead demonstrate compliance with a dynamic vertical seat test with the following criteria:*
>
> - *The test impact velocity is 25.0 ft/s*
>   - *(the vertical component of the test impact velocity is therefore 21.7 ft/s)*
> - *Peak floor deceleration must occur in not more than 0.028 seconds,*
> - *Peak g-load must reach a minimum of 27.5 g,*
> - *ATD (Anthropomorphic Test Device) injury criteria are unchanged from 27.562(c),*
> - *All other relevant criteria from 27.562 remain valid"*

The rationale for the 21.7 ft/s vertical test velocity is discussed below. A detailed technical discussion of the other test parameters is included in Appendix E.

Note that these test criteria would allow the test labs to continue using the same test equipment, test dummies, instrumentation, and procedures as is currently used for the 26 ft/s vertical seat tests, minimizing the effort and expense required to conduct this alternative test. Also note that the ROPWG is recommending that Part 29 helicopters meet the current 30 ft/s (with vertical component of 26 ft/s) requirement for all seats.

RATIONALE FOR 21.7 FT/S VERTICAL IMPACT VELOCITY

The 26 ft/s vertical impact velocity of 27/29.562(b)(1) was chosen to represent the 95th percentile vertical impact velocity for survivable accidents. The data supporting this velocity comes from CT-85/11, which determined the distribution of vertical impact velocities in survivable civil helicopter accidents. The 95th percentile standard was chosen as a reasonable compromise, *in newly designed helicopters*, between crash safety and weight and structural considerations. This approach also mirrored the approach taken by Army experts to establish military crashworthiness standards.

While the 95th percentile level was deemed a reasonable compromise for new designs, the constraints present in previously designed helicopters make it much more difficult to implement major changes such as stroking seats. As a result, the 95th percentile level is probably above the level of diminishing returns for some previously designed helicopters since the incremental increase in crash safety will be offset by the significant design penalties and disruptions incurred in making the necessary changes in some seating positions. This issue is discussed in the ROPWG Task 2 report, which presents data concerning the potential disruption of full compliance with 27.562(b)(1).

For previously certified, legacy helicopters with seating positions that cannot accommodate the requirements of 27.562(b)(1), a reduced crash percentile and the corresponding vertical impact design velocity for helicopters were explored. The ROPWG analyzed the data in CT-85/11 for vertical impact velocity distribution data for survivable crashes. This data is reproduced in Figure 5 below, along with additional annotations as explained below.

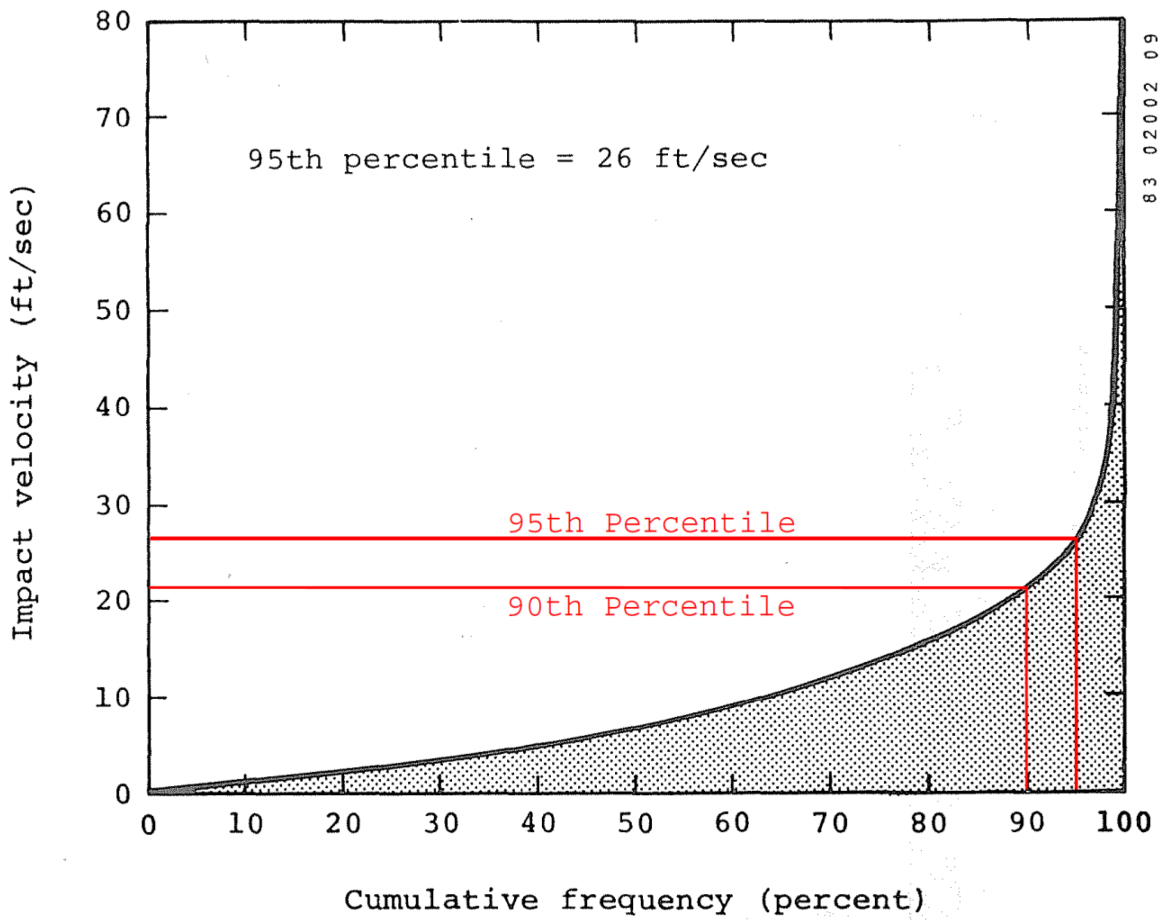

Figure 5: Vertical Impact Velocity Distribution for Civil Significant Survivable Accidents

Reproduced from CT-85/11 Figure 7

(95th and 90th percentile lines added by ROPWG)

As can be seen in Figure 5, the 26 ft/s vertical impact velocity specified in 27/29.562(b)(1) corresponds to the 95th percentile vertical impact velocity occurring in survivable accidents. Also note that the 90th percentile accident corresponds to a 21.7 ft/s vertical impact velocity. The ROPWG believes that this 90th percentile vertical velocity coverage level, and the corresponding 21.7 ft/s vertical impact test velocity, is a reasonable compromise between safety and disruption for some previously certified, Part 27 legacy helicopters, for reasons as follows:

- Calculations presented in Appendix E show that a seat tested to a vertical velocity component of 21.7 ft/s would provide approximately 70% of the expected injury reduction of a 26 ft/s (vertical velocity component) seat.
- As shown in Appendix E, the ROPWG estimates a required stroking distance of 2.8" for a 21.7 ft/s vertical impact test, compared to 4.6" for a 26 ft/s test.
    - A stroking distance of 2.8", and the corresponding 21.7 ft/s vertical test velocity, is near the maximum that can likely be incorporated into several currently manufactured, legacy helicopters.

- Stroking distances (and by extension, vertical test velocities) even slightly above these values would likely lead to the major disruptions and the discontinuation of certain models previously discussed.

Since a 21.7 ft/s vertical dynamic seat test would provide most of the protection of a 26 ft/s seat, but with much less disruption to the industry, the ROPWG believes that for seating positions in Part 27 helicopters where it is not practicable to accommodate 26 ft/s vertical velocity requirement seats, a 21.7 ft/s vertical velocity requirement seat provides a reasonable compromise for increasing occupant protection, in newly-manufactured legacy helicopters, while minimizing the negative effects on OEMs and operators.

TECHNICAL DISCUSSION OF VERTICAL DYNAMIC SEAT TEST CONSIDERATIONS

Appendices D and E contain a detailed technical discussion of the following 21.7 ft/s vertical dynamic seat test considerations:

- Detailed calculation of benefit from reduced velocity dynamic seat tests
- Determination of test pulse shape, peak deceleration, and peak g-load
- Determination of required seat stroking distances

RECOMMENDATIONS

METHODS

In order to perform a cost-benefit estimation of ROPWG CRSS recommendations for newly manufactured, legacy rotorcraft, it was necessary for ROPWG to define the characteristics of what it considered an appropriate set of regulations based upon its analysis of the crash data discussed above. Without this information, OEMs could not estimate the costs of meeting the recommended regulations. Therefore, the recommendations are presented first, followed by estimates of the cost/weight penalties and benefits.

The ROPWG recommendations for CRSS regulatory compliance with 27/29.561, 27/29.562, and 27/29.785 for newly manufactured legacy aircraft are summarized below in Table 5, and discussed in detail following the table. The ROPWG recommendations for newly manufactured, legacy helicopters were determined in consideration of the following:

- The hazard ranking applicable to the regulation under consideration
- The practicability of applying the regulation to newly manufactured, legacy helicopters, including consideration of the cost and weight penalty estimates provided by the OEMs, and the potential disruption to the helicopter industry if certain models were discontinued
- The expected benefit of the regulations under consideration, based upon the data presented earlier in this report

There were a number of helicopters where the requirements of 27.562(b)(1) could not be implemented in certain seating positions because meeting the requirement for vertical energy absorption of the seat requires a minimum stroking distance and this distance was not practicably available. This occurred in several small to medium helicopter models where the rear seats are mounted on top of fuel tanks. Providing the necessary stroking distance would reduce the fuel capacity and/or occupant capacity in these models to a level where the OEM or operator would be forced to discontinue that model. To accommodate these helicopters where full compliance with 27/562(b)(1) was impracticable at certain seating positions, a compromise solution for these specific seating positions is proposed here, and detailed in the section Reduced Velocity Vertical Seat Tests. While the ROPWG is aware that the FAA asked for a recommendation on “which Paragraphs of each Section for the existing occupant protection standards cited in the referenced Federal Register Notice can be made effective for newly manufactured rotorcraft”, the ROPWG members believe that the inclusion of a reduced velocity vertical seat test is required in order to produce effective CRSS regulations for all newly manufactured, legacy helicopters.

It should be stressed that the ROPWG is recommending these regulatory requirements and modifications in the context of newly manufactured, legacy helicopters only. While the data in this report could conceivably be used in consideration of modifications to the regulations as they apply to new type designs, such recommendations are beyond the scope of the ROPWG tasking. This report should not be interpreted as making any recommendations for or against the amendment of current CRSS regulations.

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' Comments section at the end of this report. Members were also free to concur with the report, but include additional statements pertaining to the study.

Note that unless otherwise stated, all recommendations apply to both Part 27 and Part 29 helicopters.

CRSS RECOMMENDATIONS

The ROPWG recommendations for CRSS regulatory compliance with 27/29.561, 27/29.562, and 27/29.785 for newly manufactured legacy aircraft are summarized below in Table 5, and discussed in detail following the table.

Table 5. CRSS (27/29.561, 27/29.562 and 27/29.785) Regulatory Recommendations for Newly Manufactured, Legacy Helicopters* **Unless otherwise noted, recommendations apply to both Part 27 and Part 29 helicopters.*		
Regulation	**Recommendation**	**Notes**
27/29.561(b)(3): Restraint of occupants and items of mass in cabin	Recommended	The loss of occupant retention and flailing are among the greatest hazards in helicopter crashes, and anecdotal evidence suggests that items of mass in the cabin are a potential hazard as well. Also, the associated cost and weight penalties are relatively small, and no other significant impediments to meeting these requirements were identified.
27/29.561(c): Restraint of items of mass above and behind cabin	NOT Recommended	Items of mass above and behind the cabin are a relatively low priority hazard according to CT-85/11, and no known evidence shows that existing levels of tie-down strength are inadequate. Also, the associated cost and weight penalties would be severe.
27/29.561(d): Restraint of fuel tanks below floor	NOT Recommended	No evidence from crash reports supports the contention that failure of below floor fuel tank retention is a hazard in legacy helicopters. Also, the associated cost and weight penalties would be significant.
27/29.562(b)(1): Dynamic seat testing, Vertical Direction	Part 27: Recommended w/changes	Reduction in spinal injuries is a high priority for occupant protection, but some legacy Part 27 models have insufficient space under certain seats to meet the full requirement, which would lead to the discontinuation of these models. However, seats rated to a 21.7 ft/s vertical impact could be incorporated into nearly all seats in existing helicopters, and would provide 71% of the protection afforded by fully compliant seats. The ROPWG therefore recommends full compliance in those seats where practicable, and a 25 ft/s (21.7 ft/s vertical component) test requirement in only those seating positions where full compliance is not practicable.
	Part 29: Recommended	Reduction in spinal injuries is a high priority for occupant protection. Due to their greater size and near universal incorporation of bolt-in seats, the cost and weight penalties associated with full compliance are relatively small for Part 29 helicopters. There is no known significant impediment to requiring the full regulation for Part 29 helicopters other than a possible small reduction in seating capacity in some models.

27/29.562(b)(2): Dynamic seat testing, Horizontal direction	Recommended	The loss of occupant retention and flailing are among the greatest hazards in helicopter crashes. Also, the associated cost and weight penalties are relatively small, and no other significant impediments to meeting this requirement were identified.
27/29.785: Seats, berths, litters, safety belts, and harnesses	Recommended	While the group found that most aspects of this regulation are also covered by other regulations, compliance with the regulation is recommended as there would be a modest safety benefit, and the associated costs and weight penalties are relatively small. Note that the text of 27/29.785 references 27/29.561 and 27/29.562. Therefore, although no changes are required to the intent of the regulation, revised/additional text may be required to clarify that regulations referenced in the text of 27/29.785 are, as applicable, the modified regulations mandated for newly manufactured, legacy helicopters.
Requirement for full compliance 10 years after approval of new CRSS rules	NOT recommended	Since the cost and weight penalties required for full compliance are due to engineering challenges as opposed to development schedules, delaying full compliance by 7-10 years will not result in appreciably lower costs, weight penalties, or disruptions caused by discontinued models.

DISCUSSION OF RECOMMENDATIONS (TABLE 5)

27/29.561(b)(3): Restraint of occupants and items of mass in cabin

Recommended

Accident investigations have demonstrated that loss of occupant retention due to failure at any point in the occupant tie-down chain can be catastrophic due to the released occupant impacting interior or intruding structures and, potentially, being completely ejected from the aircraft. Although, as demonstrated in Table 2, this injury mechanism is not particularly common (Hazard Ranking #9 and #12), injuries caused by seat failures result in a high percentage of life-threatening injuries (21%). Furthermore, the OEMs reported that the cost and weight penalties for implementing the occupant retention portion of 27/29.561(b)(3) were fairly low, and working group members were not able to identify any other impediments to implementing this section of the rules into currently manufactured, legacy helicopters.

While the working group did not find specific data on the frequency or resulting injuries related to loss of retention of cabin interior items, medical evacuation operators identified this as a very significant hazard in their operations. Additionally, the OEMs reported that relatively low cost and weight penalties would be required for implementation of this section of the rules for newly-manufactured, legacy helicopters.

In consideration of the above, implementation of this rule is recommended for currently manufactured, legacy helicopters.

27/29.561(c): Restraint of items of mass above and behind cabin

Not Recommended

The implementation of this rule in previously certified helicopters has been assessed by OEMs as being extremely impracticable 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. Table 2 further 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 impracticable in many helicopters, the ROPWG deemed implementation of this rule in legacy helicopters to be extremely costly without a reasonable expectation that implementation would yield a significant benefit in safety. Therefore, implementation of this rule is NOT recommended for newly manufactured, legacy helicopters.

Note that 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 the weight penalties at reduced g-loads were still excessively high in comparison to the anticipated benefit.

27/29.561(d): Restraint of fuel tanks below floor

Not Recommended

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 ROPWG Task 5 CRFS Report and Effectiveness of CRSS Features section in this report). Also, OEMs reported that complying with this section in legacy helicopters would involve considerable cost and weight penalties.

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 newly manufactured, legacy helicopters.

27/29.562(b)(1): Dynamic Seat Testing, Vertical Direction

Part 27: Recommended w/changes

While the data presented earlier in this report shows that a reduction in spinal injuries is a high priority for occupant protection, the ROPWG determined that there were a number of currently manufactured, legacy Part 27 helicopters where the requirements of 27.562(b)(1) could not be implemented in certain seating positions, since meeting the requirement for vertical energy absorption of the seat requires a minimum stroking distance and this distance was not practicably available. This occurred in several small and medium size helicopter models where the seats are mounted on top of fuel tanks or control system components. Providing the necessary stroking distance would reduce the fuel capacity and/or occupant capacity in these models to a level where the OEM or operator would be forced to discontinue that model.

In an effort to minimize disruption to the industry that would be caused by a requirement for full compliance with 27.562(b)(1), the ROPWG sought an alternative requirement that could provide much of the benefit of full compliance, but with substantially reduced fuel and occupant capacity penalties. The ROPWG determined that a reduced velocity vertical dynamic seat test could provide much of the same protection against serious spinal injury as full compliance, but with substantially reduced fuel and occupant capacity penalties as a result of much smaller requirements for seat stroking distance.

Specifically, the ROPWG is proposing the following alternative requirement for newly manufactured, legacy Part 27 helicopters:

"Where practicable, all seats must meet the requirements of 27.562(b)(1). Where compliance with 27.562(b)(1) is not practicable in certain seats due to existing design constraints, those seats may instead demonstrate compliance with a dynamic vertical seat test with the following criteria:

- *The test impact velocity is 25.0 ft/s*
    - *(the vertical component of the velocity change is therefore 21.7 ft/s)*
- *Peak floor deceleration must occur in not more than 0.028 seconds*
- *Peak g-load must reach a minimum of 27.5g*
- *ATD (Anthropomorphic Test Device) injury criteria is unchanged from 27.562(c)*
- *All other relevant criteria from 27.562 remain valid"*

Note that these test criteria would allow the test labs to continue using the same test equipment, test dummies, instrumentation, and procedures as is currently used for full compliance tests, minimizing the effort required to conduct this alternative test.

A detailed discussion of this recommendation is included in the Reduced Velocity Vertical Seat Tests section. Also, additional technical considerations are discussed in Appendices D and E.

Part 29: Recommended

As discussed earlier in this report, the reduction of spinal injuries is a high priority for occupant protection. Unlike some Part 27 helicopters, the greater size and near universal incorporation of bolt-in seats in Part 29 helicopters means the cost and weight penalties associated with full compliance are relatively small. The ROPWG was not able to identify any other significant impediments to requiring the full regulation for Part 29 helicopters, other than a possible small reduction in seating capacity in some models.

In consideration of the above, implementation of this rule is recommended for currently manufactured, Part 29 legacy helicopters.

27/29.562(b)(2): Dynamic Seat Testing, Horizontal Direction

Recommended

The loss of occupant retention and flailing are among the greatest hazards in helicopter crashes. The horizontal dynamic seat test address both of these hazards as follows:

- Occupant retention under dynamic loads is established up to the level of the test
- Head and torso impacts experienced during the test are required to be at or below the threshold for serious injury

The cost and weight penalties required to meet this regulation are relatively small, though it should be noted that the test burden on the OEMs can be significant, particularly if multiple rounds of design revision and testing are required to demonstrate compliance. However, in the opinion of the ROPWG, these drawbacks are outweighed by the benefit of implementing this rule.

In consideration of the above, implementation of this rule is recommended for currently manufactured, legacy helicopters (Part 27 and Part 29).

27/29.785: Seats, berths, litters, safety belts, and harnesses

Recommended

The ROPWG found that while most aspects of this regulation are also covered by other regulations, the unique aspects of 27/29.785 are expected to provide a modest safety benefit. The group also found that the associated cost and weight penalties are relatively small. The ROPWG was not able to identify any other significant impediments to requiring the full regulation. Therefore, compliance with this regulation is recommended.

Note that the text of 27/29.785 references 27/29.561 and 27/29.562. Therefore, although no changes are required to the intent of the regulation, revised/additional text may be required to clarify that regulations referenced in the text of 27/29.785 are, as applicable, the modified regulations mandated for newly manufactured, legacy helicopters.

Requirement for full compliance 10 years after approval of new CRSS rules

Not Recommended

The analysis of data in this report shows that, in comparison to the partial-compliance recommendations summarized in Table 5, the additional benefits of mandating full compliance would be outweighed by the additional costs, weight penalties, and disruption to the industry. In particular, the requirement for full compliance with 27.562(b)(1) would likely result in the discontinuation of certain helicopter models due to the infeasibility of making the required changes in these models, whereas ~70% of the benefit could be achieved with the reduced velocity vertical test at a fraction of the cost/weight/disruption. Also, the requirement for full compliance with 27/29.561(c) would result in substantial weight penalties for many helicopters while providing an uncertain but likely modest benefit.

Since the cost and weight penalties required for full compliance are due to engineering challenges as opposed to development schedules, delaying full compliance by 7-10 years will not result in appreciably lower costs, weight penalties, or disruptions caused by discontinued models. Therefore, the ROPWG recommends that the FAA **does not** require full compliance with 27/29.561, 27/29.562, and 27/29.785 after a 10-year period for newly-manufactured, legacy helicopters.

COST AND PERFORMANCE PENALTIES OF ROPWG RECOMMENDATIONS

Estimates of the cost and performance penalties for the ROPWG CRSS recommendations defined earlier in this report were developed using the same methodology used for developing the full compliance cost/performance penalties detailed in the ROPWG Task 2 report submitted on November 10, 2016. A summary of the methodology and results is presented below, while a detailed discussion of the methodology and results is included in Appendix B.

Note that the cost and performance penalties presented in this section are applicable only to the specific ROPWG recommendations presented in the "Recommendations" section in this report. Deviations from these recommendations could significantly impact the final cost/performance penalties required to demonstrate compliance.

Also note that all costs are presented in 2016 dollars to be consistent with previous ROPWG reports.

SUMMARY OF METHODOLOGY

The estimated cost of the recommended regulatory changes is best understood by dividing the costs into two categories:

Original Equipment Manufacturer (OEM) costs, which are further divided into two subcategories:

- Non-recurring costs: The expenses incurred for design, testing, certification, and retooling to comply with the recommended regulatory changes.
- Unit costs: The increased expenses incurred for parts and labor required for installation of mandated features on each aircraft produced.

Operator costs, which are primarily due to the increase in the empty weight of the helicopter incurred by the inclusion of additional/revised CRSS components, and are further divided into three subcategories:

- The reduction in revenue due to the reduction in payload, requiring additional flights to ferry a given quantity of payload/passengers
- The reduction in fuel load/range, requiring additional fuel stops, auxiliary fuel tanks, or different helicopters to ferry payload/passengers a given distance
- The increase in the fuel burn rate, requiring additional fuel to ferry payload/passengers a given distance

SUMMARY OF ESTIMATED COSTS TO INDUSTRY FOR ROPWG RECOMMENDATIONS

Non-recurring costs, 10-year anticipated unit cost increase, and 10-year operator cost increases caused by compliance with the ROPWG recommended regulatory changes are summarized in Table 6. The costs are broken down by Part 27 and Part 29. Note that the total estimated 10-year increased industry costs for CRSS as reported by rotorcraft manufacturers were approximately $322M.

Table 6. Summary of 10-Year Industry Costs (2016 USD) of Compliance for Models Still in Production, ROPWG Recommendations

Cost Category	Part 27	Part 29	Combined Costs Parts 27 & 29
Non-recurring Cost	$39,280,000	$72,000,000	$111,280,000
10-Year Unit Cost Increase	$47,524,000	$60,990,000	$108,514,000
Total 10-Year OEM Costs	$86,804,000	$132,990,000	$219,794,000
10-Year Operator Cost Increase	$79,522,278	$22,774,283	$102,296,561
Total 10-Year Estimated Industry Cost	**$166,326,278**	**$155,764,283**	**$322,090,561**

SUMMARY OF ESTIMATED PERFORMANCE PENALTIES FOR ROPWG RECOMMENDATIONS

Table 7 shows the estimated increase in empty weight due to the requirement to comply with the ROPWG recommendations. The data presented is a weighted average based on the estimated number of helicopters of each model within the category expected to be produced.

Table 7. Weighted Average Increase in Empty Weight, ROPWG Recommendations

Subcategory	Average Increase in Empty Weight (lb)
Part 27 – Single Piston	17.9
Part 27 – Single Turbine	77.4
Part 27 – Twin Turbine	0.0
Part 29	118.9

Table 8 shows the estimated reduction in fuel capacity due to the requirement to comply with the ROPWG recommendations. This reduction in fuel capacity is primarily due to the requirement to reduce the size of the fuel tanks to accommodate energy absorbing, stroking seats.

Table 8. Weighted Average Reduction in Fuel Capacity, ROPWG Recommendations

Subcategory	Average Reduction in Fuel Capacity (lb)
Part 27 – Single Piston	0.0
Part 27 – Single Turbine	4.5
Part 27 – Twin Turbine	0.0
Part 29	0.0

REVISED COST AND PERFORMANCE PENALTIES FOR FULL COMPLIANCE

Since the submittal of the Task 2 report that detailed the costs for full compliance, one helicopter model that was part of that analysis has been discontinued by the manufacturer. Since the new ROPWG recommendation cost estimates discussed in the previous section were developed without the costs associated with the recently-discontinued model, the ROPWG recommendation estimates would appear artificially low relative to the original full-compliance estimates since the full-compliance estimates included the costs of the now-discontinued model. Therefore, to provide a more meaningful comparison between the cost/performance penalties for full compliance and the ROPWG recommendations, the full-compliance estimates from the Task 2 report have been revised to reflect the current set of applicable helicopters in active production.

Additionally, while developing the cost/performance penalties associated with ROPWG recommendations, several OEMs found that their original cost/performance penalty estimates for full compliance should be revised based on new data and insight developed since the submittal of the Task 2 report. These revisions are also incorporated in the revised full-compliance estimates.

The revised cost/performance penalty estimates for full compliance were developed using the identical methodology that is detailed in the ROPWG Task 2 report submitted on November 10, 2016. This is also the same methodology that is utilized and detailed in Appendix B for the ROPWG recommendations. A summary of these cost and performance penalties is presented in this section, while the complete set of data is presented in Appendix C. Since the cost/performance penalty methodology is presented in detail in Appendix B for the ROPWG recommendations, only the revised cost/performance penalty tables for full compliance with 27/29.561, 27/29.562, and 27/29.785 are included in Appendix C.

Note that all costs are presented in 2016 dollars to be consistent with previous ROPWG reports.

Table 9. Summary of 10-Year Industry Costs (2016 USD) of Compliance for Models Still in Production, Revised Estimates for Full Compliance			
Cost Category	**Part 27**	**Part 29**	**Combined Costs Parts 27 & 29**
Non-recurring Cost (.561, .562, .785)	$112,450,000	$72,700,000	$185,150,000
10-Year Unit Cost Increase (.561, .562, .785)	$91,830,000	$62,490,000	$154,320,000
Total 10-Year OEM Costs	$204,280,000	$135,190,000	$339,470,000
10-Year Operator Cost Increase	$123,325,028	$39,226,895	$162,551,923
Total 10-Year Estimated Industry Cost	**$327,605,028**	**$174,416,895**	**$502,021,923**

Table 10. Weighted Average Increase in Empty Weight, Revised Estimates for Full Compliance	
Subcategory	**Average Increase in Empty Weight (lbs.) CRSS: (.561, .562, .785)**
Part 27 – Single Piston	30.0
Part 27 – Single Turbine	137.0
Part 27 – Twin Turbine	0.0
Part 29	213.0

Table 11. Weighted Average Reduction in Fuel Capacity, Revised Estimates for Full Compliance	
Subcategory	**Average Reduction in Fuel Capacity (lb) CRSS: .561, .562, .785**
Part 27 – Single Piston	0.0
Part 27 – Single Turbine	5.4
Part 27 – Twin Turbine	0.0
Part 29	0.0

BENEFIT OF ROPWG RECOMMENDATIONS

BACKGROUND

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 kinds of 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, missions, 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 full compliance. For instance, if one does not know the energy absorption characteristics of all seats in existing currently-produced, legacy helicopters, one cannot determine the benefit of requiring these seats to be fully compliant. Generally, such data is not available, even within most OEMs. Similarly, one cannot determine the benefit of meeting the mass retention requirements of 27/29.561(c) if one does not know the existing mass retention strength of every currently-produced, legacy helicopter.

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 limits its utility. That said, a quantitative estimate, even with substantial uncertainty, may be useful for regulatory decision making when comparing the relative costs and benefits of the ROPWG recommendations versus full compliance. Therefore, the benefit analysis presented for the ROPWG recommendations is both qualitative and quantitative.

RELATIVE BENEFIT OF ROPWG RECOMMENDATIONS

The relative benefits of the ROPWG CRSS recommendations for each applicable regulation are presented below in Table 12. For each regulation, a determination was made of the following:

- The relative benefit of each ROPWG recommendation as compared to the benefit of full compliance, reported as a percentage
- The estimated impact of each regulation on overall crash safety, designated as none, low, medium, or high. A numerical weighting factor was also applied to each impact level as follows:
    - None = 0
    - Low = 1
    - Medium = 2
    - High = 3

The benefit determinations were based on the data and analysis presented earlier in the following sections of this report:

- Relative Frequency and Severity of Injury Hazards in Civilian Helicopter Crashes
- Effectiveness of CRSS Features

- Reduced Velocity Vertical Seat Tests

Note that for those regulations/paragraphs that were not recommended by the ROPWG, the benefit is necessarily zero.

The overall relative benefit of the ROPWG recommendations was calculated by multiplying the estimated benefit of each regulation by its weighting factor and dividing by the total of the weighting factors for each helicopter category (10). This yielded an overall benefit of the ROPWG recommendations relative to the benefits of full compliance.

Table 12. Benefit of ROPWG CRSS Recommendations

Regulation	ROPWG Recommendation	Benefit of ROPWG Recommendation Relative to Full Compliance	Qualitative Assessment of Regulation's Impact on Crash Safety	Weighting Factor for Regulation
27/29.561(b)(3): Restraint of occupants and items of mass in cabin	Recommended	100%	Medium	2
27/29.561(c): Restraint of items of mass above and behind cabin	NOT Recommended	0%	Low	1
27/29.561(d): Restraint of fuel tanks below floor	NOT Recommended	0%	None*	0
27/29.562(b)(1): Dynamic seat testing, Vertical direction	Part 27: Recommended w/changes (reduced velocity vertical dynamic seat test)	71%	High	3
	Part 29: Recommended	100%	High	3
27/29.562(b)(2): Dynamic seat testing, Horizontal direction	Recommended	100%	Medium	2
27/29.785: Seats, berths, litters, safety belts, and harnesses	Recommended	100%	Medium	2
All Recommendations Combined	**N/A**	**Part 27: 81%** **Part 29: 90%**	**Part 27 & 29: High**	**N/A**

*Note: While ROPWG acknowledges that this regulation may provide some benefit for certain helicopters, we found no evidence that non-compliance with this regulation contributed to occupant injuries in the crash data reviewed for this report.

QUANTITATIVE BENEFIT ESTIMATE FOR ROPWG RECOMMENDATIONS FOR PART 27 HELICOPTERS

As part of the ROPWG Task 2 report, the FAA Office of Accident Investigation and Prevention (AVP) provided an estimate of the monetary benefit of requiring full compliance with the applicable CRSS regulations for newly-manufactured, Part 27 legacy helicopters. This monetary benefit was generated 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 a monetary benefit to each of the injuries and fatalities that would be avoided. This estimate was limited to Part 27 helicopters, as there was not enough crash data to determine the benefit for Part 29 helicopters.

As stated above, the ROPWG feels that this estimate has a great deal of uncertainty due to the factors previously discussed; nevertheless, it is potentially useful for generating a general cost-benefit comparison for full compliance versus the ROPWG recommendations. The benefit estimate for the ROPWG recommendations for Part 27 helicopters was calculated by multiplying the AVP estimate for full compliance (from the ROPWG Task 2 report) by the relative benefit of the ROPWG recommendations (from Table 12).

The monetary benefit of full compliance from the ROPWG Task 2 report over a 10-year period was estimated to be $113,217,324 (Part 27), and the relative benefit of the ROPWG recommendations as compared to full compliance is estimated to be 81% (Part 27). Therefore, the monetary benefit (in 2016 USD) of the ROPWG recommendations over a 10-year period is estimated to be:

Part 27: $113,217,324 * 81% = $91,706,032

Part 29: Benefit estimate is not available due to a lack of crash data for Part 29 helicopters

DETERMINATION OF MONETARY VALUES ASSOCIATED WITH PREVENTION OF INJURIES AND FATALITIES

Note that the monetary values associated with the saving of a life and the prevention of serious and minor injuries were provided by the FAA Office of Aviation Policy and Plans (APO), and 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 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.

ADDITIONAL BENEFIT CONSIDERATIONS

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, with many of the victims of spinal injuries rendered paraplegic, and in some cases, quadriplegic.[25] The most common location for spinal injuries in helicopter crashes is the thoracolumbar spine. Although these injuries are not immediately threatening to life, most 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.

Reduction of Safety Margins

The ROPWG members with aircraft engineering and operator expertise expressed cautionary concerns about the effects of the proposed regulatory changes on smaller Part 27 aircraft. The empty weight and fuel capacity/range penalties outlined in this report 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 task 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 number and severity of injuries per accident would be offset by an increase in the number of accidents. 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 are significant, especially for smaller helicopters.

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 is able to take care of himself 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.

---

[25] 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.

COST/BENEFIT ANALYSIS

OVERVIEW

This section presents an analysis of the cost/benefit ratio of the ROPWG recommendations for CRSS, and compares this ratio to that for full compliance. As discussed previously in this report, due to the lack of data regarding the effectiveness of both legacy and current CRSS features, the calculated quantitative benefit of the ROPWG recommendations has considerable uncertainty. That said, a quantitative estimate, even with substantial uncertainty, may be useful for regulatory decision making when comparing the relative costs and benefits of the ROPWG recommendations versus full compliance.

SUMMARY OF COSTS AND BENEFITS

Table 13 provides a summary of the 10-year industry costs and monetary benefits for compliance with the ROPWG recommendations, and compares this to the cost of full compliance with 27/29.561, 27/29.562, and 27/29.785. Note that for Part 27 helicopters, the ROPWG recommendations are estimated to provide 81% of the benefit of full compliance at only 50% of the cost.

Table 13. Summary of 10-Year Industry Costs (2016 USD) for Models Still in Production, ROPWG Recommendations and Full Compliance

Cost Category	Part 27		Part 29		Combined Costs Parts 27 & 29	
	ROPWG Recommendations	Full Compliance	ROPWG Recommendations	Full Compliance	ROPWG Recommendations	Full Compliance
Non-recurring Cost	$39,280,000	$112,450,000	$72,000,000	$72,700,000	$111,280,000	$185,150,000
10-Year Unit Cost Increase	$47,524,000	$91,830,000	$60,990,000	$62,490,000	$108,514,000	$154,320,000
Total 10-Year OEM Costs	$86,804,000	$204,280,000	$132,990,000	$135,190,000	$219,794,000	$339,470,000
10-Year Operator Cost Increase	$79,522,278	$123,325,028	$22,774,283	$39,226,895	$102,296,561	$162,551,923
Total 10-Year Estimated Industry Cost	**$166,326,278**	**$327,605,028**	**$155,764,283**	**$174,416,895**	**$322,090,561**	**$502,021,923**
Total 10 Year Estimated Benefit	**$91,706,032**	**$113,217,324**	**	**	**	**

**Note: Per Task 2 report, Part 29 benefit could not be calculated due to the limited number of Part 29 accidents with applicable CRSS data.

Table 14 provides a summary of the weight and fuel capacity penalties for compliance with the ROPWG recommendations, and compares this to the penalties of full compliance with the applicable CRSS regulations.

Table 14. Weighted Average Increase in Empty Weight and Reduction in Fuel Capacity for ROPWG Recommendations and Full Compliance

Subcategory	ROPWG Recommendations	Full Compliance	Difference
Increase in Empty Weight (lb)			
Part 27 – Single Piston	17.9	30.0	12.1
Part 27 – Single Turbine	77.4	137.0	59.6
Part 27 – Twin Turbine	0.0	0.0	0.0
Part 29	118.9	213.0	94.1
Reduction in Fuel Capacity (lb)			
Part 27 – Single Piston	0.0	0.0	0.0
Part 27 – Single Turbine	4.5	5.4	0.9
Part 27 – Twin Turbine	0.0	0.0	0.0
Part 29	0.0	0.0	0.0

REASONS FOR DIFFERENCE IN ROPWG RECOMMENDATIONS VS. FULL-COMPLIANCE COST AND WEIGHT PENALTIES

The reduction in cost and weight penalties for ROPWG recommendations versus full compliance is due to two primary factors:

- The ROPWG recommendations allow Part 27 helicopters to conduct reduced velocity vertical dynamic seat tests when passing the full velocity test is not practicable and would lead to substantial weight and cost penalties and the discontinuation of some models. Note that the reduced velocity tests/seats are expected to provide ~71% of the benefit provided by fully compliant seats.
- The ROPWG recommendations avoid the substantial weight penalties associated with 27/29.561(c) (retention of items of mass above and behind the cabin). Note that the associated hazard ranking for this regulation was low.

ADDITIONAL COST/BENEFIT CONSIDERATIONS

Although the costs of implementing the ROPWG recommendations for CRSS in newly-manufactured, legacy helicopters exceed the calculated monetary benefits for Part 27 helicopters (the ratio for Part 29 helicopters is unknown due to lack of crash data for this class of helicopter), the ROPWG still believes that these recommendations should be implemented for reasons as follows:

- The estimated costs of full-compliance did not, per FAA request, factor in the costs of discontinuation of any models. However, the high cost of full-compliance combined with decreases in range and payload could, nevertheless, result in OEMs deciding to discontinue certain marginal models. Implementing the ROPWG recommendations instead would significantly lower the odds of the discontinuation of these models.
- Army crash data shows that most excessive decelerative force injuries are typically spinal injuries potentially preventable with an energy absorbing seat, and many of the victims of spinal injuries were paraplegic, and some, quadriplegic.[26] Although not immediately threatening to life, spinal cord injuries result in a shorter life expectancy and the cost and suffering involved is far greater than that for most blunt force injuries.

Lastly, it is noted that the ROPWG Recommendations for Part 29, as compared to full compliance, provide 90% of the benefit for 89% of the cost. While this indicates that ROPWG recommendations are essentially no more cost effective than full compliance, the ROPWG believes the weight penalties and disruption that would be caused by requiring full compliance for Part 29 helicopters (in particular compliance with 29.561(c)) are more significant than suggested by the quantitative analysis. Therefore, the ROPWG feels that its recommendations for Part 29 helicopters are more appropriate than full compliance.

RELATIVE IMPACT ON SMALL HELICOPTERS

Note that the increased cost and weight penalties disproportionally affect smaller, less expensive helicopters. As a result, insistence on requiring full-compliance would place a much greater relative burden on the OEMs and operators of small helicopters.

Also, as discussed in the prior section Reduction of Safety Margins, the empty weight and fuel capacity/range penalties outlined in this report could potentially increase the accident rate, particularly for small helicopters with limited power margins. This reduction in safety margins would decrease the calculated benefit, as the reduction in the number and severity of injuries per accident would be offset by an increase in the number of accidents. As a result, regulatory requirements beyond those recommended could be detrimental to safety relative to the ROPWG recommendations, and are therefore strongly discouraged.

[26] 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.

CONCLUSIONS

Based upon the data and analyses in this report, we conclude the following:

1. Military and civilian helicopter accident data has shown that the greatest hazards in survivable accidents are:
    a. Thermal injuries from post-crash fires following survivable accidents.
    b. Excessive vertical deceleration.
    c. Head, torso, and extremity contact with cabin structure due to inadequate restraint.
2. The ROPWG determined and reported in its Task 2 Report that full compliance with CRSS regulations is not the optimal regulatory approach for newly manufactured, legacy rotorcraft. The analysis described in this report shows that partial-compliance provides a significant safety benefit while substantially reducing the costs compared to full compliance.
3. Qualitative and quantitative analyses of the ROPWG recommendations indicate that they provide a reasonably cost-effective method of improving crash safety in currently-manufactured, legacy helicopters.
4. There are a number of currently manufactured, legacy Part 27 helicopters where the requirements of 27.562(b)(1) (vertical dynamic seat test) cannot be implemented in some seating positions because providing the necessary stroking distance would reduce the fuel capacity and/or occupant capacity in these models to a level where the OEM or operator would be forced to discontinue that model.
    a. As a compromise, the ROPWG determined that a reduced velocity vertical dynamic seat test could be practicable and effective in these seating positions.
    b. It is estimated that a reduction in the vertical velocity component for the dynamic seat test from 26 ft/s to 21.7 ft/s would provide 71% of the protection against serious spinal injury as full compliance, but with substantially reduced fuel and occupant capacity penalties as a result of much smaller requirements for seat stroking distance.
5. Inadequate restraint of items of mass above and behind the passenger compartment contributes to only a small number of injuries, but full compliance with 27/29.561(c) (restraint of items of mass above and behind cabin) would entail considerable expense and severe weight penalties in currently manufactured, legacy helicopters.
6. The empty weight and fuel capacity/range penalties described in this report could potentially increase the accident rate, particularly for small helicopters with small power margins. As a result:
    a. The reduction in the number and severity of injuries per accident could be offset by an increase in the number of accidents.
    b. Regulatory requirements beyond those recommended by the ROPWG (in particular, requiring full compliance with 27/29.561(c) (restraint of items of mass above and behind cabin) and/or 27.562(b)(1) (vertical dynamic seat test) could be detrimental to safety, and are therefore strongly discouraged.
7. While the ROPWG is aware that the FAA asked for a recommendation on “which Paragraphs of each Section for the existing occupant protection standards cited in the referenced Federal Register Notice can be made effective for newly manufactured rotorcraft”, the ROPWG members believe that the inclusion of an alternative, reduced velocity vertical seat test for certain seating positions is required in order to provide effective CRSS regulations for newly manufactured, legacy helicopters.

8. The ROPWG recommends that the FAA **does not** require full compliance with 27/29.561, 27/29.562, and 27/29.785 after a 10-year period for legacy, newly-manufactured helicopters, for the following reasons:
    a. The analysis of data in this report shows that, in comparison to the partial-compliance recommendations summarized in Table 5, the additional benefits of mandating full compliance would be outweighed by the additional costs, weight penalties, and disruption to the industry.
    b. The requirement for full compliance with 27.562(b)(1) (vertical dynamic seat test) would likely result in the discontinuation of certain helicopter models due to the infeasibility of making the required changes in these models, whereas approximately 70% of the benefit could be achieved with the reduced velocity vertical test at a fraction of the cost/weight/disruption.
    c. The requirement for full compliance with 27/29.561(c) (restraint of items of mass above and behind cabin) would result in substantial weight penalties for many helicopters while providing an uncertain but likely modest benefit.
    d. Since the cost and weight penalties required for full compliance are due to engineering challenges as opposed to development schedules, delaying full compliance by 7-10 years will not mitigate any of these factors.
9. The NTSB database and supporting dockets do not provide sufficient data to conduct an analysis of crash injuries and injury causes in civil aviation crashes. Specifically, they lack data on crash impact parameters, injuries to occupants, and injury causes (mechanisms). Without this information, it is impossible to assess the effectiveness of civil occupant protection regulations in preventing injury to occupants in crashes. Consequently, the regulatory process is driven by anecdotal data, which is inherently unreliable and leads to potentially faulty and inefficient regulations.

ROPWG VOTING MEMBERS' COMMENTS

BELL HELICOPTER

While Bell Helicopter concurs with this report in its entirety, the influence of rotor inertia on vertical velocity in terminal autorotation has not been sufficiently discussed herein. The greater the rotor inertia (lower Lock number, which is the ratio of the rotor's aerodynamic lifting capability to its inertia), the lower the rate of descent for terminal autorotation (ROD-TA). Correspondingly, as the ROD-TA decreases, so does the velocity percentile in the frequency of occurrence (c.f., Figure 11). For example, in Shanahan, D.F., (Jan 1992) *Crash Experience of the U.S. Army Black Hawk Helicopter*:

> "*The relative risk for fatal injury as well as for fatal and major injury combined is 3.8 times greater for the Black Hawk* [Table 15]. *This is due to the comparatively high crash rate for the Black Hawk as well as to the increased severity of UH-60 crashes. … The most important factor relating to the crash performance of the Black Hawk is its propensity to crash at extremely high velocities* [44.2 ft/s mean vertical velocity at impact] *in comparison to the UH-1* [17.7 ft/s mean vertical velocity at impact]."

Table 15. Comparison of Fatal and Fatal/Major Injury Rates for the UH-1 and UH-60
(reproduced from Table III in Shanahan, Jan 1992)

Parameter	UH-1	UH-60
Total flight hours	8,411,301	1,267,648
Number of occupants	776	282
Injuries:		
Fatal	117	84
Major	20	13
Fatal injuries		
Rate (per 100,00 flight hours)	.31	1.18
Relative risk	1.00	3.80
Fatal and major injuries		
Rate (per 100,00 flight hours)	.36	1.37
Relative risk	1.00	3.80

This demonstrates the influence of ROD-TA on crash survivability which is not reflected in the discussion within this report. While the UH-60 was designed to protect occupants during higher vertical impact velocities (Figure 6), the corresponding rotor system subjects the platform to higher energy impacts (Table 15). Therefore, evaluating the rotorcraft system as a whole enables a better systemic assessment of its crashworthiness.

This illustrates the more comprehensiveness of **Performance Based Standards** (PBS) in lieu of the current prescriptive based standards. When evaluated with the platform's rotor system inertia (i.e., ROD-TA), the vertical velocity energy absorption (EA) capability of the seating system can more sufficiently be scaled. The recommendations herein, however, remain with the prescriptive based approach.

While the Bell 407 has insufficient stroke distance for passenger seats to meet the full requirement of 14 CFR § 27.562(b)(1), its rotor system has higher inertia (lower Lock number) than most other Part 27 rotorcraft (with the exception of Bell 2-bladed helicopters) and hence if evaluated from a PBS perspective would reveal that the statistical frequency of occurrence at 95th percentile would likely be less than what is being proposed for the reduced test pulse.

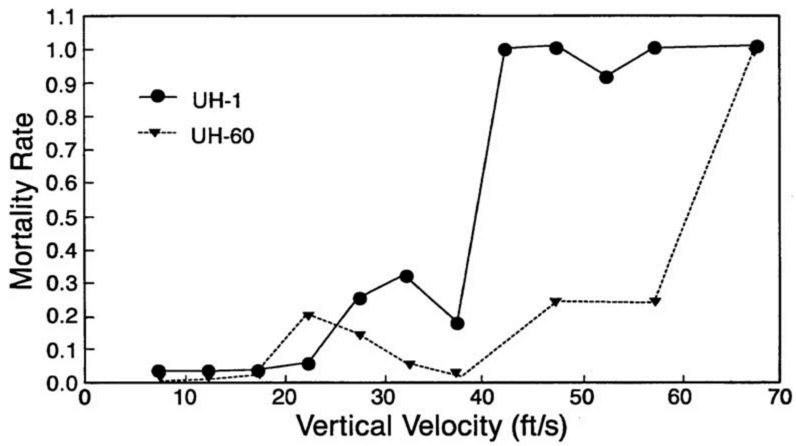

Figure 6: Mortality vs. Vertical Impact Velocity for UH-1 Huey and UH-60 Black Hawk
(reproduced from Figure 1 for convenience)

ROBINSON HELICOPTER COMPANY

Robinson Helicopter Company (RHC) generally concurs with the Rotorcraft Occupant Protection Working Group (ROPWG) Task 5 CRSS report reviewed on January 24, 2018, but supports small changes to two of the recommendations, as detailed below.

<u>27/29.561(b)(3): Restraint of Occupants and Items of Mass in Cabin</u>

Robinson concurs with the ROPWG recommendation that compliance with 27/29.561(b)(3) be required for newly-manufactured, legacy helicopters. However, Robinson additionally requests that the FAA issue a clarification to the associated AC guidance regarding its application to integral seats. The ROPWG recommendation is shown below, with Robinson's suggested addition shown in bold, underlined text.

> ***27/29.561(b)(3): Restraint of occupants and items of mass in cabin***
>
> *Recommended*
>
> *Accident investigations have demonstrated that loss of occupant retention due to failure at any point in the occupant tie-down chain can be catastrophic due to the released occupant impacting interior or intruding structures and, potentially, being completely ejected from the aircraft. Although, as demonstrated in Table 2, this injury mechanism is not particularly common (hazard ranking 9 and 12), seat failures are noted to result in 21% of life-threatening injuries. Furthermore, the OEMs reported that the cost and weight penalties for implementing the occupant retention portion of 27/29.561(b)(3) were fairly low, and working group members were not able to identify any other impediments to implementing this section of the rules into currently manufactured, legacy helicopters.*
>
> *While the working group did not find specific data on the frequency or resulting injuries related to loss of retention of cabin interior items, medical evacuation operators identified this as a very significant hazard in their operations. Additionally, the OEMs reported that relatively low cost and weight penalties would be required for implementation of this section of the rules for newly-manufactured, legacy helicopters.*
>
> ***<u>It is recommended that the guidance for 27/29.561(b)(3) be amended to clarify the requirements as applied to integral seats, which have the ability to provide occupant protection in a vertical impact through crushing of the support structure. The text of 27/29.561(b)(3)(iv) regarding "intended displacement" is ambiguous in this situation as there is no limit to the intended displacement. Since the intent of the static load requirements of 27/29.561(b)(3) is to retain the occupant and items of mass in an accident, and an integral seat will not separate under downward loading, the guidance should clarify that a downward static test of the seat is unnecessary for an integral seat that is not limited in intended displacement.</u>***
>
> *In consideration of the above, implementation of this rule is recommended for currently manufactured, legacy helicopters.*

In some smaller helicopters like the R22 and R44, the seats are not removable bolt-in seats like those found in many helicopters. Rather, they are composed of a hollow sheet metal "seat box" that is riveted into the cabin structure such that it cannot be removed, with a "lid" (seat) on top where occupants sit. They are "integral" in the sense that they are as much a part of the fuselage structure as the ceiling/floor/doorframe/etc. In a vertical accident, the sides of the seat box crush/buckle, absorbing energy and providing "stroking" distance for the occupant. This design has proven to be extremely effective at minimizing injuries in R22 and R44 accidents.

The problem with the ambiguity present in the guidance for 27/29.561(b)(3) is that a mandatory test for demonstration of compliance for the 20g downward condition could possibly cause the seat to stroke all the way to the ground plane. Without clarification through guidance, there is a risk that this could be interpreted as unacceptable. A revision to the seat design to prevent stroking all the way to the ground plane could increase the buckling strength of the seat support, thereby diminishing or eliminating its ability to act as an energy absorber. There is consequently a risk that without clarification of "intended displacement", a complete redesign may be necessary for a seat that meets the intent of the requirement.

Such a redesign would add several pounds per seat, and would therefore lead to a reduction in safety margins. The net result would be an overall decrease in safety, as occupant protection levels would remain unchanged, but performance safety margins would be decreased due to the increase in empty weight.

Therefore, it is imperative that the FAA amend the guidance for 27/29.561(b)(3) to clarify that downward static testing of seats is unnecessary for integral seats that are not limited in intended displacement.

Note that the text proposed above was drafted shortly before the approval of this report, and as a result, there was not sufficient time for the ROPWG to debate and vote on the proposed text. Therefore, the fact that the text was not included in the ROPWG recommendations should not be taken as an indication that it was rejected by the ROPWG membership. Rather, the reader should assume that the ROPWG's opinion of the proposed text is unknown, and should make his/her own determination of the merits of the text.

<u>27/29.562(b)(1): Dynamic Seat Testing, Vertical Direction</u>

Robinson concurs with the general ROPWG recommendation for 27/29.562(b)(1). However, Robinson additionally requests that when determining whether the required design changes are "practicable", excessive weight penalties should be among the factors considered. Specifically, Robinson's suggested addition to the ROPWG recommendation is shown below in bold, underlined text.

> ***27/29.562(b)(1): Dynamic Seat Testing, Vertical Direction***
>
> *"Where practicable, all seats must meet the requirements of 27.562(b)(1). Where compliance with 27.562(b)(1) is not practicable in certain seats due to existing design constraints, those seats may instead demonstrate compliance with a dynamic vertical seat test with the following criteria:*
>
> - *The test impact velocity is 25.0 ft/s*

- *(the vertical component of the test impact velocity is therefore 21.7 ft/s)*
- *Peak floor deceleration must occur in not more than 0.028 seconds,*
- *Peak g-load must reach a minimum of 27.5 g,*
- *ATD (Anthropomorphic Test Device) injury criteria are unchanged from 27.562(c),*
- *All other relevant criteria from 27.562 remain valid*

<u>Examples of design constraints where compliance with 27.562(b)(1) may not be practicable include, but are not limited to, the following:</u>

- ***<u>Seats that do not have sufficient stroking distance due to the existence of fuel tanks, control system components, or other items under the seat, if these components cannot be practicably moved, resized, or eliminated.</u>***
- ***<u>Aircraft with limited power margins such that the weight penalty required to fully comply with 27.562(b)(1) would result in a negative overall effect on safety."</u>***

As stated in the report, increasing the empty weight of a helicopter reduces performance safety margins, potentially leading to a higher accident rate. For helicopters that have limited power margins, the reduction in safety margins due to excess weight from modified seats is likely to outweigh any benefits from the modified seats. Therefore, it is imperative that the FAA consider the weight penalties required for compliance with 27.561(b)(1) when determining whether the modifications are practicable.

SIKORSKY AIRCRAFT CORPORATION

Sikorsky agrees with the majority of the conclusions and recommendations in the referenced report. However, we have concerns that the report does not fully address the implications of the proposed changes on some Part 29 helicopters. For this reason, Sikorsky does not concur with the following recommendations as proposed in the report:

- 27/29.561(b)(3) – Sikorsky recommends limiting the requirement to the occupant, or as it is referred to in the document, the “occupant tie-down chain”. Including “items of mass inside the cabin” creates a new requirement affecting VIP cabinets, entertainment systems, etc. that have not been shown to be a significant factor in enhancing occupant safety.
- 27.29.785 – Sikorsky recommends limiting the requirement to the seat, seat belts, and harnesses. Again, this keeps the focus on the “occupant tie-down chain”.
- 27/29.952(b)(1) – Sikorsky recommends the same requirements be applied to both Part 27 and Part 29. While the goal of a new seat design would be full compliance, having the reduced criteria available would provide the flexibility needed to keep the same number of seats in the cabin. Without this flexibility reduced passenger seating is possible to such an extent where Part 29 OEMs and operators would be forced to discontinue certain models.

AIRBUS HELICOPTERS

Airbus concurs with the majority of the ROPWG CRSS Report conclusions and recommendations. They do not agree with the majority ROPWG recommendation that all Part 29 helicopters should fully comply with the requirements of 29.562(b)(1): Dynamic Seat Testing, Vertical Direction. It is their opinion that certain medium models of helicopters certified to Part 29 should be eligible for the proposed reduced velocity dynamic test due to similar configurational issues encountered in some models of Part 27 helicopters. Consequently, Airbus proposed the following change to the CRSS Report:

27/29.562(b)(1): Dynamic Seat Testing, Vertical Direction

Part 27: No additional remarks

Part 29: Recommended

As discussed earlier in this report, the reduction of spinal injuries is a high priority for occupant protection.

Concerning the heavy models which generally offer wide and high cabins, the greater size and near universal incorporation of bolt-in seats in Part 29 helicopters means the cost and weight penalties associated with full compliance are relatively small. In such a case, the ROPWG was not able to identify any other significant impediments to requiring the full regulation for Part 29 helicopters, other than a possible small reduction in seating capacity in some models.

In consideration of the above, implementation of this rule is recommended for currently manufactured, Part 29 legacy helicopters.

Concerning the medium models [certified to Part 29], for which the architecture is close to the Part 27 models, some problems of integration exist [for a fully-compliant seat] since the necessary stroke to absorb the energy cannot be practically obtained without deep structural modifications, which can generate a loss of fuel capacity.

In these cases, a comparable approach to Part 27 helicopters is proposed:

> *"Where practicable, all seats must meet the requirements of 29.562(b)(1). Where compliance with 29.562(b)(1) is not practicable in certain seats due to existing design constraints, those seats may instead demonstrate compliance with a dynamic vertical seat test with the following criteria:*
>
> - *The test impact velocity is 25.0 ft/s*
>   - *(the vertical component of the velocity change is therefore 21.7 ft/s)*
> - *Peak floor deceleration must occur in not more than 0.028 seconds*
> - *Peak g-load must reach a minimum of 27.5g*
> - *ATD (Anthropomorphic Test Device) injury criteria is unchanged from 29.562(c)*
> - *All other relevant criteria from 29.562 remain valid"*

APPENDIX A: ROPWG MEMBERSHIP

NAME	COMPANY/REPRESENTING	Position
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, SPO	Airborne Law Enforcement Association's (ALEA)	Voting Member
Krista Haugen	Survivors Network for Air & Surface Medical Transport	Voting Member
Joan Gregoire	MD Helicopters, Inc.	Voting Member
Rohn Olson Michael Smith, Alternate	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

APPENDIX B: DETAILED COSTS, ROPWG RECOMMENDATIONS

This appendix provides a detailed description of the methodology used to calculate the costs and performance penalties required to demonstrate compliance with the ROPWG recommendations detailed in the main body of this report. These estimates were developed using the same methodology used for developing the full compliance cost/performance penalties detailed in the ROPWG Task 2 report submitted on November 10, 2016. For convenience, the Cost Analysis section from the Task 2 report is reproduced verbatim below, with the following exceptions:

- The cost/performance penalty estimates are changed to reflect the ROPWG estimates
- The discussion is limited to compliance with the ROPWG recommendations for 14 CFR 27/29.561, 27/29.562, and 27/29.785 (i.e., the cost/performance penalties required for compliance with 27/29.952 are discussed in a separate report)
- Minor editorial edits are incorporated as required

OVERVIEW

The estimated cost of the recommended regulatory changes is best understood by dividing the costs into two categories:

- Original Equipment Manufacturer (OEM) costs consisting of non-recurring design costs and recurring manufacturing costs.
- Operator costs related to the reduction in payload, the reduction in fuel load/range, and the increase in the fuel burn rate caused by the required design changes.

Each of these cost categories are discussed in detail below.

OEM COST DATA

The ROPWG included representatives from all major OEMs, foreign and domestic, who still manufacture Part 27/29 rotorcraft for the U.S. market. For each of their currently produced aircraft models that are not currently fully compliant with 14 CFR 27/29.561, 27/29.562, and 27/29.785, each OEM provided estimates of the Non-Recurring Costs and Unit Costs (defined below) that would be required to comply with the recommended regulatory changes.

- **Non-recurring costs:** The expenses incurred for design, testing, certification, and retooling to comply with the recommended regulatory changes. This is the expense associated with the effort to develop and certify a compliant aircraft.
- **Unit costs:** The increased expenses incurred for parts and labor required for installation of mandated features on each aircraft produced.

Non-Recurring Costs

Table 16 details the OEM estimated non-recurring costs required to bring non-compliant rotorcraft models still in production into compliance with the recommended regulatory changes. Note that Part 27 rotorcraft were broken into three subcategories to better represent the wide range of Part 27 helicopter types.

Table 16. Industry Total Non-Recurring Costs (USD) of Compliance for Models Still in Production, ROPWG Recommendations

Rotorcraft Groups	Non-recurring Cost, CRSS
Part 27 - Single Piston	$17,780,000
Part 27 - Single Turbine	$21,200,000
Part 27 - Twin Turbine	$300,000
Part 29	$72,000,000
All Groups Combined	**$111,280,000**

Unit Costs

Table 17 summarizes OEM-provided estimates of the unit costs required to bring Part 27 and Part 29 rotorcraft currently in production into compliance with the recommended regulatory changes. Note that Table 17 is divided so that unit costs for Part 27 helicopters and Part 29 helicopters can be determined separately. Also, note that the costs presented in Table 17 and subsequent tables are (as applicable) weighted averages based on the estimated number of helicopters of each model within the category expected to be produced.

Table 17. Unit Costs (USD) to Bring Models Still in Production Up to ROPWG Recommendations				
Rotorcraft Groups	**Estimated Annual Production**	**Weighted Average Unit Cost (CRSS) (per aircraft)**	**Total Annual Unit Costs (CRSS)**	**10-Year Total Unit Cost Increase (CRSS)**
Part 27 - Single Piston	85	$12,485	$1,061,220	$10,612,200
Part 27 - Single Turbine Models	84	$43,907	$3,688,180	$36,881,800
Part 27 - Twin Turbine	3	$1,000	$3,000	$30,000
Total Part 27	172	N/A	$4,752,400	$47,524,000
Total Part 29	13	$469,154	$6,099,000	$60,990,000
All Groups Combined	**185**	**N/A**	**$10,851,400**	**$108,514,000**

Discussion

Non-recurring and unit costs varied widely between aircraft models due to differences in certification basis (starting point) and differences in OEM design standards. For instance, some models are almost fully compliant with applicable regulations and would require minimal or zero changes to meet the ROPWG recommendations, while other models would require substantial revisions (inclusion of energy absorbing seats, significant strengthening of structure, etc.). Lastly, note that these costs only apply to newly manufactured aircraft; retrofitting of fielded aircraft would likely be far costlier, and will be the subject of further study by the ROPWG.

International Cost Considerations

While OEMs were asked to discern costs specific to the U.S. market versus the international market, OEMs working in international operations reported a dispersion of engineering and manufacturing costs across different countries, making specific demarcations of U.S. costs versus international costs unfeasible for this report. Airbus provided the following statement:

> "*Airbus Helicopters is a global company. Engineering activities are performed in Europe and/or in Customer Centers Design Offices (including Airbus Helicopter Inc. and Vector Design Offices [no longer with Airbus] in the U.S.) and wherever the non-recurring costs are spent, they impact product cost of sales worldwide.*
>
> *Allocation of engineering activities is performed on a case-by-case basis for each project depending on competences/resources availability. Considering the maturity of the potential*

modifications required, it is premature to assess the workload distribution between U.S. and the rest of the world."

ROTORCRAFT PERFORMANCE DATA

This section presents estimates of performance penalties as provided by the OEMs, which are used in the Operator Cost section later in this appendix.

Aircraft performance was evaluated consistent with the methods used to evaluate OEM Costs. The aircraft models were separated by Parts 27 and 29; then Part 27 was broken into three subcategories. Costs for the four aircraft categories were determined using weighted averages based upon the estimated annual production of each model of helicopter, thus giving appropriate weight to each helicopter model based upon the quantity expected to be produced. From there, performance was evaluated based on the following criteria:

- Reduction in payload
- Reduction in fuel capacity
- Increase in fuel consumption

Reduction in Payload

Table 18 outlines the weighted average reduction in payload for each of the four aircraft categories due to the increase in basic empty weight required to comply with the applicable regulatory changes. The increase in basic empty weight is required due to the incorporation of:

- Energy absorbing seats
- Strengthening of structure to restrain occupants and items of mass in the cabin

In addition to these factors, for some helicopter models, compliance with the recommended regulatory changes would reduce the number of passengers due to the inability to install complaint seats; in those instances, it was assumed that the "effective" loss of payload due to the loss of a passenger was equal to 85 pounds per lost passenger (see Operator Cost section later in this appendix).

Table 18. Weighted Average Reduction in Effective Payload, ROPWG Recommendations

Subcategory	Average Reduction in Effective Payload (lb)
Part 27 – Single Piston	37.9
Part 27 – Single Turbine	97.6
Part 27 – Twin Turbine	0.0
Part 29	158.2

Reduction in Fuel Capacity
Fuel capacity reductions generally resulted from the requirement to reduce the size of fuel tank in order to incorporate stroking (energy absorbing) seats. Table 19 outlines the average fuel capacity reduction by aircraft category.

Table 19. Weighted Average Reduction in Fuel Capacity, ROPWG Recommendations

Subcategory	Average Reduction in Fuel Capacity (lb)
Part 27 – Single Piston	0.0
Part 27 – Single Turbine	4.5
Part 27 – Twin Turbine	0.0
Part 29	0.0

Increase in Fuel Consumption
In general, engine fuel consumption increases as aircraft weight increases, however the impact is platform dependent and is often influenced by several variables. The FAA has previously used 0.005 gallon per pound per hour; since this value was within the range that each OEM provided for their respective models, for consistency this FAA-accepted value was selected for this study[27]. This value was used by the operators to determine additional fuel costs per year based on their operations.

[27] Castedo, J. (2014). *Regulatory Evaluation: Air Ambulance and Commercial Helicopter Operations, Part 91 Helicopter Operations, and Part 135 Aircraft Operations; Safety Initiatives and Miscellaneous Amendments.* Washington, DC: U.S. Dept. of Transportation, FAA, Office of Aviation Policy and Plans, Operations Regulatory Analysis Branch, APO-310

OPERATOR COST DATA

Overview

Revising older airframe designs to comply with the recommended regulatory changes generally requires an increase in empty weight, reduced fuel capacity, and a resulting reduced range and/or reduced seating capacity of the affected rotorcraft. These changes in the aircraft will result in significant monetary costs to operators by requiring affected operators to make any or all of the following changes to their operations:

- Reducing the number of passengers and/or cargo capacity
- Reducing the fuel load and therefore reducing the range of the aircraft
- Experiencing an increase in fuel burn rate due to greater empty weight

To estimate the cost due to the reduction in passengers and cargo, the following methodology was used:

Total Yearly Cost to Industry = N * C * H * P

where,

N =The number of helicopters in the U.S. fleet that are subject to the regulatory changes under consideration

C = Average baseline cost (before the regulatory changes take effect) to operate a single helicopter, in USD per flight hour

H = Average number of flight hours per year per aircraft

P = Average percentage increase in costs/reduction in revenue per flight hour

The average percentage increase in costs was for each of the different factors was calculated as detailed below. Determination of the other variables (flight hours, fleet size, etc.) follows the cost factor analysis.

Percentage Increase in Operator Costs Due to Reduction of Payload

For purposes of this analysis, increases in operator costs were considered equivalent to decreases in operator revenue.

The percentage loss of revenue was assumed to be equal to the percentage loss of payload with full fuel. This assumption is based on the following reasoning:

For large and/or repetitive operations (ferrying groups of people, or transporting multiple loads of cargo), a decrease in passenger or cargo capacity will require a corresponding increase in the number of trips required to transport all the passengers or cargo, with a corresponding increase in costs. For instance, if the passenger capacity of a helicopter is reduced by 20%, then the number of trips required will increase by 25%, as will the cost to the operator. This burden can be met with additional trips by one helicopter, or the addition of additional helicopter(s) to the operator’s fleet.

For smaller operations (transporting, on average, less than the maximum passenger/cargo capacity of the helicopter), the reduced passenger/cargo capacity will not be needed most of the time, so the cost of those trips will remain the same. However, some percentage of the time, the reduced passenger/cargo capacity will require a second trip, doubling the cost of that operation. Assuming that the passenger/cargo load is evenly distributed between zero passengers/cargo and maximum passengers/cargo, the increase in the number of flights required is equal to the percentage reduction in passenger/cargo capacity. For instance, if the passenger capacity of a helicopter is reduced by 20%, then 80% of the time the flight can be completed as before at no additional (payload related) cost, but 20% of the time, a second flight will be required with a corresponding 100% increase in the cost of that trip. The resultant average increase in cost is therefore:

20% chance of second flight * 100% cost of second flight = 20% average increase in cost

For each of the recommended regulatory changes, initial payload and loss of payload data was estimated by the participating OEMs, and used to calculate a weighted average for the four aircraft categories (Table 20).

Table 20. Resultant Increase in Operator Costs/Decrease in Operator Revenue Due to Reduction of Payload, Per Year, ROPWG Recommendations							
Aircraft Type	**Number of Aircraft Affected per Year (N)**	**Weighted Average Operational Cost per Flight Hour (C)**	**Weighted Average Number of Flight Hours per Aircraft per Year (H)**	**Weighted Average Payload Before Required Modifications (full fuel; lb)**	**Weighted Average Effective Reduction in Payload (lb)**	**Weighted Average Percentage Increase in Operator Costs/Decrease in Operator Revenue (%)**	**Resultant Total Increase in Operator Costs/Decrease in Operator Revenue Due to Reduction in Payload, per Year**
					CRSS	**CRSS**	**CRSS**
Single Engine Piston	85	$201	298	632	37.9	6.0%	$305,377
Single Engine Turbine	84	$463	338	1199	97.6	8.1%	$1,069,294
Twin Turbine (Part 27)	3	$950	500	3125	0.0	0.0%	$0
Part 29	13	$1,114	627	3646	158.2	4.3%	$393,724
						Total	**$1,768,395**

Percentage Increase in Operator Costs Due to Reduction in Fuel Capacity/Range

The cost to operators of reduced fuel capacity/reduced range assumed that for a percentage of flights equal to the percent reduction in fuel capacity/range, operators would have to use a different helicopter at an additional cost of 20% per flight hour. This assumption is based on the following reasoning:

- Assuming that the distance flown by a helicopter is evenly distributed between zero and the (original) maximum range of the helicopter, the percentage of flights that will be beyond the range of the "modified" helicopter is equal to the percentage reduction in range. For instance, if the range of a helicopter is reduced by 5%, then 95% of the time flights can be completed as before at no additional (range-related) cost, but 5% of the time, a different helicopter with a longer range will be required.

- The 20% cost factor was the average estimate by the participating OEMs for the typical increase in hourly operating costs required when upgrading to helicopters with increased range. Alternatively, rather than using a different helicopter, the existing helicopter could possibly be outfitted with a larger/additional fuel tank, and/or refueling stops could be added to the operation. While these alternate solutions would not require the use of a more expensive helicopter, they would require additional costs in the form of fleet upgrades (for extra fuel capacity), loss of passenger/cargo capacity (due to the installation of the extra/larger fuel tanks), extra time (to stop for refueling), and/or extra logistical costs (to preposition the fuel at the refueling point). It was estimated by the OEMs that the cost of these alternative solutions is comparable to the 20% cost of using a different helicopter.

- The estimates for number of affected aircraft, cost per flight hour, and number of flight hours per year are the same as those detailed for the payload calculations (Table 21). The average fuel capacity for each model was provided by the OEMs and used to calculate a weighted average for the four aircraft categories.

Table 21. Resultant Increase in Operator Costs/Decrease in Operator Revenue, Per Year Due to Reduction in Range, ROPWG Recommendations

Aircraft Type	Number of Aircraft Affected per Year	Weighted Average Operational Cost per Flight Hour	Weighted Average Number of Flight Hours per Aircraft per Year	Weighted Average Fuel Capacity Before Required Modifications (U.S. gallons)	Weighted Average Reduction in Fuel Capacity (U.S. gallons)	Weighted Average Reduction in Fuel Capacity (%)	Percentage Increase in Costs for Helicopter with Longer Range (%)	Resultant Total Increase in Operator Costs/Decrease in Operator Revenue, per Year
					CRSS	CRSS		CRSS
Single Engine Piston	85	$201	298	43	0.0	0.0%	20.0%	$0
Single Engine Turbine	84	$463	338	127	0.7	0.5%	20.0%	$13,782
Twin Turbine (Part 27)	3	$950	500	146	0.0	0.0%	20.0%	$0
Part 29	13	$1,114	627	323	0.0	0.0%	20.0%	$0
							Totals	**$13,782**

Percentage Increase in Operator Costs Due to Increase in Fuel Consumption

As noted in the Summary of the Rotorcraft Performance Data section, the increase in empty weight of the affected aircraft will increase fuel consumption. As stated in that section, the increased fuel consumption was assumed to be 0.005 gallons/flight hour/extra pound of empty weight. The extra fuel burn and cost was calculated using the previous estimates for the number of affected aircraft and the number of flight hours flown per year (Table 22). The assumed average fuel cost was a nationwide average of Jet A and 100LL fuel prices as reported by www.100LL.com on August 22, 2016. The estimated change in empty weight used in the range calculations was the same as that outlined for the operator costs related to loss of payload.

Table 22. Resultant Increase in Operator Fuel Costs, Per Year, ROPWG Recommendations						
Aircraft Type	**Number of Aircraft Affected per Year**	**Weighted Average Number of Flight Hours per Aircraft per Year**	**Additional Fuel Burn Rate (gallons/lb/hour)**	**Cost of Fuel (2016 USD/gallon)**	**Weighted Average of Increase in Empty Weight Due to Proposed Regulatory Changes (lb)**	**Resultant Total Increase in Operator Fuel Costs, per Year**
					CRSS	**CRSS**
Single Engine Piston	85	298	0.005	$4.99	37.9	$23,970
Single Engine Turbine	84	338	0.005	$4.20	97.6	$58,121
Twin Turbine (Part 27)	3	500	0.005	$4.20	0.0	$0
Part 29	13	627	0.005	$4.20	158.2	$27,068
					Totals	**$109,159**

Additional Variables

Below is a detailed description of the parameters used to estimate the additional operator costs due to a reduction in payload/passengers, a reduction in fuel capacity/range, and an increase in the fuel burn rate.

Number of Affected Helicopters

Sales forecast data provided by the FAA (http://www.faa.gov/data_research/aviation/aerospace_forecasts/media/FY2016-36_FAA_Aerospace_Forecast.pdf, Tables 28-31) projects the following average U.S. sales for the next 10 years:

Piston helicopters: 85/year
Turbine helicopters: 200/year

Based on data from the participating OEMs, all the piston aircraft were assumed to be non-compliant and therefore affected by the proposed regulatory changes, while 50% (100 aircraft) of the turbine market was estimated to be affected.

Of those 100 affected turbine aircraft, model-specific sales figures provided by the OEMs were used to generate the following estimated breakdown by aircraft group:

Part 27 Single Turbine: 84/year
Part 27 Twin Turbine: 3/year
Part 29: 13/year

Baseline Operator Cost per Flight Hour

Model-specific direct operating cost estimates were provided by the participating OEMs for most of the helicopter models that would be affected by the proposed regulations. These costs represent the present day estimated hourly direct operating costs (before the required modifications). These costs were combined in a weighted average for each of the subgroups based on the estimated future sales of each helicopter model.

Flight Hour Estimates

Yearly flight hour estimates were available to some of the OEMs, and were combined in a weighted average for each of the subgroups.

Total Increase in Operator Costs

For the helicopters manufactured in the first year after the proposed changes are required, the total yearly cost to operators from the considerations detailed above (reduction in payload, reduction in fuel capacity, and increase in fuel consumption) is shown in Table 23. Consistent with other sections of this report, data is summarized for four different classes of helicopter and was determined using weighted averages based upon the estimated annual production of each model of helicopter. Thus, giving appropriate weight to each helicopter model based upon the quantity expected to be produced.

Table 23. Total Increase in Operator Costs/Decrease in Operator Revenue Due to Changes in Payload, Fuel Capacity, and Range, Per Year, ROPWG Recommendations

Aircraft Type	CRSS
Single Engine Piston	$316,711
Single Engine Turbine	$1,129,148
Twin Turbine (Part 27)	$0
Part 29	$414,078
Total	**$1,859,937**

While this total yearly cost to operators is relatively small in comparison to the non-recurring OEM costs, this is an annual recurring cost for the operator, which grows at an accelerated pace as more affected helicopters enter the fleet. Helicopters that are manufactured in Year 1 incur this annual increase in cost of operation each year in Year 1 through Year 10 (and all subsequent years), helicopters manufactured in Year 2 incur this annual increase cost of operation each year in Year 2 through Year 10, and so forth. As a result, in the first 10 years after the proposed regulations take effect, the total cumulative additional operator cost is:

Cumulative cost = Additional operator cost for Year 1 * (10 + 9 + 8 + ... + 2 + 1)

or

Cumulative cost = Additional operator cost for Year 1 * 55

Note that this 10-year cost analysis (Table 24) simply adds together the costs for each of the first 10-years of affected helicopters. It does not account for interest nor use any other more sophisticated financial analysis.

Table 24. Cumulative Increase in Operator Costs/Decrease in Operator Revenue Due to Reduction in Payload, Fuel Capacity, and Range, First 10 Years After Regulatory Changes, ROPWG Recommendations	
Aircraft Type	**CRSS**
Single Engine Piston	$17,419,119
Single Engine Turbine	$62,103,159
Twin Turbine (Part 27)	$0
Part 29	$22,774,283
Total	**$102,296,561**

Cost Impact of Miscellaneous Operator Issues

Replacement of fleet aircraft may be required by some operators due to the inability of affected aircraft to comply with published government contract terms. As an example, based upon OEM data presented in the Summary of Rotorcraft Performance Data section of the ROPWG Task 2 Report, full compliance for the AS350B incurs an additional weight load that virtually eliminates its application with currently bid U.S. government contracts already in place. If governmental agencies are unwilling to reduce payload requirements currently published for contract use for the purposes of meeting new Part 27 compliance, operators will have great difficulty competing for future bids utilizing currently published (unrevised) U.S. Government specifications. Operators utilizing the AS350B will likely have to identify an alternative aircraft for this business line, with an increased operational cost.

Data from air medical operators demonstrates the following impacts to fleet operations:

- Part 27 and 29 aircraft are dispatch-ready with a fuel load of 400 pounds. The payload reductions specified in the Rotorcraft Performance Section of the ROPWG Task 2 Report will therefore substantially reduce the range of the average air medical helicopter, as patient weight is nominally fixed.
- Changes in aircraft capability have the potential to reduce access to rural patients because affected aircraft will be unable to operate far enough from receiving hospitals to make a meaningful difference in transport times for ill or injured patients.

It is difficult to estimate the impact to aircraft insurance costs; while the possible decrease in injuries or fatalities may result in lower payouts following an accident, this may be offset by higher aircraft replacement prices set by OEMs for aircraft that comply with the applicable regulations.

Additional Monetary Considerations

Older airframes revised to meet the applicable regulations may not meet an operator’s existing contract requirements due to the performance penalties discussed above, forcing the operators to renegotiate contracts or purchase a different model helicopter. Unfortunately, it was not possible to provide a meaningful dollar estimate for this cost.

SUMMARY OF ESTIMATED COSTS TO INDUSTRY FOR COMPLIANCE WITH RECOMMENDED REGULATORY CHANGES

Non-recurring costs, 10-year anticipated unit cost increase, and 10-year operator cost increases caused by compliance with the recommended regulatory changes are combined and summarized in Table 25. All costs are shown in 2016 dollars. The costs are broken down by Part 27 and Part 29. Note that the total estimated 10-year increased industry costs for CRSS were estimated at approximately $322,000,000.

Table 25. Summary of 10-Year Industry Costs (USD) of Compliance for Models Still in Production, ROPWG Recommendations

Cost Category	Part 27	Part 29	Combined Costs Parts 27 & 29
Non-recurring Cost	$39,280,000	$72,000,000	$111,280,000
10-Year Unit Cost Increase	$47,524,000	$60,990,000	$108,514,000
Total 10-Year OEM Costs	$86,804,000	$132,990,000	$219,794,000
10-Year Operator Cost Increase	$79,522,278	$22,774,283	$102,296,561
Total 10-Year Estimated Industry Cost	**$166,326,278**	**$155,764,283**	**$322,090,561**

Table 26 shows projected costs and present value costs discounted at an annual 7% for OEMs over a 10-year period if the recommended regulatory changes are applied to new production rotorcraft, both Part 27 and Part 29, in 2020. Present value costs account for the decreasing value of money with time due to an estimated 7% annual investment return rate over the next 10-year period. The costs for year 2020 include non-recurring costs plus annual unit costs. For the remaining years, only annual unit costs are included based on the assumption that unit costs are paid in the first year.

Table 26. Costs and Present Value Costs for OEMs Over 10-Years, ROPWG Recommendations		
Calendar Year	**Costs in 2016 Dollars**	**Present Value Costs at 7%**
2015		
2016		
2017		
2018		
2019		
2020	$122,131,400	$93,173,460
2021	$10,851,400	$7,736,898
2022	$10,851,400	$7,230,746
2023	$10,851,400	$6,757,707
2024	$10,851,400	$6,315,614
2025	$10,851,400	$5,902,443
2026	$10,851,400	$5,516,302
2027	$10,851,400	$5,155,422
2028	$10,851,400	$4,818,151
2029	$10,851,400	$4,502,945
Total	**$219,794,000**	**$147,109,687**

Table 27 shows projected 2016 costs and present value costs discounted at 7% for both OEMs and operators over a 10-year period if the recommended regulatory changes are applied to new production rotorcraft, both Part 27 and Part 29, in 2020. Table 28 provides a comparison of this data.

Table 27. Costs and Present Value Costs for OEMs and Operators Over 10-Years, ROPWG Recommendations		
Calendar Year	**Costs in 2016 Dollars**	**Present Value Costs at 7%**
2015		
2016		
2017		
2018		
2019		
2020	$123,991,337	$94,592,398
2021	$14,571,275	$10,389,118
2022	$16,431,212	$10,948,811
2023	$18,291,150	$11,390,809
2024	$20,151,087	$11,728,116
2025	$22,011,025	$11,972,539
2026	$23,870,962	$12,134,787
2027	$25,730,900	$12,224,565
2028	$27,590,837	$12,250,662
2029	$29,450,775	$12,221,024
Total	**$322,090,561**	**$199,852,828**

Table 28. 10-Year Total Projected Costs and Present Value Costs, ROPWG Recommendations		
Calendar Year	**Costs in 2016 Dollars**	**Present Value Costs at 7%**
OEM Costs	$219,794,000	$147,109,687
Operator Costs	$102,296,561	$52,743,141
Total	**$322,090,561**	**$199,852,828**

Reduction of Safety Margins

The ROPWG members with aircraft engineering and operator expertise expressed cautionary concerns about the effects of the proposed regulatory changes on smaller Part 27 aircraft. The empty weight and fuel capacity/range penalties outlined in this report 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 task 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 number and severity of injuries per accident would be offset by an increase in the number of accidents. 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 are significant, especially for smaller helicopters.

APPENDIX C: DETAILED COSTS, REVISED FULL COMPLIANCE ESTIMATES

Since the submittal of the Task 2 report that detailed the costs for full compliance, one helicopter model that was part of that analysis was subsequently discontinued by the manufacturer. Since the new cost estimates based on the ROPWG recommendations were developed without the costs associated with the recently-discontinued model, the ROPWG recommendation estimates would appear artificially low relative to the original full-compliance estimates since the full-compliance estimates included the costs of the now-discontinued model. Therefore, to provide a more meaningful comparison between the cost/performance penalties for full compliance and the ROPWG recommendations, the full-compliance estimates from the Task 2 report have been revised to reflect the current set of applicable helicopters with active production. These revised cost estimates are presented in this appendix.

Additionally, while developing the cost/performance penalties associated with the ROPWG recommendations, several OEMs found that their original cost/performance penalty estimates for full compliance could be revised based on new data and insight developed since the submittal of the Task 2 report. These revisions are incorporated in the revised full-compliance estimates presented in this appendix.

The revised cost/performance penalty estimates for full compliance were developed using the identical methodology that is detailed in the Task 2 report submitted on November 10, 2016. This is also the same methodology that is utilized and detailed in Appendix B of this report for the ROPWG recommendations. Therefore, rather than detailing the methodology again, only the revised cost/performance penalty tables for full compliance with 27/29.561, 27/29.562, and 27/29.785 are included here.

Note that all costs are presented in 2016 dollars to be consistent with previous ROPWG reports.

Table 29. Industry Total Non-Recurring Costs (USD) of Compliance for Models Still in Production, Revised Estimates for Full Compliance

Rotorcraft Groups	Non-recurring Cost, CRSS (.561, .562, .785)
Part 27 - Single Piston	$19,150,000
Part 27 - Single Turbine	$93,000,000
Part 27 - Twin Turbine	$300,000
Part 29	$72,700,000
All Groups Combined	**$185,150,000**

Table 30. Unit Costs (USD) to Bring Models Still in Production Up to Standard, Revised Estimates for Full Compliance				
Rotorcraft Groups	**Estimated Annual Production**	**Weighted Average Unit Costs (.561, .562, .785) (per aircraft)**	**Total Annual Unit Costs (.561, .562, .785)**	**10-Year Total Unit Cost Increase (.561, .562, .785)**
Part 27 - Single Piston	85	$12,753	$1,084,000	$10,840,000
Part 27 - Single Turbine Models	84	$96,381	$8,096,000	$80,960,000
Part 27 - Twin Turbine	3	$1,000	$3,000	$30,000
Total Part 27	172	N/A	$9,183,000	$91,830,000
Total Part 29	13	$480,692	$6,249,000	$62,490,000
All Groups Combined	**185**	**N/A**	**$15,432,000**	**$154,320,000**

Table 31. Total Increase in Operator Costs/Decrease in Operator Revenue Due to Changes in Payload, Fuel Capacity, and Range, Per Year, Revised Estimates for Full Compliance	
Aircraft Type	**CRSS: .561, .562, .785**
Single Engine Piston	$421,605
Single Engine Turbine	$1,820,668
Twin Turbine (Part 27)	$0
Part 29	$713,216
Total	**$2,955,490**

Table 32. Cumulative Increase in Operator Costs/Decrease in Operator Revenue Due to Reduction in Payload, Fuel Capacity, and Range, First 10 Years After Regulatory Changes, Revised Estimates for Full Compliance	
Aircraft Type	**CRSS: .561, .562, .785**
Single Engine Piston	$23,188,281
Single Engine Turbine	$100,136,747
Twin Turbine (Part 27)	$0
Part 29	$39,226,895
Total	**$162,551,923**

Table 33. Weighted Average Reduction in Effective Payload, Revised Estimates for Full Compliance	
Subcategory	**Average Reduction in Effective Payload (lbs.) CRSS: .561, .562, .785**
Part 27 – Single Piston	50.0
Part 27 – Single Turbine	157.3
Part 27 – Twin Turbine	0.0
Part 29	271.8

Table 34. Weighted Average Reduction in Fuel Capacity, Revised Estimates for Full Compliance	
Subcategory	**Average Reduction in Fuel Capacity (lb) CRSS: .561, .562, .785**
Part 27 – Single Piston	0.0
Part 27 – Single Turbine	5.4
Part 27 – Twin Turbine	0.0
Part 29	0.0

Table 35. Summary of 10-Year Industry Costs (2016 USD) of Compliance for Models Still in Production, Revised Estimates for Full Compliance			
Cost Category	**Part 27**	**Part 29**	**Combined Costs Parts 27 & 29**
Non-recurring Cost (.561, .562, .785)	$112,450,000	$72,700,000	$185,150,000
10-Year Unit Cost Increase (.561, .562, .785)	$91,830,000	$62,490,000	$154,320,000
Total 10-Year OEM Costs	$204,280,000	$135,190,000	$339,470,000
10-Year Operator Cost Increase	$123,325,028	$39,226,895	$162,551,923
Total 10-Year Estimated Industry Cost	**$327,605,028**	**$174,416,895**	**$502,021,923**

Table 36. Costs and Present Value Costs for OEMs Over 10-Years, Revised Estimates for Full Compliance		
Calendar Year	**Costs in 2016 Dollars**	**Present Value Costs at 7%**
2015		
2016		
2017		
2018		
2019		
2020	$200,582,000	$153,023,047
2021	$15,432,000	$11,002,803
2022	$15,432,000	$10,282,993
2023	$15,432,000	$9,610,274
2024	$15,432,000	$8,981,565
2025	$15,432,000	$8,393,986
2026	$15,432,000	$7,844,846
2027	$15,432,000	$7,331,632
2028	$15,432,000	$6,851,993
2029	$15,432,000	$6,403,731
Total	**$339,470,000**	**$229,726,870**

Table 37. Costs and Present Value Costs for OEMs and Operators Over 10-Years, Revised Estimates for Full Compliance		
Calendar Year	**Costs in 2016 Dollars**	**Present Value Costs at 7%**
2015		
2016		
2017		
2018		
2019		
2020	$203,537,490	$155,277,776
2021	$21,342,979	$15,217,249
2022	$24,298,469	$16,191,096
2023	$27,253,958	$16,972,395
2024	$30,209,448	$17,582,174
2025	$33,164,937	$18,039,528
2026	$36,120,427	$18,361,793
2027	$39,075,916	$18,564,686
2028	$42,031,406	$18,662,447
2029	$44,986,895	$18,667,962
Total	**$502,021,923**	**$313,537,106**

Table 38. 10-Year Total Projected Costs and Present Value Costs, Revised Estimates for Full Compliance		
Calendar Year	**Costs in 2016 Dollars**	**Present Value Costs at 7%**
OEM Costs	$339,470,000	$229,726,870
Operator Costs	$162,551,923	$83,810,237
Total	**$502,021,923**	**$313,537,106**

Table 39. Resultant Increase in Operator Costs/Decrease in Operator Revenue Due to Reduction of Payload, Per Year, Revised Full Compliance Estimates							
Aircraft Type	**Number of Aircraft Affected per Year (N)**	**Weighted Average Operational Cost per Flight Hour (C)**	**Weighted Average Number of Flight Hours per Aircraft per Year (H)**	**Weighted Average Payload Before Required Modifications (full fuel; lb)**	**Weighted Average Effective Reduction in Payload (lb)**	**Weighted Average Percentage Increase in Operator Costs/Decrease in Operator Revenue (%)**	**Resultant Total Increase in Operator Costs/Decrease in Operator Revenue Due to Reduction in Payload, per Year**
					.561, .562, .785	**.561, .562, .785**	**.561, .562, .785**
Single Engine Piston	85	$201	298	632	50.0	7.9%	$402,637
Single Engine Turbine	84	$463	338	1199	157.3	13.1%	$1,722,501
Twin Turbine (Part 27)	3	$950	500	3125	0.0	0.0%	$0
Part 29	13	$1,114	627	3646	271.8	7.5%	$676,761
						Total	**$2,801,899**

Table 40. Resultant Increase in Operator Costs/Decrease in Operator Revenue, Per Year Due to Reduction in Range, Revised Full Compliance Estimates								
Aircraft Type	Number of Aircraft Affected per Year	Weighted Average Operational Cost per Flight Hour	Weighted Average Number of Flight Hours per Aircraft per Year	Weighted Average Fuel Capacity Before Required Modifications (U.S. gallons)	Weighted Average Reduction in Fuel Capacity (U.S. gallons)	Weighted Average Reduction in Fuel Capacity (%)	Percentage Increase in Costs for Helicopter with Longer Range (%)	Resultant Total Increase in Operator Costs/Decrease in Operator Revenue, per Year
					.561, .562, .785	.561, .562, .785		.561, .562, .785
Single Engine Piston	85	$201	298	43	0.0	0.0%	20.0%	$0
Single Engine Turbine	84	$463	338	127	0.8	0.6%	20.0%	$16,590
Twin Turbine (Part 27)	3	$950	500	146	0.0	0.0%	20.0%	$0
Part 29	13	$1,114	627	323	0.0	0.0%	20.0%	$0
							Totals	**$16,590**

Table 41. Resultant Increase in Operator Fuel Costs, Per Year, Revised Full Compliance Estimates						
Aircraft Type	Number of Aircraft Affected per Year	Weighted Average Number of Flight Hours per Aircraft per Year	Additional Fuel Burn Rate (gallons/lb/hour)	Cost of Fuel (2016 USD/gallon)	Weighted Average of Increase in Empty Weight Due to Proposed Regulatory Changes (lb)	Resultant Total Increase in Operator Fuel Costs, per Year
					CRSS	CRSS
Single Engine Piston	85	298	0.005	$4.99	50.0	$31,604
Single Engine Turbine	84	338	0.005	$4.20	157.3	$93,626
Twin Turbine (Part 27)	3	500	0.005	$4.20	0.0	$0
Part 29	13	627	0.005	$4.20	271.8	$46,526
					Totals	**$171,756**

APPENDIX D: CALCULATION OF BENEFIT FROM REDUCED VELOCITY VERTICAL DYNAMIC SEAT TESTS

The benefit of the reduced velocity vertical dynamic seat tests was calculated using data from the following studies:

- "Spinal Injury in a U.S. Army Light Observation Helicopter", Aviation, Space, and Environmental Medicine, 55(1):32-40, 1984. Prepared for the U.S. Army by Dennis Shanahan and George Mastroianni.
- CT-85/11, "Analysis of Rotorcraft Crash Dynamics for Development of Improved Crashworthiness Design Criteria". Prepared for the FAA.

These studies are first discussed individually, followed by an analysis combining data from the two studies.

SPINAL INJURY IN A U.S. ARMY LIGHT OBSERVATION HELICOPTER

This study analyzed the ground impact accident experience of OH-58A/C Kiowa, a U.S. Army light observation helicopter fitted with conventional (non-stroking/non-energy absorbing) seats, and which is a derivative of the Bell Jet Ranger 206B.

Of particular interest to the present report, the study determined the probability of serious spinal injury as a function of vertical impact velocity. The data was analyzed by grouping the accidents into vertical impact velocity ranges spanning 10 ft/s (0-10, 10-20, etc.), and determining the percentage of occupants in each group that received spinal injuries. The spinal injuries were further identified as one of the following:

- Back strain
- Fracture/dislocation
- Multiple extreme injury (individuals who sustained fatal injuries to more than one major body area or system)

The data was further limited to survivable and partially survivable accidents.

The raw data is presented in Table 42 and Figure 7 below, and shows the percentage of occupants receiving spinal injuries as a function of vertical impact velocity (impact velocities were converted to ft/s for the present report):

Table 42. Injury Data from "Spinal Injury in a U.S. Army Light Observation Helicopter" Survivable and Partially Survivable Accidents in OH-58A/C Kiowa					
Vertical Impact Velocity (ft/s)	Percentage of Occupants Receiving Specified Spinal Injury				
	Back Strain	Fracture/Dislocation	Multiple Extreme	Any	Fracture or Extreme
0-10	2%	1%	0%	3%	1%
11-20	10%	8%	0%	18%	8%
21-30	17%	60%	9%	86%	69%
31-40	11%	44%	44%	99%	88%
40-50	0%	17%	66%	83%	83%

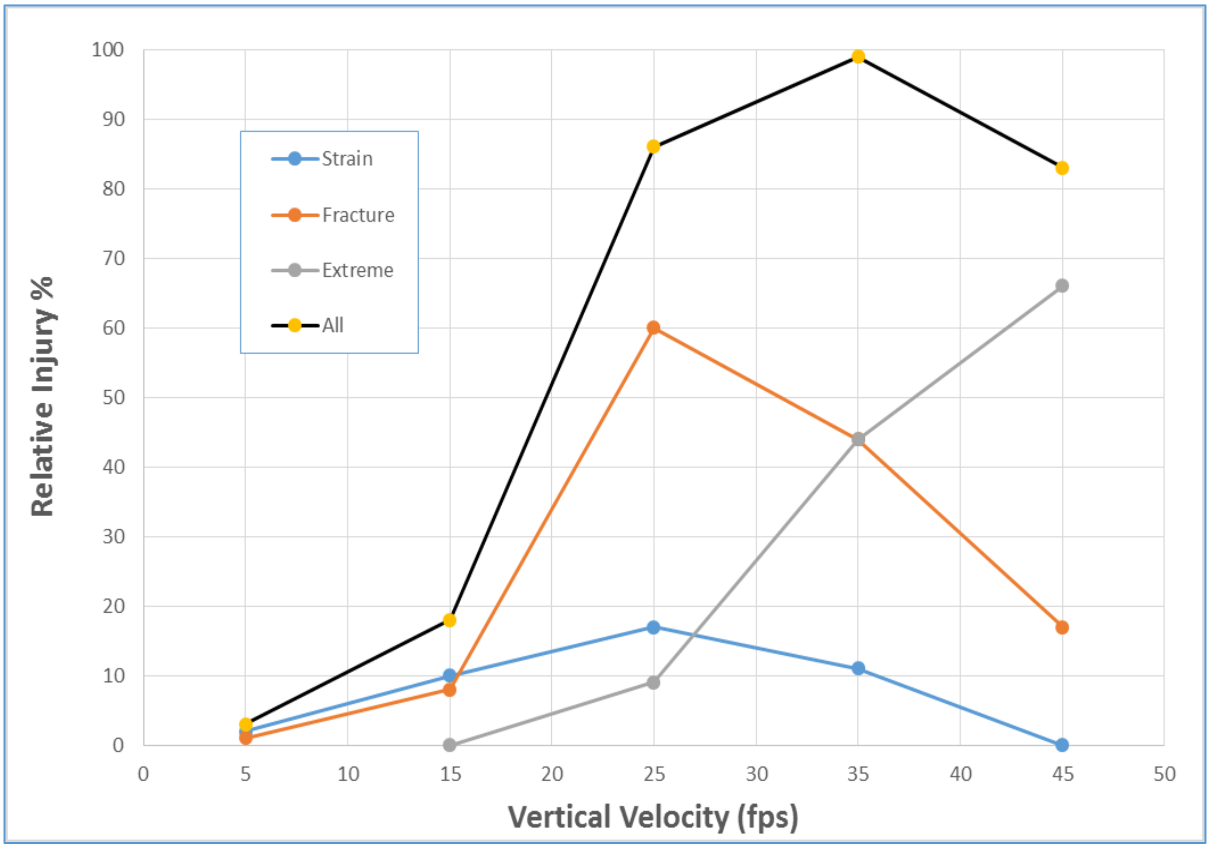

Figure 7: Percentage of Occupants with Spinal Injuries vs. Vertical Impact Velocity
Injury Data from "Spinal Injury in a U.S. Army Light Observation Helicopter"
Survivable and Partially Survivable Accidents in OH-58A/C Kiowa

As would be expected, the data generally show the following trends:

- At low vertical impact velocities, there is a small probability of spinal injury
- As vertical impact velocity increases, a threshold is met above which spinal injuries become much more probable
- At high vertical impact velocities, the probability of spinal injury approaches 100%

For purposes of this analysis, a curve fit was applied to this data, and is presented in Figure 8 below. The data fit used the following parameters:

- Only fracture and extreme injuries were included, as "back strain" is a broad term that could have many causes not addressed by energy absorbing seats
- The 45 ft/s data point was not included. As discussed by Shanahan, this point is considered an outlier, as there is no rational reason to believe that the probability of injury would decrease at impact velocities above 45 ft/s. Shanahan further reports that the data likely show this trend due to the fact that accidents at this speed in the Kiowa were generally severe, with many occupants receiving fatal non-spinal injuries as well as severe spinal injuries; these data would not be included in the plot as it is confined to survivable and partially survivable accidents only.

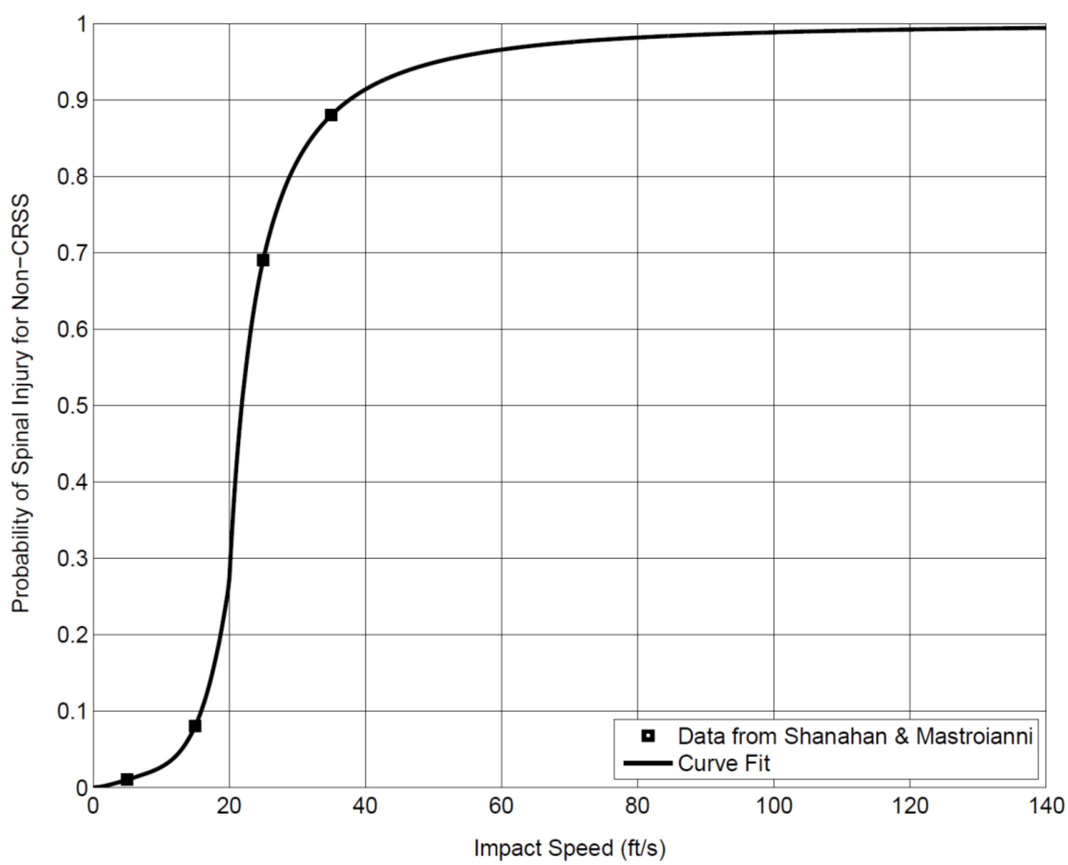

Figure 8: Probability of Serious Spinal Injury vs. Vertical Impact Speed
Non-CRSS OH58A/C, Data from Shanahan & Mastroianni

CT-85/11, "ANALYSIS OF ROTORCRAFT CRASH DYNAMICS FOR DEVELOPMENT OF IMPROVED CRASHWORTHINESS DESIGN CRITERIA"

As discussed previously, CT-85/11 provides vertical impact velocity distribution data for "significantly survivable" crashes for civil helicopters over a 5-year period from 1974-1978. This data was presented in Figure 5 in the main body of this report, and is reproduced in Figure 9 below for convenience.

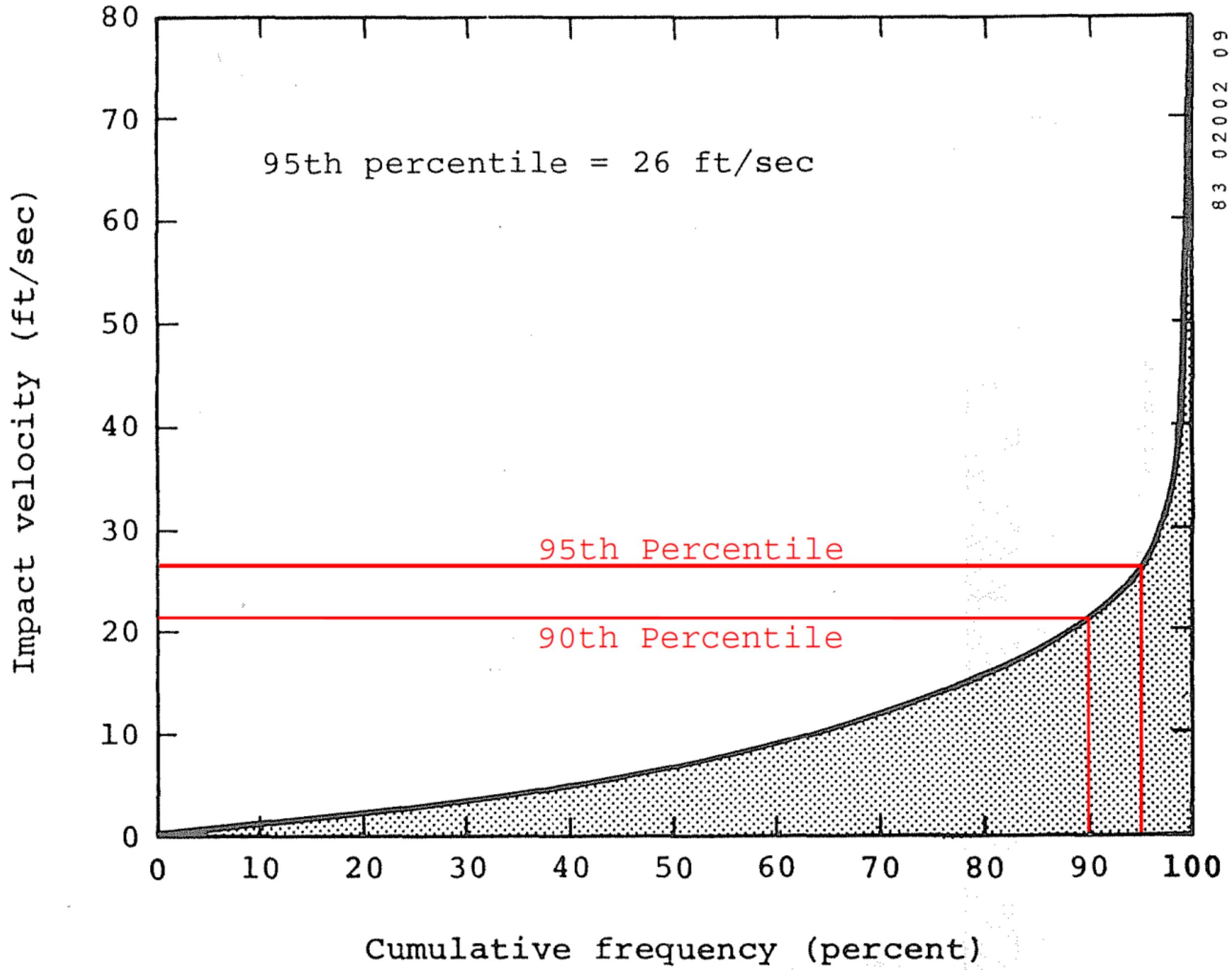

Figure 9: Vertical Impact Velocity Distribution for Civil Significant Survivable Accidents

Reproduced from CT-85/11, Figure 7

(95th and 90th percentile lines added by ROPWG)

COMBINED ANALYSIS OF SHANAHAN AND CT-85/11

The primary objective of incorporating energy absorbing seats is to reduce the total number of occupants that receive serious spinal injuries. This number is a function of the following parameters:

- The number of flights that take place
- The number of occupants on board each flight
- The accident rate per flight
- The vertical velocity distribution of those accidents
- The probability of spinal injury as a function of vertical impact velocity

Since for the purposes of this analysis the first three parameters can be assumed to be fixed, the total number of occupants that receive serious spinal injuries is therefore proportional to the last two parameters:

- The vertical velocity distribution of accidents
- The probability of spinal injury as a function of vertical impact velocity

With this data, one can calculate the overall probability of serious spinal injury by multiplying the probability of spinal injury at a given impact velocity by the probability of an accident occurring at that velocity, and then integrating over impact velocity. That is, for each finite division of impact velocity (for instance, 15 to 16 ft/s), multiply the probability of serious spinal injury for an accident with that velocity (8% per the regression fit for Shanahan in Figure 8) by the probability of an accident occurring at that velocity (approximately 3% per CT-85/11: 82% of accidents have a vertical velocity less than or equal to 16 ft/s, and 79% have a vertical velocity less than or equal to 15 ft/s, therefore 3% occur in the range of 15 to 16 ft/s). The result is 8% * 3% = 0.24% - this is the probability that if an accident occurs, it will have an impact velocity of 15-16 ft/s AND the occupant will receive a serious spinal injury. By performing this calculation for every division of impact velocity (0-1 ft/s, 1-2, 2-3, etc.) and summing the result of each calculation, one arrives at the overall probability that an occupant will receive a serious spinal injury given the fact that an accident occurs.

<u>Probability of Serious Spinal Injury in a Non-Crashworthy Seat in a Civil Helicopter</u>

The example above calculates the probability that an occupant will receive a serious spinal injury in an accident, assuming that the accident distribution matches the civil distribution from CT-85/11, and the probability of serious spinal injury as a function of vertical impact velocity matches that of the non-crashworthy Kiowa (i.e., the seats do not absorb significant energy by stroking). The result obtained by integrating over the vertical impact velocity (not shown; performed by MATLAB) is that the overall probability of serious spinal injury, given that an accident occurs, is 11%. Said another way, if 100 occupants were involved in accidents in the Kiowa, and the vertical impact velocity distribution of those accidents matched that from CT-85/11, one would expect 11 of the occupants to receive serious spinal injuries.

Note that as stated previously, the AH-58A/C Kiowa is very similar to the Bell 206B Jet Ranger, a very common helicopter in the civil helicopter fleet. Therefore, it is reasonable to expect that the calculations presented here would be equally applicable to the Jet Ranger and the civil helicopter fleet at large.

Probability of Serious Spinal Injury in a Crashworthy (Energy Absorbing) Seat in a Civil Helicopter

The calculation above provides a benchmark injury rate for a non-crashworthy seat. By calculating the corresponding probability of serious spinal injury for an energy absorbing seat, one can determine the benefit of the energy absorbing seat. This analysis is performed in the same manner as described above, except the probability of spinal injury at a given vertical impact speed is different due to the energy absorption of the seat. In particular, the following assumptions are made:

- When the vertical impact velocity is equal to the design speed of the seat (i.e., 26 ft/s for a fully compliant seat), it is assumed that the occupant will experience a lumbar spine load of 1500 lb, as would be the case if the seat just barely passed the dynamic seat test. It is further assumed that the occupant in this situation will have a 9% chance of receiving a serious spinal injury - this is based on Dynamic Response Index (DRI) data showing that a DRI of 19 corresponds to a lumbar spine load of 1500 lb, and based on cadaver testing, a DRI of 19 corresponds to a spinal injury rate of 9%.[28]
- At vertical impact speeds above the design speed, the probability of serious spinal injury increases at a rate equal to the corresponding change in injury rate for Kiowa data from Shanahan. This assumption is based on the idea that at speeds in excess of the design speed, the seat absorbs an amount of energy proportional to its rating before bottoming out. That is, from the standpoint of the occupant, bottoming out in a 26 ft/s seat during a 27 ft/s impact will feel like a low velocity impact in a non-energy absorbing seat, as such seats can be thought of as effectively "bottomed out" before the accident occurs.

  For instance, to calculate the probability of spinal injury during a 31 ft/s impact in a 26 ft/s seat, we start from the assumption that had this been a 26 ft/s impact, the probability of serious spinal injury would have been 9% based on the data presented previously. Looking at the probability of serious spinal injury versus impact speed data in Figure 8, we see that a 9% probability of serious spinal injury in a non-crashworthy seat corresponds to a vertical impact velocity of 17 ft/s in a non-crashworthy seat. Since a 31 ft/s impact is 31-26 = 5 ft/s faster than a 26 ft/s impact, the equivalent impact speed for a non-crashworthy seat is 17 + 5 = 22 ft/s, which corresponds to a 60% probability of serious spinal injury per Figure 8. Therefore, we conclude that an occupant in a 31 ft/s vertical velocity impact in a 26 ft/s seat would have a 60% probability of sustaining a serious spinal injury.
- At vertical impact speeds up to and including the design speed of the seat, the assumptions and calculations are the same as those described above for impact speeds that exceed the design speed of the seat, with the following exception: At sufficiently slow impact speeds, the procedure above would result in a negative equivalent impact speed (for instance, a 6 ft/s impact in a 26 ft/s seat would correspond to a negative 3 ft/s impact in a non-crashworthy seat).

[28] Thyagarajan, R. et al. Occupant-Centric Platform (OCP) Technology Enabled Capabilities Demonstration (TECD): Comparing the Use of Dynamic Response Index (DRI) and Lumbar Load as Relevant Spinal Injury Metrics. U.S. Army Tank and Automotive Research, Development, and Engineering Center, TARDEC TR 24373, January 9, 2014.

For these cases, the probability of spinal injury was assumed to be equal to that for a non-crashworthy seat at the same impact speed (i.e., in a 6 ft/s impact in a 26 ft/s seat, the occupant is assumed to have the same probability of spinal injury as in a 6 ft/s impact in a non-crashworthy seat: 2%). This is reasonable since a typical energy absorber in a crashworthy seat will not stroke at all below a certain impact threshold, and therefore behaves the same as a non-crashworthy seat at those slower impact velocities.

This analysis was performed over the range of design vertical speeds from 0 to 26 ft/s (i.e., no energy absorption to fully compliant with 27/29.562(b)(1)). The result is shown below in Figure 10.

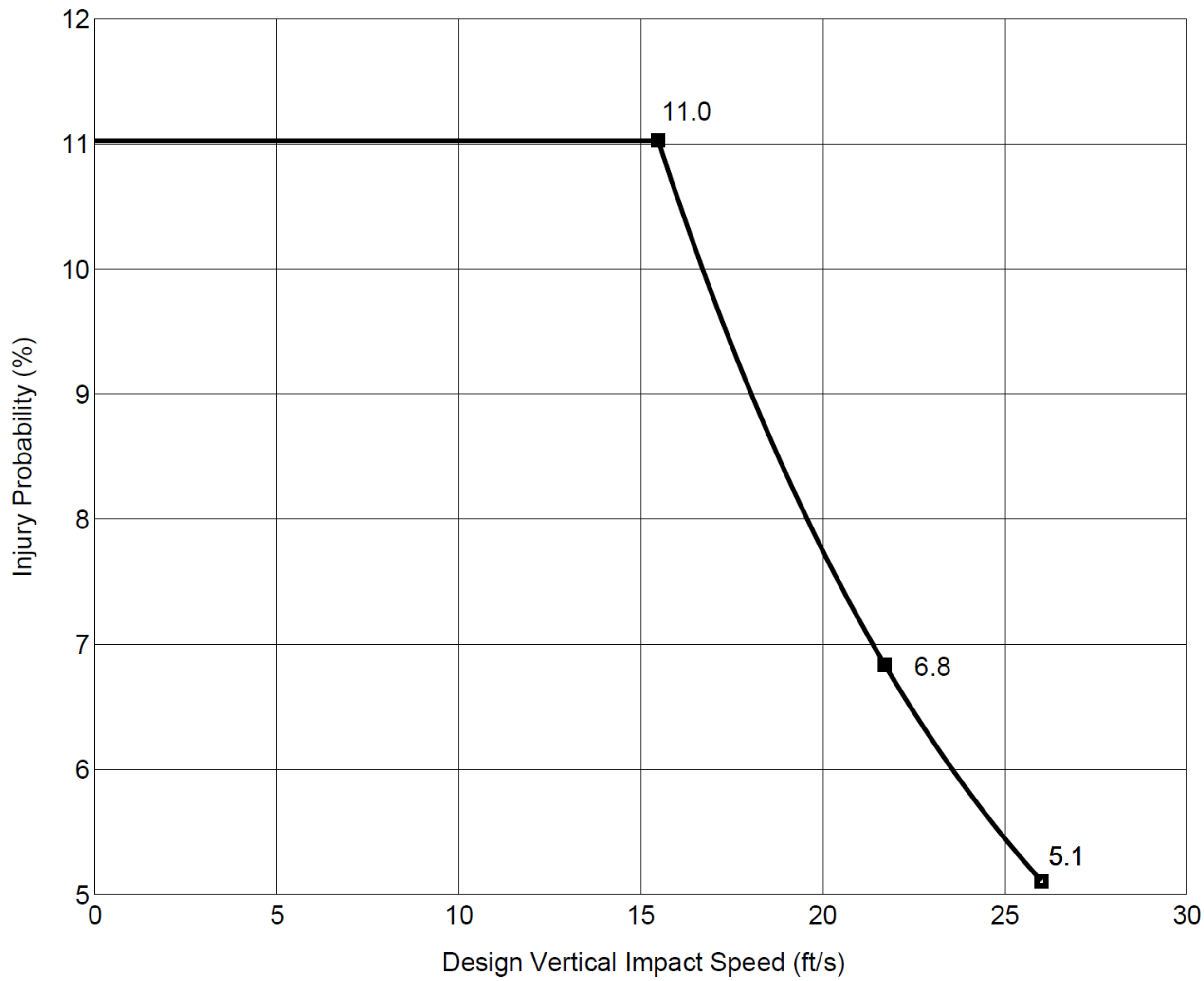

Figure 10: Overall Probability of Serious Spinal Injury vs. Seat Design Impact Velocity

Note in particular the probability of serious spinal injury for the following seat design speeds:

Table 43. Probability of Serious Spinal Injury vs. Seat Design Speed	
Seat Design Speed (ft/s)	Number of Serious Spinal Injuries per 100 Occupants Involved in Accidents
0	11.0
21.7	6.8
26	5.1

The results show that when upgrading from non-energy absorbing seats to fully compliant (26 ft/s) seats, one would expect to reduce the serious spinal injury rate by (11 - 5.1)/11 = 54%, whereas upgrading to 21.7 ft/s seats would reduce the injury rate by (11 - 6.8)/11 = 38%. Put another way, compared to non-CRSS seats, 21.7 ft/s seats provide 71% of the benefit of 26 ft/s seats (4.2 serious spinal injuries avoided per 100 occupants for 21.7 ft/s seats versus 5.9 serious spinal injuries avoided for 26 ft/s seats: 4.2/5.9 = 71%).

The ROPWG acknowledges that this analysis contains many simplifications and underlying assumptions. In particular:

- The Kiowa injury data was generated for a particular military helicopter, flying military missions, and flown by U.S. Army aviators (young, healthy men). Note, however, that the Kiowa is very similar to the Bell 206B Jet Ranger, a typical helicopter in the civilian fleet.
- The Kiowa injury data is influenced by confounding effects such as energy absorption due to landing gear and structure, attitude at impact, etc.
- The injury prevention effectiveness of dynamic seats is more complicated than the model used for the analysis
- The benefit of mandating energy absorbing seats is dependent on the energy absorption capability of fleet helicopters that are currently manufactured, a quantity that is unknown. For instance, if the average seat in a new civil helicopter was designed to 20 ft/s, then the relative benefit of a 26 ft/s seat versus a 21.7 ft/s seat would be much higher than if the fleet was starting from 0 ft/s. However, in this same scenario the absolute benefit seen by mandating 26 ft/s seats would also be much lower than if starting from 0 ft/s.
- The baseline injury rates are calculated based on injury data for military aviators, who are younger and healthier than the average civilian helicopter pilot, and therefore less susceptible to spinal injury in a given accident. While this may make the actual injury rates in civilian helicopter accidents higher than the estimates provided, the accuracy of the relative benefit of adding dynamic seats is unlikely to be significantly affected by this possible baseline error. Also note that the relative benefit calculations are based partly on cadaver data, which tend to be older individuals, making that data more representative of the civilian helicopter population, and therefore reasonably accurate when used to predict the relative benefit of energy absorbing seats for civil helicopters.

Despite these concerns, the ROPWG believes that the data is useful for providing a reasonable estimate for the relative effectiveness of energy absorbing seats of different design velocities.

APPENDIX E: TECHNICAL DISCUSSION OF 21.7 FT/S VERTICAL DYNAMIC SEAT TEST CONSIDERATIONS

DETERMINATION OF TEST PULSE SHAPE, PEAK FLOOR DECELERATION, PEAK G-LOAD

The current 27/29.562 (b)(1) downward dynamic test condition is a 30g minimum peak deceleration occurring not more than 0.031 sec after impact, with a velocity change not less than 30 ft/s. The seat orientation is pitched nose downward 30 degrees with respect to the impact vector. The vertical component of the test pulse is 26 ft/s (30 ft/s * cos (30°)), which matches the 95th percentile survivable accident defined in CT-85/11 (shown in Figure 11 for reference). The vertical impact velocity for the 95th and 90th percentile impacts are 26.0 and 21.7 ft/s respectively, and are marked on the figure for reference.

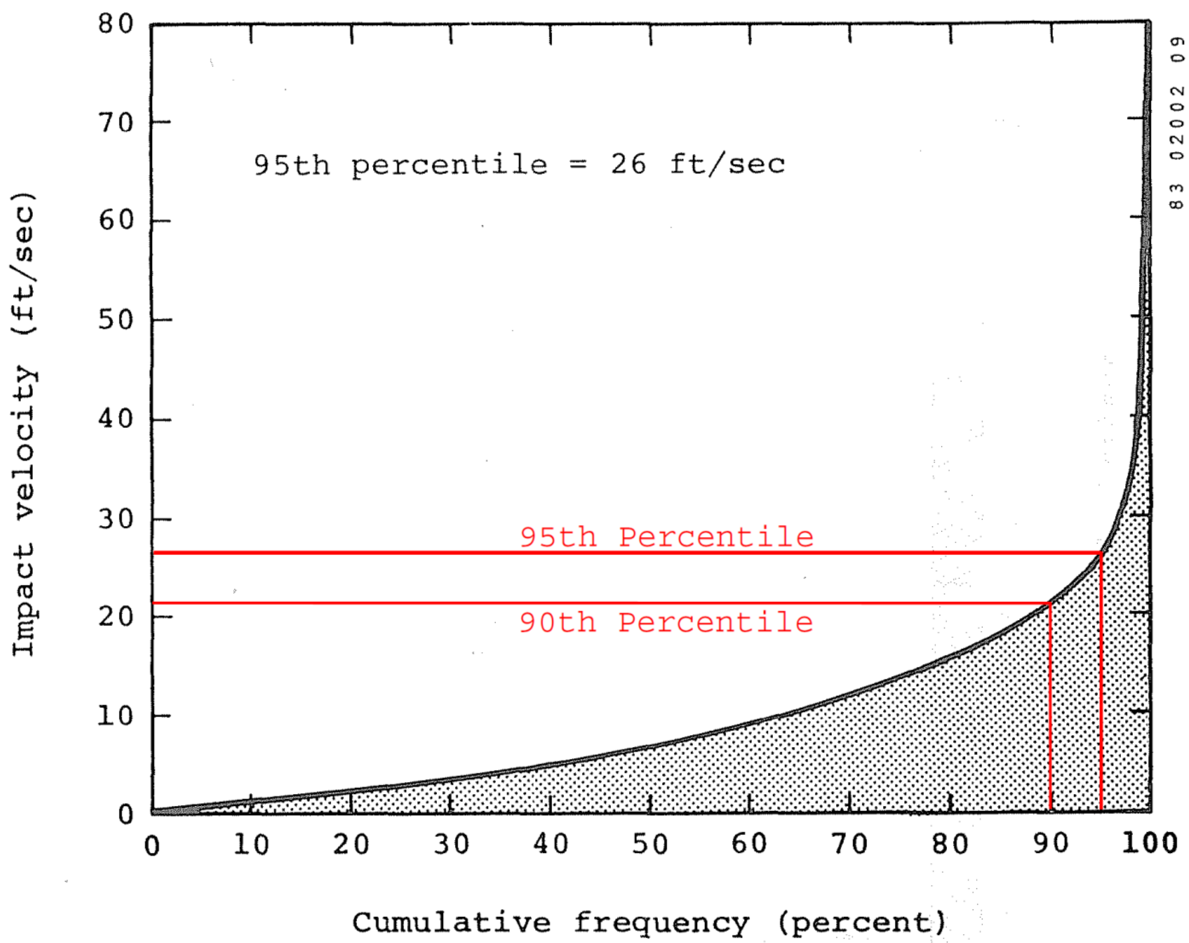

Figure 11: Vertical Impact Velocity Distribution for Civil Significant Survivable Accidents

Reproduced from CT-85/11 Figure 7

(95th and 90th percentile lines added by ROPWG)

A reduced test pulse providing a velocity change equivalent to the 90th percentile survivable accident has been determined based on the following criteria being satisfied:

- The crash pulse loading rate remains constant (aircraft structure provides same loading rate at the reduced impact velocity).
- The portion of the velocity change during the pulse onset remains constant (50 percent of the total velocity change during the onset phase). The reduced velocity test pulse has nearly identical onset rate though due to rounding is 1.4% greater than the standard test pulse. The onset rate and seat stroke distance trend in the same direction, i.e., greater seat stroke distance trends with higher onset rate.
- The input vector direction remains at 30-degree pitch down angle.
- The optimal solution is rounded to the nearest ½ g level and velocity change (ft/s), and the pulse rise time rounded to the nearest millisecond.

The proposed solution that satisfies the above criteria is shown in Table 44 below and Figure 12 below.

Table 44. Proposed Reduced Test Pulse Parameters

Pulse	Peak Deceleration (g)	Maximum Time to Peak g (seconds)	Minimum Velocity Change (ft/s)	Reference Onset Rate (g/sec)	Total Velocity Change Fraction at Peak	Reference Pure Vertical Velocity Change (ft/s)
Standard (95th)	30	0.031	30	968	0.5	26.0
90th	27.5	0.028	25.0	982	0.5	21.7

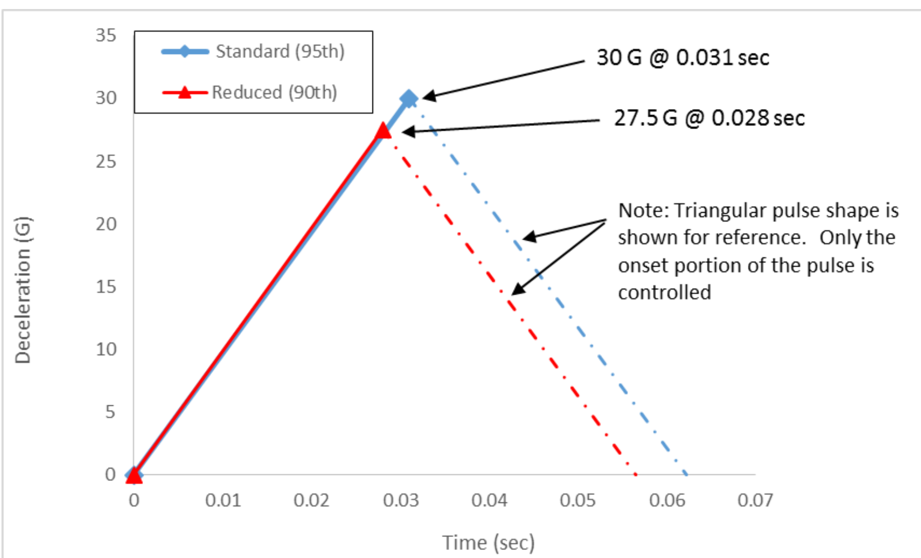

Figure 12: Reduced Test Pulse Profile

DETERMINATION OF REQUIRED SEAT STROKING DISTANCES

For reference, the estimated seat stroke to attenuate the crash pulse to within the stated injury criteria (i.e. maximum measured lumbar load less than 1,500 lb) has been calculated. The calculation is based on the following criteria:

- A constant load limiting energy absorber is used, set at a 12g threshold (known near optimal limit load).
- The test pulse is an isosceles triangular shape.
- The peak g load is 10 percent over the minimum (g_{peak} = 30.25g), which is typical for a certification test to ensure meeting the required minimum.
- The total velocity change is 2 ft/s above the minimum (V = 23.7 ft/s), which is typical for a certification test to ensure meeting the required minimum.

The seat stroke is calculated from the change in vertical displacement of the airframe (crash pulse) relative to the seat pan. The displacement is calculated by double integration of the acceleration profiles. Table 45 shows the solution to the seat stroke calculation both for the standard 95th percentile crash pulse and the 90th percentile crash pulse. Figure 13 illustrates the seat stroke calculation for the 90th percentile crash pulse.

Table 45. Calculated Seat Stroke for Standard Test Pulse and Reduced Test Pulse

Pulse	Vertical Seat Stroke (in)
Standard 95th percentile	4.6
Reduced 90th percentile	2.8

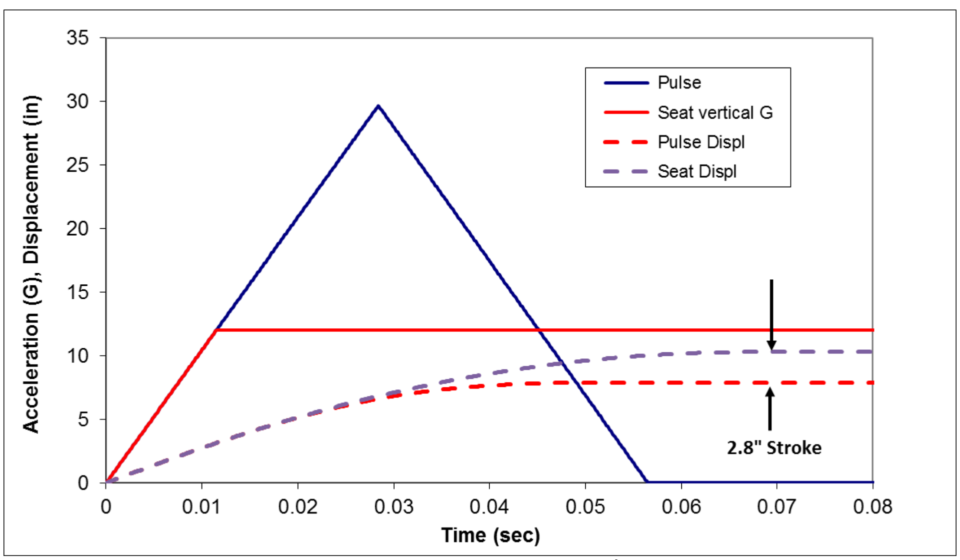

Figure 13: Seat Sroke Calculation for 90th Percentile Pulse