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

Submitted: March 15, 2018

EXECUTIVE SUMMARY

BACKGROUND

This report contains the Rotorcraft Occupant Protection Working Group (ROPWG) recommendations for incorporating crash resistant fuel systems (CRFS) regulations into newly manufactured rotorcraft that were certified before these regulations went into effect (legacy helicopters). These recommendations supersede the interim ROPWG proposals submitted on May 11, 2017.

BENEFIT METHODOLOGY

For the purposes of this report, the effectiveness of "partially-compliant" CRFS in crashes was analyzed first. Partially-compliant refers to currently produced, legacy helicopters that include some CRFS features in their fuel system designs, but that do not fully comply with current (1994) Airworthiness Standards for Fuel System Crash Resistance defined in 14 CFR 27.952 and 29.952. The effectiveness of these systems was then compared to that of the fully-compliant fuel systems analyzed in the Task 2 report, as well as legacy, non-CRFS fuel systems.

The crash data for the current study was extracted from the National Transportation Safety Board (NTSB) Microsoft Access Accident Database and included the last 20 years of accidents involving U.S. registered helicopters equipped with partially-compliant CRFS at the time of the accident. The result was a dataset containing 624 accidents involving partially-compliant CRFS helicopters, consisting of seven models of helicopters from five different manufacturers.

Additionally, a similar but independent analysis was performed for helicopters that had standard fuel systems without significant CRFS features and were, therefore, considered non-compliant with respect to 27.952. This second dataset of non-CRFS compliant helicopters contained 558 accidents.

Note that all partially-compliant helicopters in this study were certified to Part 27. While there were partially-compliant Part 29 aircraft in the NTSB database, the number of crashes for these helicopters was too small to be statistically significant and, therefore, these crashes were not included in this analysis.

BENEFIT RESULTS

Each of the partially-compliant and non-compliant accidents described above was individually reviewed to determine the following:

- Whether or not there was a post-crash fire (PCF), and if so, the cause of the fire
- The severity (survivability) of the accident
- The number of occupants that sustained thermal injuries after surviving the accident impact

The results of this analysis are summarized in Table 1 along with data on fully-compliant helicopters extracted from the Task 2 Report. The data show that the crash performance of the partially-compliant Part 27 helicopters, with regard to the prevention of post-crash fires, is far superior to that of non-compliant helicopters and, for most partially-compliant models studied, equally effective as fully-compliant models.

Table 1. Comparison of Post-Crash Fire and Thermal Injury Rates for Fully-Compliant, Partially-Compliant, and Non-Compliant CRFS Models			
CRFS System	**Post-Crash Fire Rate**		**Occupants That Received Thermal Injuries After Surviving Impact (all accidents)**
	Accidents filtered by: • Post-crash fire of any source • Any accident severity	**Accidents filtered by:** • Post-crash fire due to fuel spillage • "Survivable" accidents only (Severity Level 1-3)	
Fully-Compliant	13%	0%	0 in 53 accidents
Partially-Compliant	9%	1.0% –1.4%	1-2 in 624 accidents
Non-Compliant	15%	11%	Unknown

COST METHODOLOGY

Estimates of the cost and performance penalties for the partially-compliant 27/29.952 ROPWG recommendations 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. In brief, cost and performance penalty estimates provided by the OEMs were used to estimate the costs to OEMs and operators of the ROPWG recommended regulatory changes. Costs were reported in 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 and reduction in fuel capacity of the helicopter incurred by the inclusion of additional/revised CRFS 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.

COST RESULTS

Table 2 provides a summary of the estimated 10-year industry costs for compliance with the ROPWG recommendations and compares this to the benefit for compliance with the ROPWG recommendations and to the cost and benefit of full compliance with 27/29.952. Note that partial-compliance provides a 9.3% reduction in industry costs compared to full-compliance for Part 27 helicopters and a 6.0% reduction for Part 29 helicopters. Also note that the calculated costs of implementing the ROPWG recommendations for CRFS in newly-manufactured, legacy helicopters exceed the calculated monetary benefits for Part 27 helicopters; the relationship for Part 29 helicopters is unknown due to lack of crash data for this class of helicopter.

Table 2. Summary of 10-Year Industry Costs (2016 USD) for Models Still in Production, Partial Compliance Recommendations and Full Compliance

Cost Category	Part 27		Part 29		Combined Costs Parts 27 & 29	
	Partial Compliance	Full Compliance	Partial Compliance	Full Compliance	Partial Compliance	Full Compliance
Non-recurring Cost (.952)	$12,050,000	$14,491,000	$71,715,000	$78,080,000	$83,765,000	$92,571,000
10-Year Unit Cost Increase (.952)	$37,940,000	$41,750,000	$14,310,000	$14,310,000	$52,250,000	$56,060,000
Total 10-Year OEM Costs	$49,990,000	$56,241,000	$86,025,000	$92,390,000	$136,015,000	$148,631,000
10-Year Operator Cost Increase	$19,999,326	$20,980,780	$14,146,864	$14,214,404	$34,146,190	$35,195,184
Total 10-Year Estimated Industry Cost	**$69,989,326**	**$77,221,780**	**$100,171,864**	**$106,604,404**	**$170,161,190**	**$183,826,184**
Total 10 Year Estimated Benefit	**$17,142,135**	**$17,142,135**	**	**	**	**

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

SUMMARY OF ROPWG RECOMMENDATIONS

The ROPWG recommendations for CRFS regulatory compliance with 27.952 for newly manufactured legacy aircraft are summarized below in Table 3, and discussed in detail in the Recommendations section in the body of this report. Since the CRFS features/components of the partially-compliant CRFS helicopters included in the study have been proven to be effective, ROPWG recommendations for newly manufactured, legacy helicopters are based upon an amalgamation of these CRFS.

Note that while ROPWG members unanimously approved this report, several members disagreed with certain technical aspects of the recommendations below. Their objections have been included in the "ROPWG Voting Members Statements of Non-Concurrence" at the end of the body of the report.

Table 3. 27/29.952 Regulatory Recommendations for Newly Manufactured, Legacy Helicopters		
Regulation	**Recommendation**	**Notes**
27/29.952(a)(1)(2)(3)(5)(6): Drop test requirements	Recommended	Regulation should allow bladder-only drop test (i.e., surrounding structure optional).
27/29.952(a)(4) Drop test requirements	NOT recommended	
27/29.952(b): Fuel tank load factors	NOT recommended	See discussion in Recommendations section of this report.
27/29.952(c): Flexible fuel hoses and breakaway fittings	Recommended w/changes to guidance	Remove AC27-1B/29-2C guidance specifying 20-30% slack.
27/29.952(d): Frangible or deformable structural attachments	NOT recommended	27/29.952(f) and the associated AC guidance address these same items, but have a regulatory standard that is more appropriate for incorporation into a previously-certified legacy rotorcraft.
27/29.952(e): Separation of fuel and ignition sources	NOT recommended	
27/29.952(f): Other basic mechanical design criteria	Recommended	Requirements for new production legacy rotorcraft should additionally include elements of 27.963(g)/29.963(b) (fuel tank puncture resistance) and 27.975(b)/29.975(a)(7) (rollover vent valves). Fuel tank puncture resistance requirement should be dependent on drop test results as detailed in the Discussion of Recommendations section.
27/29.952(g): Rigid or semi-rigid fuel tanks	Recommended w/changes to guidance	Recommended if AC guidance is revised to clarify that this requirement applies to rigid or semi-rigid fuel tank or bladder walls only and that flexible liners are excluded.
Requirement for full compliance 10 years after approval of new CRFS rules	NOT recommended	Data for partially-compliant helicopters show that the recommendations in this report are equally effective at preventing post-crash fires and thermal injuries, but with a substantially lower weight penalty and monetary cost. Delaying full compliance by 7-10 years will not result in appreciably lower costs, weight penalties, or disruptions caused by discontinued models.

DISCLAIMER

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

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INTRODUCTION

The Federal Aviation Administration (FAA) amended regulations 14 CFR 27/29.561 (General, Emergency Landing Conditions), 27/29.562 (Emergency Landing Dynamic Conditions), 27/29.785 (Seats, Berths, Litters, Safety Belts, and Harnesses), and 27/29.952 (Fuel System Crash Resistance), 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. Its 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, 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."

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[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.

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

> "...an interim report to the ARAC containing initial recommendations on the findings and results related to 14 CFR 27/29.952 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 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.

The current report is the ROPWG final report on its recommendations for how all or part of the existing 27/29.952 standards should be made effective via §§ 27.2 and 29.2 for newly-manufactured, legacy helicopters as delineated in the referenced Federal Register tasking (Tasks 3-5). This final report is based on the interim report from May 11, 2017 and shares much of the same text and organization, with the following notable changes:

- Revised analysis of "partially-compliant" CRFS effectiveness to include newly available data.
- Added section "Cost and Performance Penalties of Partially-Compliant Fuel Systems" to detail newly formed estimates of the cost/performance penalties of the ROPWG final recommendations when applied to newly manufactured, legacy helicopters.
- Revised estimates of the cost/performance penalties of requiring newly manufactured, legacy helicopters to demonstrate full-compliance with 27/29.952.
- Added section "Benefit of Partially-Compliant Fuel Systems."
- Finalized 27/29.952 recommendations and accompanying explanatory text to account for newly available effectiveness data, cost data, and ROPWG member deliberation.
- Revised Executive Summary to account for the changes described above.

EFFECTIVENESS OF PARTIALLY-COMPLIANT FUEL SYSTEMS

METHODS

DEVELOPMENT OF DATASET

National Transportation Safety Board (NTSB) accident data from crashes involving helicopters with fully-compliant Crash Resistant Fuel Systems (CRFS) were analyzed in the previous ROPWG Task 2 Report, and these CRFS were found to be highly effective in preventing post-crash, fuel-fed fires for most crashes. The next step in our analysis was to analyze the effectiveness of partially-compliant CRFS in crashes, and then compare their effectiveness to that of the fully-compliant fuel systems. These crashes were also compared to a subset of accidents of legacy helicopters with standard, non-CRFS fuel systems.

Five rotorcraft manufacturers were found to cumulatively manufacture seven models of helicopters with partially-compliant fuel systems that have been involved in crashes recorded in the NTSB database. Partially-compliant refers to the inclusion of some CRFS features in their fuel system design while not fully complying with the requirements of 27/29.952, and spans aircraft models that are certified to nearly all 27/29.952 requirements to those that have only a few CRFS features. As an example, most of the partially-compliant helicopters have crash resistant fuel bladders, but they demonstrate a range of compliance with both the current drop test requirements and penetration requirements of 27/29.952, 27.963(g)/29.963(b), and associated Advisory Circulars (AC).

Note that all partially-compliant helicopters in this study were certified to Part 27 or CAR 6. While there were partially-compliant Part 29 aircraft in the NTSB database, the number of crashes was too small to be statistically significant, and therefore these crashes weren't included in this analysis.

Details of the CRFS features incorporated into these models are described in the "Partially-Compliant CRFS Model Designs" section below. The manufacturer and model names have been redacted to protect proprietary manufacturer data. Note that one additional manufacturer has recently begun incorporating a partially-compliant fuel system in at least one of its legacy ("grandfathered") models, but no crashes of these helicopters had been reported in the NTSB database as of December 31, 2015, the cut-off date for the current study.

The crash data for the current study was extracted from the NTSB's Microsoft Access Accident Database, current through December 2016. The initial filter criteria were as follows:

- Registration Number = U.S. registration only
- Aircraft Category = Helicopters only
- Event Type = Accidents only, not incidents
- Date of Accident = Between 1/1/1996 and 12/31/2015 (most recent 20-year data available)
- Homebuilt = *N* or is null (excludes homebuilt helicopters that were not type certified and catches cases where NTSB inadvertently left the field unpopulated)

The database was then manually filtered to include only those helicopters equipped with partially-compliant CRFS at the time of the accident, as identified to the ROPWG by OEM representatives. This included helicopters originally manufactured with CRFS features, as well as those that were originally manufactured without the CRFS features and then later retrofit with CRFS components. No other filters were applied. The end result was a dataset containing 624 accidents involving partially-compliant CRFS helicopters.

Additionally, a similar but independent analysis was performed for helicopters that had standard fuel systems without significant CRFS features and were, therefore, considered non-compliant with respect to 27.952. This second dataset of non-CRFS compliant helicopters contained 558 accidents.

PARTIALLY-COMPLIANT CRFS MODEL DESIGNS

The fuel systems of the partially-compliant CRFS helicopters included in the dataset are detailed in Table 4 below:

Table 4. Partially-Compliant CRFS Compliance Matrix

Regulation	Model						
	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
27/29.952(a): Drop Test	Bladder only[2]	Bladder only[2]	Certified	Certified	Incorporates fuel bladder, but drop test not performed	Incorporates fuel bladder, but drop test not performed	Bladder only, 23-foot drop[11]
27/29.952(b): Fuel Tank Load Factors	(b)(1): No (b)(2): Meets (b)(3): Meets	(b)(1): No (b)(2): Meets (b)(3): Meets	(b)(1): No (b)(2): Certified (b)(3): Certified	Unlikely	(b)(1): N/A (b)(2): Unknown (b)(3): Likely	(b)(1): No (b)(2): Likely (b)(3): Likely	Likely
27/29.952(c): Flexible fuel hoses and breakaway fittings	Meets	Meets	Certified	Partial[5]	Meets[5]	Unlikely	No
27/29.952(d): Frangible or deformable structural attachments	Meets	Meets	Certified	Partial[6]	Likely	Likely	Partial
27/29.952(e): Separation of fuel and ignition sources	Meets	Meets	Certified	Likely	Likely	Likely	Partial
27/29.952(f): Other basic mechanical design criteria	Meets	Meets	Certified	Likely	Likely	Likely	Meets
27/29.952(g): Rigid or semi-rigid fuel tank (tear resistance)	N/A	N/A	N/A	N/A	N/A	N/A	N/A
27.963(g)/29.963(b): Fuel bladder puncture resistance	Partial[3]	Partial[3]	Certified[4]	Partial[7]	Likely[9]	Partial[10]	Partial[12]
27.975(b)/29.975(a)(7): Rollover vent valves	No	No	Certified	Partial[8]	No	Meets	Meets

Table Notes:

1. Definition of compliance terms:
    a. Certified: Test data and/or analysis demonstrating compliance was approved by the FAA.
    b. Meets: Proprietary tests and/or analysis show that the design meets or exceeds requirements of the regulation and advisory circular, but the tests/analysis were not submitted to the FAA.
    c. Likely: Proprietary tests and/or analysis indicate that compliance is likely, but test results/analysis have not been submitted to the FAA.
    d. Unlikely: Proprietary tests and/or analysis indicate that compliance is possible but unlikely without a design change.
    e. No: Proprietary tests and/or analysis indicate that compliance cannot be demonstrated without a design change.
    f. Partial: The general intent of the regulation (in whole or in part) is incorporated in the design, but compliance was not demonstrated to the full extent of the regulation and/or associated advisory circular.
    g. Unknown: The relevant tests and/or analysis have not been performed, so the level of compliance is undetermined.
2. Fuel cell/bladder alone (no structure) survived drop from 50 feet while 80% full of water.
3. Fuel bladder material meets 250 lb puncture test.
4. Early units were FAA certified and delivered with fuel bladders meeting 370 lb puncture resistance on bottom surface and the lower part of the sides, and 250 lb puncture resistance elsewhere. Later units were/are delivered with a fuel bladder that meets 370 lb puncture requirement on all surfaces.
5. Most but not all fuel hoses are flexible. Slack is incorporated in fuel hoses in lieu of breakaway fittings, but due to geometry constraints, the available slack is less than that specified by the regulation and advisory circular.
6. The bladder connection to the airframe is frangible, but tests and/or analysis were not performed to determine compliance with the detailed requirements of the regulation and advisory circular.
7. Fuel bladder surfaces at a higher risk of puncture meet 370 lb puncture test requirement. Other surfaces meet 265 lb test.
8. Rollover vent valves are incorporated that were shown to be effective at preventing fuel leaks at angles between 90° and inverted. Valves are likely less effective at angles between 0-90°, but this is mitigated by the fact that OEM accident investigation experience indicates that angles in this range are less likely to be seen in practice, as helicopters that roll over typically come to rest fully on one side.
9. Installation utilizes a bladder inside rigid and semi-rigid structure. The FAA and the manufacturer have not discussed the possibility of issuing an Equivalent Level of Safety (ELOS) finding.
10. Fuel bladder meets 15 lb puncture resistance.

11. A bladder only drop test was performed, but from a reduced height of 23 feet (50 feet is required for 27/29.952(a)).
12. Fuel bladder meets 270 lb puncture test requirement.
    Compliance is provided by circuitous vent lines (no rollover vent valves are used).

RESULTS

PARTIALLY-COMPLIANT CRFS PERFORMANCE

Each of the 624 accidents in the partially-compliant CRFS accident dataset was individually reviewed to determine the following:

- Whether or not there was a post-crash fire (PCF), and if so, whether the fire was due to:
  - A malfunction of the engine ("engine fire")
  - The ignition of ground foliage due to contact with the hot engine or exhaust component ("grass fire")
  - A post-crash rupture of a fuel line and/or fuel tank ("fuel spillage")
    - Note that only fuel spillage fires are addressed by the CRFS regulations under review; grass fires and engine fires are not affected by the regulatory changes under consideration
- The severity (survivability) of the accident
  - Rated on a scale of 1-4 as defined in Table 18 of the ROPWG Task 2 report, and reproduced below as Table 5
- The number of occupants that sustained thermal injuries
  - Occupants that received fatal blunt force trauma injuries during the accident were not included in the thermal injury tally

Table 5. Definition of Accident Severity Levels Utilized for the CRFS Review (reproduced from Task 2 report)

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

Note that in some survivability classification schemes, Severity 3 would be considered "partially survivable." The Working Group elected to combine these accidents with Severity 1-2 and refer to the group of Severity 1-3 accidents as "survivable."

To make determinations of survivability, the working group primarily reviewed information in the NTSB database and publicly available news reports. However, since the NTSB reports rarely contain information on impact conditions and injury data is infrequently recorded for occupants other than pilots, the assistance of manufacturer accident investigators was required to establish accident severity and injury data for some accidents. This is the same procedure used for the ROPWG Task 2 Report submitted on November 10, 2016, as well as the CT85-11 Report "*Analysis of Rotorcraft Crash Dynamics for Development of Improved Crashworthiness Design Criteria*" completed in June 1985 that was used by the FAA in support of the original CRFS and CRSS (Crash Resistant Seat and Structure) rulemaking effort.

The results of this analysis are included below in Table 6 and Table 7.

Table 6. Post-Crash Fire and Thermal Injury Rates for Partially-Compliant Models				
Helicopter Model	**Total Accidents**	**Post-Crash Fire Rate**		**Occupants That Received Thermal Injuries After Surviving Impact (all accidents)**
		Accidents filtered by: • **Post-crash fire of any source** • **Any accident severity**	**Accidents filtered by:** • **Post-crash fire due to fuel spillage** • **"Survivable" accidents (severity level 1-3)**	
Model 1	59	5 (8%)	0-3[1] (0%-5%)	0
Model 2	106	6 (6%)	0 (0%)	0
Model 3	72	7 (10%)	0 (0%)	0
Model 4	31	1 (3%)	0 (0%)	0
Model 5	6	1 (17%)	0 (0%)	0
Model 6	227	19 (8%)	5 (2%)	0-1[2]
Model 7	123	16 (13%)	1 (0.8%)	1
Cumulative Total for All Partially-Compliant Models	**624**	**55 (8.8%)**	**6-9[1] (1.0%-1.4%)**	**1-2[2]**

Notes:

1. For Model 1, for the 5 accidents with a post-crash fire, 2 of the fires were known to be engine fires. The other 3 fires are suspected to be engine fires or fires fed by fuel spilling through non-compliant vent lines, but there was insufficient data available to confirm the fire source. The fires that occurred were small, spread slowly, and did not cause any thermal injuries.
2. For Model 6, the 1 occupant that sustained a thermal injury is a pilot who received thermal injuries upon returning to the wreckage to rescue a passenger.

Table 7. Breakdown of Partially-Compliant CRFS Accidents by Accident Severity							
Helicopter Model	**Total Accidents**	**Accident Severity**					
		Unknown	**0**	**1**	**2**	**3**	**4**
Model 1	59	1 (2%)	0 (0%)	13 (22%)	37 (63%)	6 (10%)	2 (3%)
Model 2	106	2 (2%)	3 (3%)	46 (43%)	41 (39%)	5 (5%)	9 (8%)
Model 3	72	0 (0%)	7 (10%)	26 (36%)	23 (32%)	3 (4%)	13 (18%)
Model 4	31	0 (0%)	4 (13%)	6 (19%)	19 (61%)	1 (3%)	1 (3%)
Model 5	6	0 (0%)	0 (0%)	3 (50%)	0 (0%)	2 (33%)	1 (17%)
Model 6	227	Accident severity distribution not available					
Model 7	123	Accident severity distribution not available					

NON-COMPLIANT CRFS PERFORMANCE

In order to provide context and perspective for the partially-compliant CRFS analysis described above (Table 6), an independent, yet similar, analysis was performed for helicopters that had standard fuel systems without significant CRFS features and were, therefore, considered non-compliant with respect to 27/29.952. This analysis looked at the post-crash fire rates over the same 1996 through 2016-time period for three representative non-CRFS, Part 27 aircraft. The results of this analysis are presented below in Table 8.

Table 8. Post-Crash Fire and Thermal Injury Rates for Non-CRFS Models

Total Accidents	Post-Crash Fire Rate		Occupants That Received Thermal Injuries After Surviving Impact (all accidents)
	Accidents filtered by: • Post-crash fire of any source • Any accident severity	Accidents filtered by: • Post-crash fire due to fuel spillage • "Survivable" accidents (severity level 1-3)	
558	81 (15%)	64 (11%)	Unknown

FULLY-COMPLIANT CRFS PERFORMANCE

The ROPWG Task 2 Report submitted on November 10, 2016, analyzed the performance of fully-compliant CRFS. For convenience, the results of that study are reproduced below in Table 9 and Table 10, presented in a format consistent with the partially-compliant and non-CRFS data above.

Note that, as described in the ROPWG Task 2 Report, there are no helicopters certified to Part 29 included in this analysis because there were very few crashes involving Part 29 helicopters in the dataset.

Table 9. Post-Crash Fire and Thermal Injury Rates for Fully-Compliant CRFS Models (Data from ROPWG Task 2 Report)

Total Accidents	Post-Crash Fire Rate		Occupants That Received Thermal Injuries After Surviving Impact (all accidents)
	Accidents filtered by: • Post-crash fire of any source • Any accident severity	Accidents filtered by: • Post-crash fire due to fuel spillage • "Survivable" accidents (severity level 1-3)	
53	7 (13%)	0 (0%)	0

Table 10. Breakdown of Fully-Compliant CRFS Accidents by Accident Severity (Data from ROPWG Task 2 Report)

Helicopter Model	Total Accidents	Accident Severity					
		Unknown	0	1	2	3	4
Cumulative Data for Fully-compliant Models	53	0 (0%)	7 (13%)	15 (28%)	19 (36%)	3 (6%)	9 (17%)

COMBINED CRFS PERFORMANCE DATA

The post-crash fire and thermal injury data for fully-compliant, partially-compliant, and non-compliant CRFS Part 27 models is summarized in Table 11 below:

Table 11. Comparison of Post-Crash Fire and Thermal Injury Rates for Fully-Compliant, Partially-compliant, and Non-Compliant CRFS Models

CRFS System	Post-Crash Fire Rate		Occupants That Received Thermal Injuries After Surviving Impact (all accidents)
	Accidents filtered by: • Post-crash fire of any source • Any accident severity	Accidents filtered by: • Post-crash fire due to fuel spillage • "Survivable" accidents only (severity level 1-3)	
Fully-Compliant	13%	0%	0 in 53 accidents
Partially-Compliant	9%	1.0%-1.4%	1-2 in 624 accidents
Non-Compliant	15%	11%	Unknown

DISCUSSION

The data presented in Table 6, Table 7 and Table 9 and summarized in Table 11 demonstrate that the crash performance of the partially-compliant Part 27 helicopters, with regard to the prevention of post-crash fires, is far superior to that of non-compliant helicopters, and for most partially-compliant models, equally effective as fully-compliant helicopters. These results are discussed in depth below.

Among partially-compliant designs that passed a 50-foot drop test (with or without structure) and had a puncture resistance of at least 250 lb (models 1-4), crash performance was essentially identical to that of fully-compliant helicopters. Both groups had no significant post-crash fires or thermal injuries for survivable crashes (Severity 1-3). This is in contrast to non-compliant helicopters that had an 11% rate of post-crash fire due to fuel spillage following survivable crashes. Furthermore, an analysis of the various makes and models of partially-compliant helicopters showed that, among this subset of partially-compliant helicopters, there were no trends of one model helicopter being more or less effective than another in preventing fuel-fed, post-crash fires and thermal injuries. The crash data also suggested that rollover vent valves were effective in preventing fuel spillage from vent lines, although there were no significant fires resulting from this mechanism in partially-compliant models that did not incorporate rollover vent valves.

Model 6 provided an interesting exception to the observed performance of the partially-compliant helicopter models described above. Model 6 has a fuel bladder with a lower puncture resistance than the other models studied (15 lb vs. 250 or 370 lb) and was not drop tested. Other bladder specifications are not known. Nevertheless, this model was only slightly less effective than other partially-compliant helicopters at preventing post-crash fires following survivable accidents. Its crash performance was much better than that of non-compliant helicopters, and the fires that did occur resulted in few if any thermal injuries. This model's relatively good performance in preventing post-crash fires is believed to be primarily due to the fact that the fuel cells are nested in small, structurally strong compartments, which protect the fuel cell from significant deformation or penetration in most survivable crashes. Also, fuel system experts report that puncture resistance in itself is not a complete predictor of the crash performance of a particular fuel bladder.

Model 7, which has a fuel bladder puncture resistance of 270 lb, but was only drop tested from 23 feet (vs. 50 feet as required by 27/29.952(a)), was nearly as effective at preventing post-crash fires following survivable accidents as the fully compliant helicopters and the other partially-compliant helicopters, with only one fire resulting in one thermal injury.

A comparison of the specifications of the seven partially-compliant models with the non-compliant models suggests that a crash-resistant fuel bladder is the most significant component of an effective CRFS. Other components such as breakaway fuel valves and rollover vent valves, although important, appear to be less effective in preventing post-crash fires than having an effective crash-resistant fuel bladder.

RECOMMENDATIONS

27/29.952 RECOMMENDATIONS

In order to perform a cost-benefit estimation of ROPWG CRFS recommendations for newly manufactured, legacy rotorcraft, it was necessary for ROPWG to define the characteristics of what it considered an appropriate partially-compliant fuel system 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 the cost analysis.

The ROPWG recommendations for CRFS regulatory compliance with 27/29.952 for newly manufactured legacy aircraft are summarized below in Table 12, and discussed in detail following the table. Since the CRFS features/components of the partially-compliant CRFS helicopters included in the study have been proven to be as effective as fully-compliant systems but with lower cost and weight penalties, ROPWG recommendations for newly manufactured legacy helicopters are based upon an amalgamation of the most effective partially-compliant CRFS.

Note that while the FAA asked for a recommendation 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,” the ROPWG members believe that the inclusion of elements of 27.963(g)/29.963(b) (fuel tank puncture resistance) and 27.975(b)/29.975(a)(7) (rollover vent valves), in addition to the recommendations for 27/29.952, is required in order to produce effective CRFS regulations for newly manufactured, legacy helicopters. The ROPWG recommends that elements of the requirements of these sections be mandated for newly manufactured, legacy helicopters, as summarized in Table 12 and discussed in detail following the table.

Also note that the preceding analysis of CRFS effectiveness was based purely upon analysis of the crash performance of Part 27 rotorcraft. As noted above, there were insufficient numbers of Part 29 rotorcraft crashes to perform an empirical analysis of their fuel system performance. Nevertheless, in the few survivable Part 29 crashes available, it appears that their fuel systems were providing adequate protection. For these reasons, ROPWG cautiously recommends that similar rules for Part 29 helicopters be adopted as for Part 27 helicopters. This approach is consistent with current regulations (27/29.952) which do not provide separate criteria for Part 27 and 29 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 CRFS 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 Statements of Non-Concurrence section at the end of this report.

Table 12. 27/29.952 Regulatory Recommendations for Newly Manufactured, Legacy Helicopters		
Regulation	**Recommendation**	**Notes**
27/29.952(a)(1)(2)(3)(5)(6): Drop test requirements	Recommended	Regulation should allow bladder-only drop test (i.e., surrounding structure optional).
27/29.952(a)(4) Drop test requirements	NOT recommended	
27/29.952(b): Fuel tank load factors	NOT recommended	See discussion below.
27/29.952(c): Flexible fuel hoses and breakaway fittings	Recommended w/changes to guidance	Remove AC27-1B/29-2C guidance specifying 20-30% slack.
27/29.952(d): Frangible or deformable structural attachments	NOT recommended	27/29.952(f) and the associated AC guidance address these same items, but have a regulatory standard that is more appropriate for incorporation into a previously-certified legacy rotorcraft.
27/29.952(e): Separation of fuel and ignition sources	NOT recommended	
27/29.952(f): Other basic mechanical design criteria	Recommended	Requirements for new production legacy rotorcraft should additionally include elements of 27.963(g)/29.963(b) (fuel tank puncture resistance) and 27.975(b)/29.975(a)(7) (rollover vent valves). Fuel tank puncture resistance requirement should be dependent on drop test results as detailed in the discussion below.
27/29.952(g): Rigid or semi-rigid fuel tanks	Recommended w/changes to guidance	Recommended if AC guidance is revised to clarify that this requirement applies to rigid or semi-rigid fuel tank or bladder walls only and that flexible liners are excluded.
Requirement for full compliance 10 years after approval of new CRFS rules	NOT recommended	Data for partially-compliant helicopters show that the recommendations in this report are equally effective at preventing post-crash fires and thermal injuries, but with a substantially lower weight penalty and monetary cost. 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 12)

27/29.952(a): Drop Test Requirements

Recommended with qualification that bladder-only drop tests are permitted.

Dropping the bladder alone is generally considered more severe with respect to pressure loads on the bladder, while dropping with surrounding structure is more critical with respect to puncture and other hazards associated with attachment to structure. Therefore, either approach to drop testing may be critical for a specific bladder installation.

As noted in Table 4 and the associated notes, as part of the non-required development testing for the CRFS in Models 1 & 2, the CRFS fuel bladders were subjected to a 50-foot drop test per the requirements of 27/29.952(a), except that the test was performed for the bladders alone (i.e., the surrounding structure was not included in the drop). It is clear from the post-crash fire data for these models that these fuel systems are extremely effective at preventing post-crash fires and thermal injuries following survivable accidents.

Therefore, while the surrounding structure may indeed create a puncture hazard, including bladder material puncture resistance and other material properties identified in AC 27-1B/29-2C as part of guidance is an equally effective but less arduous and less expensive means of ensuring bladder crash effectiveness compared to dropping the bladder inside the structure.

Note that mandating 27/29.952(a) Paragraphs 1, 2, 3, 5, and 6, and not requiring paragraph 4, would allow for tests with or without the surrounding structure.

27/29.952(b): Fuel Tank Load Factors

NOT recommended

The data in Table 4 and Table 11 show that CRFS with fuel tank load factors certified to lower levels than currently required (i.e., those required for the original certification basis) in current partially-compliant helicopters are equally effective at preventing post-crash fires and thermal injuries as CRFS in fully-compliant helicopters. For many helicopter models, increasing the structural retention strength of the fuel tanks would require a significant increase in fuselage strength, with associated weight penalties, research and development costs, and manufacturing costs. This is particularly true for small, legacy rotorcraft that were designed around lower load factors. These penalties and costs, combined with data showing the lack of a measurable benefit, lead to the recommendation that this section not be required for newly manufactured, legacy rotorcraft. Therefore, the load factors required for a particular model during its original certification should remain in effect.

27/29.952(c): Fuel Line Self-sealing Breakaway Couplings

Recommended w/changes to AC 27-1B/29-2C

27/29.952(c) and their associated Advisory Circular (AC 27-1B/29C) guidance address crash resistant fuel hoses and a means of preventing over tensioning of those lines in a survivable crash. While it is the ROPWG's opinion that the inclusion of such features is an important part of post-crash fire prevention, the advisory circular guidance for 27/29.952(c) includes prescriptive details that are impractical for some previously-certified, legacy aircraft that have demonstrated adequate post-crash fire protection in survivable crashes.

Specifically, there is no scientific basis for requiring that installations that use fuel line slack or stretch as an equivalent device should be able to elongate a minimum of "20-30 percent by stretch, slack or a combination without fuel spillage." Since installations in certain studied legacy models (e.g., Model 4) have considerably less elongation capability in certain areas yet perform well in survivable crashes, ROPWG recommends that this requirement be replaced with wording to the effect that "**where practicable**, installations that use fuel line slack or stretch as an equivalent device should be able to elongate enough to accommodate any probable relative motion between the ends of the line during an accident. 20-30 percent of the line length may be used as a guideline in lieu of a more rational analysis."

27/29.952(d): Frangible or deformable structural attachments

NOT recommended

27/29.952(d) and 27/29.952(f) and their associated AC guidance, both address crash resistant attachments of fuel system components. While these regulations and guidance address very similar topics, the regulatory requirements of 27/29.952(d) include prescriptive details that are impractical for some previously-certified, legacy rotorcraft that have demonstrated adequate post-crash fire protection as reported above. The requirement of, "as far as practicable" in 27/29.952(f) is much more appropriate for a previously-designed airframe, particularly when that airframe has demonstrated adequate post-crash fire protection in survivable crashes. Therefore, it is recommended that compliance with 27/29.952(f) be required, but compliance with 27/29.952(d) is NOT required for newly-manufactured, legacy rotorcraft.

Note that the Model 4 data from Table 4 and Table 6 show that this design, while partially-compliant with 27.952(d) but likely compliant with 27.952(f), was extremely effective at preventing post-crash fires following survivable accidents. Similarly, Models 5 and 6, which may not be fully compliant to this section, were also extremely effective at preventing post-crash fires following survivable accidents.

27/29.952(e): Separation of fuel and ignition sources

NOT recommended

27/29.952(e) and 27/29.952(f) and their associated guidance both address the separation of fuel and ignition sources. While these regulations and guidance address very similar topics, the regulatory requirements of 27/29.952(e) include prescriptive details that are impractical for some previously-certified, legacy rotorcraft showing adequate post-crash, fuel-fed fire protection. The requirement of "as far as practicable" in 27/29.952(f) is much more appropriate for a previously-designed airframe, particularly when that airframe has demonstrated adequate post-crash fire protection in survivable crashes. Therefore, it is recommended that compliance with 27/29.952(f) be required, but compliance with 27/29.952(e) is NOT required for this group of newly-manufactured, legacy rotorcraft.

While the working group agrees that separation of fuel and potential ignition sources is extremely important in a CRFS, it is clear from the data in Table 3 and Table 10 that the existing separations in the studied partially-compliant, legacy models are equally effective in their current configurations to helicopters meeting the requirements of 27/29.952(e). Consequently, the ROPWG does not recommend compliance with this section for newly-manufactured, legacy helicopters.

27/29.952(f): Other basic mechanical design criteria

Recommended

27/29.952(f) addresses, in part, the requirements of 27/29.952(c), (d), and (e), but imposes a regulatory burden ("as far as practicable") that is more appropriate for a previously-designed, legacy rotorcraft. Detailed advisory material can be proposed to describe the intent and methods of compliance that would be required to meet these criteria.

Additionally, while 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 elements of 27.963(g)/29.963(b) (fuel tank puncture resistance) and 27.975(b)/29.975(a)(7) (rollover vent valves), in addition to the recommendations for 27/29.952, is required in order to produce the most rational and cost/weight effective CRFS regulations for newly manufactured, legacy rotorcraft. This is discussed further in the subsection below for 27/29.963 and 27/29.975.

27/29.952(g): Rigid or semi-rigid fuel tanks

Recommended with changes

The rule is explicit that this requirement applies to rigid or semi-rigid fuel tank or bladder walls and the AC provides definitions of these tanks and further clarifies that flexible liners are excluded. All partially-compliant helicopter models studied for this report rely on flexible liners and therefore 27/29.952(g) is not applicable. This interpretation of the intent of the rule and guidance was confirmed by internal FAA discussions relayed to the working group by the FAA ROPWG representative.

There is, however, material within the Advisory Circular guidance (AC 27-1B/29-2C) for 27/29.952(g) that could lead to the misinterpretation that the tear resistance requirements do apply to flexible liners. It is therefore recommended that the AC guidance be revised to eliminate this ambiguity so that it is clear that this requirement applies to rigid or semi-rigid fuel tank or bladder walls only and that flexible liners are excluded.

Since this paragraph is not applicable to any of the partially-compliant helicopters in this study, there is no data to support its inclusion or exclusion. Therefore, the ROPWG recommends that the rule be required for newly manufactured, legacy rotorcraft if the AC guidance is revised as described above.

27.963(g)/29.963(b): Fuel tank puncture resistance: Recommended with changes
27.975(b)/29.975(a)(7): Rollover vent valves: Recommended

While 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 elements of 27.963(g)/29.963(b) (fuel tank puncture resistance) and 27.975(b)/29.975(a)(7) (rollover vent valves), in addition to the recommendations for 27/29.952, is required in order to produce the most rational and cost/weight effective CRFS regulations for newly manufactured, legacy rotorcraft. As noted in the above discussion, an analysis of the actual crash performance of the existing CRFS elements in partially-compliant helicopters indicates that flexible liner puncture resistance and roll-over vent valves are an important feature of effective post-crash fire protection. The ROPWG therefore recommends that the following criteria for flexible liner puncture resistance and rollover vent valves be defined within the requirements for newly manufactured legacy rotorcraft:

- Legacy rotorcraft should be required to meet the puncture resistance standard of either:
    - A minimum of 250 lb puncture resistance if the fuel bladder is successfully drop tested in-structure per 27/29.952(a)(4), or
    - A minimum of 370 lb puncture resistance if the fuel bladder drop test is NOT performed in-structure per 27/29.952(a)(4).
- Newly-manufactured, legacy rotorcraft should be required to meet the requirements of 27.975(b)/29.975(a)(7) and its associated guidance (as they are currently written).

These puncture resistance criteria are based on two observations from the data in the "Effectiveness of Partially-Compliant Fuel Systems" section of this report:

- Models that incorporated a minimum puncture resistance of at least 250 lb were equally effective at preventing post-crash fires following survivable accidents as those systems with higher puncture resistance ratings.
- CRFS that passed a drop test performed without structure (bladder only) were equally effective at preventing post-crash fires following survivable accidents as those systems that passed a drop test performed with surrounding structure.

The recommendation for a higher puncture resistance standard when a drop test is performed without structure is intended as an efficient means of ensuring that fuel bladders drop tested without structure (i.e., without puncture hazards) will have sufficient puncture resistance during real life accidents.

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

The analysis of data in this report supports the conclusion that there would be little or no benefit to mandating full compliance instead of the partial-compliance guidelines summarized in Table 12, as helicopters that mostly meet these recommendations perform as well in crashes as fully-compliant helicopters. However, as shown in the ROPWG Task 2 report, the full compliance requirement would be far more costly and disruptive to OEMs and operators and would likely result in the discontinuation of certain helicopter models due to the infeasibility of making the required changes in these models. Since the cost and weight penalties 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 27/29.952 after a 10-year period for legacy, newly-manufactured helicopters.

COST AND PERFORMANCE PENALTIES OF PARTIALLY-COMPLIANT FUEL SYSTEMS

Due to insufficient time and data for an adequate analysis, the interim ROPWG CRFS Report submitted on May 11, 2017 did not include estimated cost/performance penalties for newly-manufactured, legacy helicopters modified to meet the ROPWG recommendations. The ROPWG has since determined these cost/performance penalties based upon data submitted to ROPWG by OEMs.

Estimates of the cost and performance penalties for the partial-compliance 27/29.952 ROPWG 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 the costs presented in this section are in relation to the helicopter models as they are currently manufactured. Since many of these models already incorporate some CRFS features, the cost, weight, fuel, and range penalties presented are significantly smaller than would be required for designs with few or zero CRFS features.

Lastly, 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 CRFS 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 PARTIAL-COMPLIANCE RECOMMENDATIONS

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 are summarized in Table 13. The costs are broken down by Part 27 and Part 29. Note that the total estimated 10-year increased industry costs for CRFS were approximately $170,000,000 as reported by rotorcraft manufacturers.

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

Cost Category	Part 27	Part 29	Combined Costs Parts 27 & 29
Non-recurring Cost	$12,050,000	$71,715,000	$83,765,000
10-Year Unit Cost Increase	$37,940,000	$14,310,000	$52,250,000
Total 10-Year OEM Costs	$49,990,000	$86,025,000	$136,015,000
10-Year Operator Cost Increase	$19,999,326	$14,146,864	$34,146,190
Total 10-Year Estimated Industry Cost	**$69,989,326**	**$100,171,864**	**$170,161,190**

SUMMARY OF ESTIMATED PERFORMANCE PENALTIES FOR PARTIAL COMPLIANCE RECOMMENDATIONS

Table 14 shows the estimated reduction in effective payload due to the requirement to comply with the ROPWG partial-compliance recommendations. This reduction in payload is equal to the increased empty weight of the helicopter due to the inclusion of additional/revised CRFS components. 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 14. Weighted Average Reduction in Effective Payload, Partial Compliance Recommendations

Subcategory	Avg. Payload Δ (lbs.) CRFS: (.952)
Part 27 – Single Piston	6.5
Part 27 – Single Turbine	24.9
Part 27 – Twin Turbine	0.0
Part 29	71.9

Table 15 shows the estimated reduction in fuel capacity due to the requirement to comply with the ROPWG partial-compliance recommendations. This reduction in fuel capacity is primarily due to the addition of crash-resistant fuel bladders.

Table 15. Weighted Average Reduction in Fuel Capacity, Partial Compliance Recommendations

Subcategory	Total Avg. Fuel Capacity Δ (lbs.)
Part 27 – Single Piston	3.1
Part 27 – Single Turbine	2.4
Part 27 – Twin Turbine	0.0
Part 29	79.6

REVISED COST/PERFORMANCE PENALTIES FOR FULL COMPLIANCE WITH 27/29.952

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 partial-compliance estimates discussed in the previous section were developed without the costs associated with the recently-discontinued model, the partially-compliant 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 and partial-compliance, the full-compliance estimates from the Task 2 report have been revised to reflect the current set of applicable helicopters in active production. These revised cost estimates are presented in this section.

Additionally, while developing the cost/performance penalties associated with partial-compliance 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 incorporated in the revised full-compliance estimates presented in this section.

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 for the ROPWG partial-compliance 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 partial-compliance recommendations, only the revised cost/performance penalty tables for full compliance with 27/29.952 are included Appendix C.

Also note that the costs presented in this section are in relation to the helicopter models as they are currently manufactured. Since many of these models already incorporate some CRFS features, the cost, weight, fuel, and range penalties presented are significantly smaller than would be required for designs with few or zero CRFS features.

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

Table 16. Summary of 10-Year Industry Costs (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 (.952)	$14,491,000	$78,080,000	$92,571,000
10-Year Unit Cost Increase (.952)	$41,750,000	$14,310,000	$56,060,000
Total 10-Year OEM Costs	$56,241,000	$92,390,000	$148,631,000
10-Year Operator Cost Increase	$20,980,780	$14,214,404	$35,195,184
Total 10-Year Estimated Industry Cost	**$77,221,780**	**$106,604,404**	**$183,826,184**

Table 17. Weighted Average Reduction in Effective Payload, Revised Estimates for Full Compliance	
Subcategory	**Avg. Payload Δ (lbs.) CRFS: (.952)**
Part 27 – Single Piston	8.5
Part 27 – Single Turbine	25.0
Part 27 – Twin Turbine	0.0
Part 29	72.4

Table 18. Weighted Average Reduction in Fuel Capacity, Revised Estimates for Full Compliance	
Subcategory	**Total Avg. Fuel Capacity Δ (lbs.)**
Part 27 – Single Piston	3.1
Part 27 – Single Turbine	2.4
Part 27 – Twin Turbine	0.0
Part 29	79.6

BENEFIT OF PARTIALLY-COMPLIANT FUEL SYSTEMS

BENEFIT VALUATION

In the ROPWG Task 2 Report submitted on 10 November 2016, the approximate benefits in dollars of all newly manufactured rotorcraft fully complying with 27.952 was calculated for a 10-year production period. The general approach in forming this estimate was to examine crashes for rotorcraft manufactured over the past ten years which were representative of future production, and then determine the injuries and fatalities that would have been avoided had those aircraft been fully-compliant with 27.952. A monetary benefit for these avoided injuries and fatalities was then calculated based on data from the Federal Aviation Administration (FAA) Office of Aviation Policy and Plans (APO)[4]; this benefit was calculated as $17,142,135. Note that this benefit calculation was for Part 27 helicopters only; the benefit for Part 29 helicopters could not be calculated due to the limited number of Part 29 accidents with applicable CRFS data.

The present report has demonstrated that the ROPWG partial-compliance recommendations for CRFS in newly-manufactured, legacy helicopters would provide essentially the same benefit as full compliance with 27.952. Therefore, the monetary benefit associated with compliance with the ROPWG CRFS partial-compliance recommendations for Part 27 helicopters would also be approximately $17,142,135.

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 BURN TREATMENT

Note that the direct, lifetime cost of treating an individual with extensive burns can greatly exceed the FAA estimated cost for a serious injury ($2.4 M). Therefore, as also noted for full compliance with 27/29.952 in the ROPWG Task 2 Report, the monetary benefit of the ROPWG CRFS partial-compliance recommendations may be higher than stated due to near-elimination of severe thermal injuries following survivable accidents.

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[4] FAA Office of Aviation Policy and Plans, U.S. Federal Aviation Administration, "Economic Values for FAA investment and Regulatory Decisions, A Guide Final Report," updated September 2016.

Additionally, it is the opinion of the ROPWG that if the general public knew the extent to which severe burns typically require costly, extensive, and painful rehabilitation, the perceived value of avoiding these injuries (and therefore the calculated benefit in this report) would likely be higher.

UNCERTAINTY IN BENEFIT VALUATION

As discussed in the "Benefits Analysis" section of ROPWG Task 2 Report, the benefit calculation is proportional to the number of applicable thermal injuries and fatalities in the Task 2 dataset. Since there were relatively few accidents in the dataset where it was determined that CRFS would have been of likely value for at least one occupant, the number of preventable thermal fatalities and injuries in the dataset, and the resulting benefit calculation, could by random chance be higher or lower than what would be expected on average. For instance, a single additional accident could have doubled the expected benefit, while a single avoided accident could have reduced the calculated benefit by up to 60 percent.

In order to quantify this uncertainty and provide a range of likely benefit values, it is assumed that the number of accidents causing CRFS-preventable thermal injuries/fatalities, and the total number of CRFS-preventable fatalities and injuries, are random events, in which case it is appropriate to assume the number of these accidents/injuries/fatalities in a ten year period will each have their own Poisson distribution (a Poisson distribution is appropriate for applications that involve counting the number of times a random event occurs in a given amount of time, distance, area, etc.). With data for a single 10-year period in which two accidents with CRFS-preventable serious thermal injuries/fatalities occurred, the 25%-75% confidence interval for the expected number of such accidents is 0.96 to 3.92. Similarly, the 25%-75% confidence interval for the expected number of CRFS-preventable thermal fatalities is 1.73 to 5.11, and the interval for expected CRFS-preventable serious thermal injuries is 0.29 to 2.69. To calculate the 25%-75% confidence interval for the benefit of introducing CRFS that are fully compliant with the applicable regulations, the expected number of applicable accidents (0.96 to 3.92) is multiplied by the average benefit per accident in the dataset ($23,914,000/2 = $11,957,000), yielding a benefit confidence interval of $11,478,720 to $46,871,440.

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 post-crash thermal injuries would be offset by an increase in accidents and their associated (non-thermal) injuries. Unfortunately, it was not possible to provide a meaningful dollar estimate for the benefit reduction due to the accident rate concerns outlined above. However, the ROPWG believes these factors are significant, especially for smaller helicopters.

COST/BENEFIT ANALYSIS, PARTIAL AND FULL-COMPLIANCE

SUMMARY OF COSTS AND BENEFITS

Table 19 provides a summary of the 10-year industry costs and monetary benefits for compliance with the ROPWG recommendations and compares this to the cost/benefit of full compliance with 27/29.952. Note that partial-compliance provides a 9.3% reduction in industry costs compared to full-compliance for Part 27 helicopters and a 6.0% reduction for Part 29 helicopters. Also note that the calculated costs of implementing the ROPWG recommendations for CRFS in newly-manufactured, legacy helicopters exceed the calculated monetary benefits by a factor of 4.1 for Part 27 helicopters; the ratio for Part 29 helicopters is unknown due to lack of crash data for this class of helicopter.

Table 19. Summary of 10-Year Industry Costs (2016 USD) for Models Still in Production, Partial Compliance Recommendations and Full Compliance

Cost Category	Part 27		Part 29		Combined Costs Parts 27 & 29	
	Partial Compliance	Full Compliance	Partial Compliance	Full Compliance	Partial Compliance	Full Compliance
Non-recurring Cost (.952)	$12,050,000	$14,491,000	$71,715,000	$78,080,000	$83,765,000	$92,571,000
10-Year Unit Cost Increase (.952)	$37,940,000	$41,750,000	$14,310,000	$14,310,000	$52,250,000	$56,060,000
Total 10-Year OEM Costs	$49,990,000	$56,241,000	$86,025,000	$92,390,000	$136,015,000	$148,631,000
10-Year Operator Cost Increase	$19,999,326	$20,980,780	$14,146,864	$14,214,404	$34,146,190	$35,195,184
Total 10-Year Estimated Industry Cost	**$69,989,326**	**$77,221,780**	**$100,171,864**	**$106,604,404**	**$170,161,190**	**$183,826,184**
Total 10 Year Estimated Benefit	**$17,142,135**	**$17,142,135**	**	**	**	**

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

Table 20 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 27/29.952. Note that the weight penalties are greatest for the smallest classes of helicopters, which suffer the greatest decreases in performance due to a given increase in weight.

Table 20. Weighted Average Reduction in Effective Payload and Fuel Capacity for Partial and Full Compliance

Subcategory	Partial Compliance	Full Compliance	Difference
Payload (lbs)			
Part 27 – Single Piston	6.5	8.5	+2.0
Part 27 – Single Turbine	24.9	25.0	+0.1
Part 27 – Twin Turbine	0.0	0.0	0.0
Part 29	71.9	72.4	+0.5
Fuel Capacity (lbs)			
Part 27 – Single Piston	3.1	3.1	0.0
Part 27 – Single Turbine	2.4	2.4	0.0
Part 27 – Twin Turbine	0.0	0.0	0.0
Part 29	79.6	79.6	0.0

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

The reduction in cost and weight penalties for partial-compliance vs. full compliance is due to two primary factors:

- The partial-compliance recommendations allow OEMs to avoid the costs of developing, certifying, and implementing increased structural attachment strength for fuel tanks. Note that the lack of increased structural attachment strength for fuel tanks in partially-compliant CRFS did not appear to increase post-crash fire rates.
- The partial-compliance recommendations allow OEMs to avoid the cost of repeating fuel tank drop tests if they have already performed drop tests out of structure.

RELATIVE IMPACT ON SMALL HELICOPTERS

While the overall differential cost and weight penalties between partial and full-compliance are relatively small, 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.

Additionally, although the estimated costs of full-compliance did not, per FAA request, factor in the discontinuation of any models, the high cost of full-compliance combined with decreases in range and payload could, nevertheless, result in OEMs deciding to discontinue certain marginal models. Several OEMs participating in the ROPWG reported that the resulting aircraft performance impacts required for full-compliance with 27/29.952 may be so great that several models of aircraft could be discontinued. Implementing the ROPWG partial-compliance recommendations would significantly lower the odds of the discontinuation of these models.

Lastly, as discussed in the previous 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 smaller power margins. This would result in an increase in non-thermal injures partially offsetting the reduction in thermal injuries. As a result, regulatory requirements beyond those recommended (in particular, requiring full compliance with 27/29.952) could be detrimental to safety relative to the ROPWG partial-compliance recommendations, and are therefore strongly discouraged.

ADDITIONAL COST/BENEFIT CONSIDERATIONS

Although the costs of implementing the ROPWG recommendations for CRFS 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 direct, lifetime cost of treating an individual with extensive burns frequently exceeds, by as much as a factor of 10, the DOT/FAA "severe injury" cost estimates used in this analysis.
- It is the opinion of the ROPWG that many, or most, OEMs and operators would like to implement effective CRFS in their helicopters in order to help prevent post-crash fires and thermal injuries. However, doing so unilaterally would result in increased costs compared to competitors who choose not to make similar changes due to the lack of a Federal requirement for newly manufactured, legacy rotorcraft. As a result, many OEMs and operators that would like to implement effective CRFS are less likely to do so, as they know that the increased cost, increased weight, and decreased range of the CRFS-equipped helicopters will make it more difficult to compete with companies that choose not to implement CRFS.
- Historically, segments of the helicopter market have not been willing to pay an additional cost to voluntarily acquire these safety features. Several of the OEMs cited examples of offering some form of optional CRFS, but the sales did not justify the initial development cost. While segments of the rotorcraft industry are moving forward with implementation of optional CRFS equipment, universal implementation of these features will likely not occur unless they are mandated.
- Members of the ROPWG acknowledge the public stigma of the injuries that result from crashes, especially those with post-crash fires. Members of the ROPWG represent a cross-section of the rotorcraft industry. This group recognizes that for the good of the public, it is incumbent upon the rotorcraft industry to move forward in implementing safety measures, despite high costs to both OEMs and operators. With a goal of evolving the industry positively towards preventing thermal and blunt trauma injuries while also managing the financial impact to OEMs and operators (and their customers), members of ROPWG are supportive of this incremental approach that we believe will provide meaningful improvements in rotorcraft safety.
- Some operators are hesitant to purchase upgrade kits and/or aircraft with partially-compliant CRFS, as they wrongly assume fuel systems that are not fully compliant are ineffective at preventing post-crash fires, and/or they are concerned that the benefit that is indeed realized by these systems will not be recognized by their customers. The recognition by the FAA of the effectiveness of partially-compliant CRFS would likely encourage the adoption of these aircraft and retrofit kits, improving post-crash fire safety for both new and previously fielded aircraft.

CONCLUSIONS

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

1. The data presented in Table 6, Table 8, and Table 9 and summarized in Table 11 demonstrate that the crash performance of the partially-compliant Part 27 helicopters, with regard to the prevention of post-crash fires, is far superior to that of non-compliant helicopters, and nearly or equally effective as that of fully-compliant helicopters.
2. Partially-compliant CRFS models that passed a 50-foot drop test (with or without structure) and had a puncure resistance of at least 250 lb exhibited the following characteristics:
    a. Compared to fully-compliant CRFS helicopters, these partially-compliant CRFS helicopters were equally effective at preventing post-crash fires and thermal injuries.
    b. Compared to non-compliant CRFS helicopters, these partially-compliant CRFS helicopters reduced the post-crash fire rate due to fuel spillage in survivable accidents by 90%-100%.
3. Requiring partial compliance with CRFS regulations for this specific group of newly-manufactured, legacy helicopters per the ROPWG recommendations in Table 12 will be equally effective but less costly and far less disruptive to the industry than requiring full-compliance, for the following reasons:
    a. The partial-compliance recommendations allow OEMs to avoid the costs of developing, certifying, and implementing increased structural attachment strength for fuel tanks. In this study, the lack of increased structural attachment strength for fuel tanks in partially-compliant CRFS did not increase post-crash fire rates compared to fully compliant systems.
    b. The partial-compliance recommendations allow OEMs to avoid the cost of repeating fuel tank drop tests if they have already performed drop tests out of structure.
4. The empty weight and fuel capacity/range penalties outlined in this report could potentially increase the accident rate, particularly for small helicopters with smaller power margins. This could result in an increase in non-thermal injures partially offsetting the reduction in thermal injuries. As a result, regulatory requirements beyond those recommended (in particular, requiring full compliance with 27/29.952) could be detrimental to safety relative to the ROPWG partial-compliance recommendations, and are therefore strongly discouraged.
5. FAA requested that ROPWG make recommendations considering 27/29.952 only; however, ROPWG has included recommendations related to 27.963(g)/29.963(b) (fuel tank puncture resistance) and 27.975(b)/29.975(a)(7) (rollover vent valves) because the working group believes that the data presented in this report demonstrate that these regulations provide a cost-effective method of reducing fuel-fed, post-crash fires following survivable crashes.
6. There were insufficient crashes of Part 29 helicopters over the study period to perform a useful analysis. Nevertheless, the ROPWG recommends that Part 29 helicopters be subject to the same partial requirements as ROPWG has recommended for Part 27 helicopters, consistent with current FAA regulations.
7. Although the costs of implementing the ROPWG recommendations for CRFS 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 believes that these recommendations should be implemented for the following reasons:

a. The direct, lifetime cost of treating an individual with extensive burns frequently exceeds, by as much as a factor of 10, the DOT/FAA “severe injury” cost estimates used in this analysis.
b. It is the opinion of the ROPWG that many, or most, OEMs and operators would like to implement effective CRFS in their helicopters in order to help prevent post-crash fires and thermal injuries. However, to do so unilaterally would result in increased costs compared to their competitors who choose not to make similar changes due to the lack of a Federal requirement for newly manufactured, legacy rotorcraft. As a result, many OEMs and operators that would like to implement effective CRFS are less likely to do so.
c. Historically, segments of the helicopter market have not been willing to pay an additional cost to voluntarily acquire these safety features although several manufacturers offer retrofit fuel system modifications. Universal implementation of these features will likely not occur unless they are mandated.
d. Members of the ROPWG acknowledge the public stigma to OEMs and operators of the injuries that result from crashes, especially those with post-crash fires. With a goal of evolving the industry positively towards preventing thermal and blunt trauma injuries while also managing the financial impact to OEMs and operators (and their customers), members of ROPWG are supportive of this incremental approach that we believe will provide meaningful improvements in rotorcraft safety
e. Some operators are hesitant to purchase upgrade kits and/or aircraft with partially-compliant CRFS, as they wrongly assume fuel systems that are not fully compliant are ineffective at preventing post-crash fires, and/or they are concerned that the benefit that is indeed realized by these systems will not be recognized by their customers. The recognition by the FAA of the effectiveness of partially-compliant CRFS would likely encourage the adoption of these aircraft and retrofit kits, improving post-crash fire safety for both new and previously fielded aircraft.

8. The ROPWG recommends that the FAA **does not** require full compliance with 27/29.952 after a 10-year period for legacy, newly-manufactured helicopters, for the following reasons:
    a. The analysis of data in this report shows that there would be little or no benefit to mandating full compliance instead of the partial-compliance guidelines summarized in Table 12 since helicopters that mostly meet these recommendations perform as well in crashes as fully-compliant helicopters.
    b. The full compliance requirement would be very costly and disruptive to OEMs and operators alike and would likely yield no significant additional benefit in preventing post-crash, fuel-fed fires, and thermal injuries.
    c. Full compliance would result in the discontinuation of certain helicopter models due to the infeasibility of making the required changes in these models, resulting in considerable economic damage to OEMs and operators of affected rotorcraft.
    d. Delaying full compliance by 7-10 years will not mitigate any of these factors.

SUPPLEMENTAL DISCUSSION

While not part of the ROPWG tasking, several members of the ROPWG have voiced opinions in two areas which warrant supplemental discussion. These areas of discussion were not included in the body of the report nor formally voted on because they were not a part of the ROPWG tasking. Nevertheless, the working group is in agreement that these are significant issues which should be addressed by the FAA:

1. Recognition of CRFS Features for legacy out-of-production aircraft
2. Requirements for Fuel Bladder Tear Resistance

RECOGNITION OF CRFS FEATURES FOR OUT-OF-PRODUCTION, LEGACY ROTORCRAFT

The ROPWG has demonstrated the effectiveness of the CRFS incorporated into a number of 27/29.952 partially-compliant helicopters and recommended that most of these features be applied to all newly manufactured, legacy helicopters as a means of significantly reducing thermal injuries and fatalities due to post-crash fires following survivable accidents in these helicopters. Exclusive of that recommendation, the ROPWG is aware that several OEMs have designed partially-compliant CRFS, and for as long as several decades have offered them to operators for retrofit into out-of-production legacy helicopters. These currently available kits have undergone testing similar to that required by 27/29.952, but they are not fully compliant with the provisions of 27/29.952 either because they were certified prior to the implementation of the current regulation or because they do not meet all subparts of the regulation. Regardless, these designs, many of which have been incorporated into currently manufactured helicopters, have a proven field history of significantly reducing post-crash fire rates as was demonstrated in this report.

Because these kits are not recognized and/or given any regulatory acknowledgement by the FAA as being effective CRFS solutions, operators of out-of-production helicopters mistakenly believe that they do not have effective solutions available to them despite considerable evidence to the contrary. Many ROPWG members believe it is critical for the FAA to provide recognition of the proven benefit of these retrofit kits, which would encourage operators to invest in these available upgrades for many out-of-production helicopters. This recognition should include reassurance to operators that if they install these proven retrofit kits, they will not be subsequently required to replace them with a revised system if the FAA mandates the incorporation of CRFS features in newly manufactured, legacy helicopters. This action by the FAA could be immediate since these kits are already certified and the resulting increase in numbers installed would undoubtedly reduce thermal injuries and save lives.

FUEL BLADDER TEAR RESISTANCE

<u>Overview</u>

Several members of the ROPWG believe that paragraphs 27/29.952(g) need revision to provide better assurance that fuel bladders meeting this subpart will, in fact, provide the desired survivable crash resistance. In establishing this position reference is made to the Crash Survival Design Guide and to the recommendations for aircraft fuel tank design reported by Robertson and Turnbow.[5,6] The Robertson and Turnbow report was released in 1966 and its recommendations were incorporated into the original (1967) and subsequent versions of the Crash Survival Design Guide. These recommendations were based upon significant crash testing as well as helicopter crash investigations.

Some OEMs have made substantial improvements to crash safety in survivable accidents by voluntarily incorporating flexible fuel liners into some of their civil rotorcraft in spite of the lack of a Federal requirement to do so. Different puncture resistance values have been used by different OEMs and, at least one manufacturer routinely performs military specification testing in their fuel bladders, however, with reduced values. Nevertheless, 27.963(g) and 29.963(g) as well as TSO-C80 address fuel cell crash integrity but only require a puncture resistance criterion for crash resistant flexible fuel liners.

As the documents referenced below discuss, puncture resistance, in itself, is not predictive of flexible fuel liner crash performance. There is no real correlation between puncture resistance and the ability of the bladder materials to withstand survivable crash loads without rupturing. What requiring an increased puncture resistance has demonstrated, is that the resulting flexible liners have material properties sufficient to avoid rupture, even though those properties are not directly related to puncture resistance nor were these additional properties specified or identified by some OEMs or FAA regulations.

FAA Advisory Circular (27-1B) 27.952 amendment 27-30 (18)(i) states,

> "*Flexible liners are exempt from the requirements of 27.952(g) since an unsupported flexible liner can resist only pure tension loads...the rigid shell structure required by 27.967(a)(3) that surrounds the flexible liner (membrane) carries the crash-induced impact and tear loads; whereas, the flexible liner is only significantly loaded in tension if the shell structure is penetrated by a sharp object on impact.*"

This was interpreted as implying that only a puncture resistance requirement is necessary to produce an effective fuel cell liner, which further prompted the change in FAA requirements for puncture resistance to increase from 15 lb. to 370 lb. Unfortunately, the underlying assumption is erroneous because survivable crashes often exhibit loads that cause catastrophic failure of the host container (usually metal) with or without a crash resistant fuel bladder installed. The Crash Survival Design Guide states in paragraph 4.2, "*The ideal fuel system is one that completely contains its flammable fluid both during and*

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

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

after the accident. To accomplish this, all components of the system must resist rupture regardless of the degree of failure of the surrounding structure." When host containers yield in a survivable crash, the one thing needed to prevent a post-crash fire is a flexible bladder having sufficient tear resistance to withstand the crash loads and avoid catastrophic failure.

To be sure, tensile strength and elongation are also important, in that crash loads can generate sufficient internal tank pressure to result in the flexible bladder failing its host container, usually catastrophically. The design guide states the following in paragraph 4.2.1.3, Tank Materials:

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

Elongation of the bladder reduces the tensile loading in the bladder within the fittings and seams avoiding catastrophic failure provided tearing does not occur. The design guide states the following in paragraph 4.2.1.3, Tank Materials:

> "*The concept of fluid containment requires materials and fabrication techniques that will maximize the energy-absorbing ability of the fuel system. Tanks constructed in accordance with earlier military specifications for crash resistance lacked such qualities and, therefore, failed under minimal severity of crash conditions. Crash resistant fuel system research has shown, however, that fuel tanks constructed of materials possessing a high degree of cut and tear resistance, as well as a moderate degree of elongation, can accommodate very high impact levels without loss of fuel. These research programs resulted in Revision B to Mil-T-27422 for crash-resistant tanks (Reference 15).*"

Material properties and testing essential for crash resistance are provided for in MIL-DTL-27422 and military bladder constructions are required to pass those tests. These tests and the minimum standards for the crash resistant constructions were developed as a result of Army-sponsored testing reported in 1966. Material properties were developed and considered essential from actual crash testing using many different constructions of fuel bladders. Some worked, and some did not. A relation between survivable crash loads and material properties was developed. Because of the importance of these material properties, testing of them was considered mandatory and made regulatory for the military. MIL-STD-27422A was re-written as Revision B and the result was overwhelming. Since the early 1970's there have been no deaths from post-crash fires in survivable crashes of military rotorcraft complying with the Revision B requirements.

These same requirements, at basically half of the Mil Spec values, have been incorporated into Advisory Circulars 27-1b and 29-2c and are identical for both parts, but not regulatory. The FAA selected lower chisel heights and a constant rate tear requirement of 200 ft-lb. This was because civil rotorcraft are generally much lighter than military rotorcraft and would, therefore, be expected to experience much lower crash loads in survivable crashes. Although this may be true for some rotorcraft, some civil rotorcraft (Bell 525, S-92) are quite large and would be expected to withstand higher survivable crash loads.

The design guide states the following in paragraph 4.2.1.3, Tank Materials:

> "*What, then, defines whether or not a tank is crashworthy? The overall results of extensive U.S. Army-funded crashworthy fuel system studies indicated that cut, tear and impact resistance were the key issues...The B revision of MIL-T-27422 was prepared as a result of the U.S. Army tests, and is the best source to date to define fuel tank crashworthiness.*"

To save lives, the overriding requirement is that the aircraft have fuel system crash resistance (survivability) that is commensurate with the crash loads of a survivable crash in that aircraft. Consequently, flexible crash resistant fuel liner material properties for small helicopters such as a Robinson R44 would be significantly different than the material properties for a larger civil rotorcraft such as a Sikorsky S-92 in order to provide equivalent crash safety in survivable crashes.

<u>Conclusion & Recommendation</u>

Crash resistant flexible fuel liner material properties for Part 27 and Part 29 civil rotorcraft must be different, not equal. The correlation between the survivable crash loads and the material properties of the fuel bladder to resist yielding to those loads should dictate the values required for the three Military Specification tests noted above, and this testing should be mandatory.

Recommend the following Rule changes:

1. Change the TSO-C80 material requirement for flexible fuel liners from 370 lb. puncture to the following:

    a. Part 27 rotorcraft, test per MIL-DTL-27422F, Detail Specification: Tank, Fuel, Crash-Resistant, Ballistic-Tolerant Aircraft, dated February 2014 except use the following values;
        1. Constant rate tear - A cut is made in the sample and pulled apart at 20 inches per minute. Must withstand no less than 200 ft-lb.
        2. Impact penetration - 5 lb. chisel dropped from 8 ft. onto a construction sample, must not leak when 5 psi is applied to the construction.
        3. Impact tear - 5 lb. chisel dropped from 8 ft. onto the edge of the construction with a v-notch cut into the sample. The resulting tear cannot propagate to longer than 1 inch.
    b. Part 29 rotorcraft, test per MIL-DTL-27422;
        1. Constant rate tear - A cut is made in the sample and pulled apart at 20 inches per minute. Must withstand no less than 400 ft-lb.
        2. Impact penetration - 5 lb. chisel dropped from 15 ft. onto a construction sample, must not leak when 5 psi is applied to the construction.

3. Impact tear - 5 lb. chisel dropped from 10 ft. onto the edge of the construction with a v-notch cut into the sample. The resulting tear cannot propagate to longer than 1/2 inch.

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

2. FAA AC 27-1B, 27.952 amendment 27-30 (19) states "*Section 27.952(g) also requires that all fuel tank designs (regardless of the materials utilized and whether or not a flexible liner of any type is used) ...tested to the criteria of paragraph (18) (iv) of AC 27.952, or equivalent.*" Due to the ambiguity of the current wording, paragraphs 27.952 (g) and 29.952 (g) need to be re-written to require demonstration of tear and cut resistance for all fuel containment by performance of the MIL-DTL-27422 testing at values specified in TSO-C80, flexible crash resistant liner material property requirements.

ROPWG VOTING MEMBERS STATEMENTS OF NON-CONCURRENCE

While the ROPWG recommendations were in general agreed upon by most members, there were some recommendations where there was a difference of opinion.

With 27/29.952(c) and 27.975(b)/29.975(a)(7) (flexible fuel hoses and breakaway fittings, and rollover vent valves), a number of members did not concur with some aspects of the ROPWG recommendations for those regulations. Rather than have each non-concurring member write their own dissenting opinion for those recommendations, a group minority statement for those recommendations is included below.

Individual statements of non-concurrence on other aspects of the report follow the group minority opinion.

GROUP MINORITY OPINION ON RECOMMENDATIONS FOR 27/29.952(C) AND 27.975(B)/29.975(A)(7)

A number of members of the ROPWG were in favor of adding the following clauses to the ROPWG recommendations for CRFS:

- 27/29.952(c): Flexible fuel hoses and breakaway fittings
  - "Legacy helicopters found to provide effective post-crash fire protection should be excluded from the requirements of 27/29.952(c)."
- 27.975(b)/29.975(a)(7): Rollover vent valves
  - "Acceptable methods of compliance for rollover vent valves should ensure that legacy helicopters found to provide effective post-crash fire protection will be considered compliant."

The arguments in favor of the inclusion of the statements were as follows:

- The data in this report shows that, for legacy helicopters found to provide effective post-crash fire protection, there would be little or no benefit to requiring design changes in order to comply with the ROPWG recommendations for 27/29.952(c) and 27.975(b)/29.975(a)(7), as these helicopters already perform as well in crashes as fully-compliant helicopters.
- Mandating compliance to 27/29.952(c) and 27.975(b)/29.975(a)(7) would be very costly and disruptive to OEMs and operators alike for certain models and would likely yield no significant additional benefit in preventing post-crash, fuel-fed fires, and thermal injuries.
- Some members argued that in their experience, the ELOS process was often too time-consuming, difficult and burdensome to be relied upon for the granting of exemptions based upon crash performance.

ROBINSON HELICOPTER COMPANY

Robinson Helicopter Company (RHC) generally concurs with most sections of the Rotorcraft Occupant Protection Working Group (ROPWG) Task 5 CRFS report reviewed on January 22, 2018, but disagrees with some of the recommendations, as detailed below.

Background

As stated in the report, the ROPWG concluded the following with regards to the effectiveness of existing partially-compliant fuel systems:

> *"The data presented...demonstrate that the crash performance of the partially-compliant Part 27 helicopters, with regard to the prevention of post-crash fires, is far superior to that of non-compliant helicopters, and for most partially-compliant models, equally effective as fully-compliant helicopters."*

While the ROPWG report later states that "*ROPWG recommendations for newly manufactured legacy helicopters are based upon an amalgamation of the most effective partially-compliant CRFS*", the ROPWG recommendations exceed what has been implemented in most partially-compliant helicopters. In particular, while the report states that "*Among partially-compliant designs that passed a 50-foot drop test (with or without structure) and had a puncture resistance of at least 250 lb (models 1-4), crash performance was essentially identical to that of fully-compliant helicopters"*, the ROPWG recommendations additionally call for compliance with 27/29.952(c) and 27.975(b)/29.975(a)(7), regulations that were not shown to yield a reduction in thermal injuries. These additional requirements were included because of their potential to improve protection against post-crash fuel spillage rather than a conclusion reached from the analysis of accident data. Without accident data supporting the additional requirements, the benefit they provide is only speculative.

Decrease in Safety Caused by Extra Weight, Reduction in Fuel Capacity, and Increased Complexity

As stated in the report, regulations beyond those needed to improve post-crash fire safety are potentially detrimental to safety. Added weight and reduced fuel capacity to meet the design requirements will reduce safety margins. This is particularly critical for small, previously-certified aircraft where major structural changes may be required to accommodate the addition of new features.

In addition to the safety concerns associated with higher weights, components with increased complexity, such as breakaway fittings, can lead to an increased probability of failure in service, and maintenance errors.

The reduction in safety margins due to extra weight, decreased fuel capacity, and increased complexity is therefore likely to outweigh any benefits from a reduction in thermal injuries.

Issues Related to Compliance with 27/29.952(c)

The requirements of 27.952(c) are particularly difficult to meet for small, previously-certified rotorcraft, for reasons as follows:

- 27.952(c) requires self-sealing breakaway couplings, which are relatively large and heavy, leading to reduced power margins and decreased fuel capacity.
- Relief from self-sealing breakaway couplings is only permitted if hazardous motion of fuel system components is shown to be "extremely improbable", a regulatory standard that most OEMs on the ROPWG agreed was virtually impossible to meet.
- If relief from the requirement for self-sealing breakaway couplings is nonetheless granted, the AC guidance dictates a minimum of 20-30% slack in fuel lines, something that is not practicable for some smaller, previously-certified aircraft due to existing geometric constraints.
- The AC guidance for 27.952(c) dictates the use of heavy MIL-SPEC fuel lines where lighter-weight more flexible hoses have been shown to provide sufficient crash protection.

<u>Issues Related to Compliance with 27.975(b)/29.975(a)(7)</u>

While the regulatory text of 27.975(b)/29.975(a)(7) specifies a practicable level of fuel vent spillage protection ("minimization of fuel spillage through vents to an ignition source"), the associated guidance creates a much higher standard that is not practicable for many smaller, previously-certified rotorcraft. In particular, the leak criteria of 10 drops per minute is far more strict than necessary to prevent thermal injuries from a post-crash fire. Additionally, the requirement to meet this leak criteria at all rollover angles, as opposed to those that are most probable (90° to inverted), requires the design of valves that are larger, heavier, and more complicated than are required to prevent leakage at the probable rollover angles.

Note that as stated in the main body of this report, a simplified rollover vent valve design incorporated in some partially compliant fuel systems was shown to be extremely effective at preventing post-crash fires in survivable accidents.

<u>27/29.952(f) as an Alternative to 27/29.952(c) and 27.975(b)/29.975(a)(7)</u>

27/29.952(f) requires the incorporation of crash resistant fuel system components to the extent practicable:

> *"27/29.952(f): Other basic mechanical design criteria. Fuel tanks, fuel lines, electrical wires, and electrical devices must be designed, constructed, and installed,* ***as far as practicable*** *[RHC emphasis], to be crash resistant."*

Since previously certified aircraft typically have fixed designs, geometric constraints, and limited power margins, it is RHC's opinion that additional CRFS features beyond crash resistant fuel bladders, such as crash-resistant fuel lines and rollover vent valves, are best incorporated **to the extent practicable** via compliance with 27/29.952(f). This will achieve the same level of post-crash fire prevention as mandating 27/29.952(c) and 27.975(b)/29.975(a)(7), but without the safety detriment resulting from added weight and complexity.

Implementing a retroactive requirement that includes 27.952(c) and 27.975(b) would necessitate design revisions to helicopters that have already undergone upgrades from their original designs to incorporate crash resistant design features. These "partial-compliance" upgrades have demonstrated a record of post-crash fire protection equivalent to fully compliant designs. The most likely outcome from the retroactive application of 27.952(c) and 27.975(b) for these helicopters would therefore be a decrease in safety.

Note that while fuel tank vents are not specifically mentioned in 27/29.952(f) and the associated advisory circular, this material addresses the general intent of preventing fuel from leaking to ignition sources following crashes. Therefore, the AC guidance for newly manufactured, legacy helicopters should specify that the "as far as practicable" crash resistance requirements of 27/29.952(f) also apply to fuel tank vents.

RHC Recommendations

In consideration of the discussion above, RHC believes that the requirements for newly-manufactured, legacy helicopters should be primarily limited to those regulations that were shown to be most effective at preventing thermal injuries following survivable accidents. The requirements should also recognize that the models under consideration have relatively fixed designs due to their prior certification, making it much more difficult to incorporate new or revised components due to existing geometric and weight constraints.

Specifically, RHC believes the requirements should mandate the installation an effective crash-resistant fuel bladder, to be demonstrated by compliance with the ROPWG recommendations for 27/29.562(a) (fuel bladder drop test, surrounding structure optional) and 27.963(g)/29.963(b) (fuel bladder puncture resistance, 250 or 370 lb puncture resistance depending on drop test results). Additionally, RHC recommends the requirement for the installation of other crash-resistant fuel system components such as fuel lines and rollover vent valves **to the extent practicable** as required by 27/29.952(f).

RHC's regulatory recommendations for newly manufactured, legacy helicopters are included below in Table 21. RHC recommendations that differ from those of the ROPWG are in bold and underlined.

Table 21. 27/29.952 RHC Regulatory Recommendations for Newly Manufactured, Legacy Helicopters

Regulation	Recommendation	Notes
27/29.952(a)(1)(2)(3)(5)(6): Drop test requirements	Recommended	Regulation should allow bladder-only drop test (i.e., surrounding structure optional).
27/29.952(a)(4) Drop test requirements	NOT recommended	
27/29.952(b): Fuel tank load factors	NOT recommended	See discussion in main body of this report
27/29.952(c): Flexible fuel hoses and breakaway fittings	**NOT recommended**	**27/29.952(f) and the associated AC guidance address these same items, but have a regulatory standard that is more appropriate for incorporation into a previously-certificated legacy rotorcraft.**
27/29.952(d): Frangible or deformable structural attachments	NOT recommended	27/29.952(f) and the associated AC guidance address these same items, but have a regulatory standard that is more appropriate for incorporation into a previously-certificated legacy rotorcraft.
27/29.952(e): Separation of fuel and ignition sources	NOT recommended	
27/29.952(f): Other basic mechanical design criteria	Recommended	Requirements for new production legacy rotorcraft should additionally include elements of 27.963(g)/29.963(b) (fuel tank puncture resistance) and 27.975(b)/29.975(a)(7) (rollover vent valves). Fuel tank puncture resistance requirement should be dependent on drop test results as detailed in the discussion in this main body of this report. **The AC guidance for newly manufactured, legacy helicopters should specify that the "as far as practicable" crash resistance requirements of 27/29.952(f) also apply to fuel tank vents.**
27/29.952(g): Rigid or semi-rigid fuel tanks	Recommended w/changes to guidance	Recommended if AC guidance is revised to clarify that this requirement applies to rigid or semi-rigid fuel tank or bladder walls only and that flexible liners are excluded.

Requirement for full compliance 10 years after approval of new CRFS rules	NOT recommended	Data for partially-compliant helicopters show that the recommendations in this report are equally effective at preventing post-crash fires and thermal injuries, but with a substantially lower weight penalty and monetary cost.

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

Note that the costs presented in this section are in relation to the helicopter models as they are currently manufactured. Since many of these models already incorporate some CRFS features, the cost, weight, fuel, and range penalties presented are significantly smaller than would be required for designs with few or zero CRFS features.

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 27/29.952, 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 22 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 22. Industry Total Non-Recurring Costs (USD) of Compliance for Models Still in Production, Partial Compliance Recommendations

Rotorcraft Groups	Non-recurring Cost, CRFS (.952)
Part 27 - Single Piston	$4,150,000
Part 27 - Single Turbine	$7,900,000
Part 27 - Twin Turbine	$0
Part 29	$71,715,000
All Groups Combined	**$83,765,000**

UNIT COSTS

Table 23 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 23 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 23 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 23. Unit Costs (USD) to Bring Models Still in Production Up to Partial Compliance Recommendations				
Rotorcraft Groups	**Estimated Annual Production**	**Weighted Average Unit Costs (.952) (per aircraft)**	**Total Annual Unit Costs (.952)**	**10-Year Total Unit Cost Increase (.952)**
Part 27 - Single Piston	85	$6,194	$526,500	$5,265,000
Part 27 - Single Turbine Models	84	$38,899	$3,267,500	$32,675,000
Part 27 - Twin Turbine	3	$0	$0	$0
Total Part 27	172	N/A	$3,794,000	$37,940,000
Total Part 29	13	$110,077	$1,431,000	$14,310,000
All Groups Combined	**185**	**N/A**	**$5,225,000**	**$52,250,000**

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 27/29.952 and would require minimal or zero changes to meet the ROPWG recommendations, while other models would require substantial revisions to the fuel system (addition of crash resistant bladders and fuel lines, etc.). Also, it should be noted that the values in Table 23 reflect the broader OEM estimates for specific aircraft in production, while the fuel systems data in Appendix D of the Task 2 report represent the costs for components to outfit generic, non-specific Part 27/29 aircraft. 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 vs. 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 vs. 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 in*

the US) 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 US 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 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 24 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:

- Fuel bladders
- Revised fuel lines
- Revised/additional fuel and vent fittings

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 24. Weighted Average Reduction in Effective Payload, Partial Compliance Recommendations

Subcategory	Avg. Payload Δ (lbs.) CRFS: (.952)
Part 27 – Single Piston	6.5
Part 27 – Single Turbine	24.9
Part 27 – Twin Turbine	0.0
Part 29	71.9

REDUCTION IN FUEL CAPACITY

Fuel capacity reductions generally resulted from the addition of fuel cell bladders and the volume they consume. Table 25 outlines the average fuel capacity reduction by aircraft category.

Table 25. Weighted Average Reduction in Fuel Capacity, Partial Compliance Recommendations

Subcategory	Total Avg. Fuel Capacity Δ (lbs.)
Part 27 – Single Piston	3.1
Part 27 – Single Turbine	2.4
Part 27 – Twin Turbine	0.0
Part 29	79.6

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[7]. This value was used by the operators to determine additional fuel costs per year based on their operations.

[7] 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: US 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 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 US 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 reasoning is as follows: most of the time, the reduced passenger/cargo capacity will not be needed, 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 26).

Table 26. Resultant Increase in Operator Costs/Decrease in Operator Revenue Due to Reduction of Payload, Per Year, Partial Compliance 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**
					.952	**.952**	**.952**
Single Engine Piston	85	$201	298	632	6.5	1.0%	$52,271
Single Engine Turbine	84	$463	338	1199	24.9	2.1%	$272,849
Twin Turbine (Part 27)	3	$950	500	3125	0.0	0.0%	$0
Part 29	13	$1,114	627	3646	71.9	2.0%	$179,053
						Total	**$504,172**

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 27). 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 27. Resultant Increase in Operator Costs/Decrease in Operator Revenue, Per Year Due to Reduction in Range, Partial Compliance 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 (US gallons)**	**Weighted Average Reduction in Fuel Capacity (US 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**
					.952	**.952**		**.952**
Single Engine Piston	85	$201	298	43	0.5	1.2%	20.0%	$12,188
Single Engine Turbine	84	$463	338	127	0.4	0.3%	20.0%	$7,383
Twin Turbine (Part 27)	3	$950	500	146	0.0	0.0%	20.0%	$0
Part 29	13	$1,114	627	323	11.7	3.6%	20.0%	$65,853
							Total	**$85,424**

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 28). 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 28. Resultant Increase in Operator Fuel Costs, Per Year, Partial Compliance 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**
					.952	**.952**
Single Engine Piston	85	298	0.005	$4.99	6.5	$4,103
Single Engine Turbine	84	338	0.005	$4.20	24.9	$14,831
Twin Turbine (Part 27)	3	500	0.005	$4.20	0.0	$0
Part 29	13	627	0.005	$4.20	71.9	$12,310
					Total	**$31,243**

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 US 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 29. 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 29. Total Increase in Operator Costs/Decrease in Operator Revenue Due to Changes in Payload, Fuel Capacity, and Range, Per Year, Partial Compliance Recommendations

Aircraft Type	CRFS: .952
Single Engine Piston	$68,561
Single Engine Turbine	$295,063
Twin Turbine (Part 27)	$0
Part 29	$257,216
Total	**$620,840**

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 30) simply adds together the costs for each of the first ten years of affected helicopters. It does not account for interest nor use any other more sophisticated financial analysis.

Table 30. Cumulative Increase in Operator Costs/Decrease in Operator Revenue Due to Reduction in Payload, Fuel Capacity, and Range, First 10 Years After Regulatory Changes, Partial Compliance Recommendations	
Aircraft Type	**CRFS: .952**
Single Engine Piston	$3,770,873
Single Engine Turbine	$16,228,454
Twin Turbine (Part 27)	$0
Part 29	$14,146,864
Total	**$34,146,190**

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, full compliance for the AS350B incurs an additional weight load that virtually eliminates its application with currently bid US 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 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.

Assuming similar maintenance/inspection procedures for fuel systems complying with the ROWPG (partial compliance) recommendations, it is estimated that direct operating cost (DOC) is not impacted for these components beyond those factors already discussed. Installation of fuel systems complying with the ROPWG (partial compliance) recommendations will drive minimal or no change to pilot training procedures, with nominal costs, if any.

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 are summarized in Table 31. 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 CRFS were estimated at approximately $170,000,000.

Table 31. Summary of 10-Year Industry Costs (USD) of Compliance for Models Still in Production, Partial Compliance Recommendations

Cost Category	Part 27	Part 29	Combined Costs Parts 27 & 29
Non-recurring Cost (.952)	$12,050,000	$71,715,000	$83,765,000
10-Year Unit Cost Increase (.952)	$37,940,000	$14,310,000	$52,250,000
Total 10-Year OEM Costs	$49,990,000	$86,025,000	$136,015,000
10-Year Operator Cost Increase	$19,999,326	$14,146,864	$34,146,190
Total 10-Year Estimated Industry Cost	**$69,989,326**	**$100,171,864**	**$170,161,190**

Table 32 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 32. Costs and Present Value Costs for OEMs Over 10-Years, Partial Compliance Recommendations

Calendar Year	Costs in 2016 Dollars	Present Value Costs at 7%
2015		
2016		
2017		
2018		
2019		
2020	$88,990,000	$67,890,045
2021	$5,225,000	$3,725,353
2022	$5,225,000	$3,481,638
2023	$5,225,000	$3,253,867
2024	$5,225,000	$3,040,998
2025	$5,225,000	$2,842,054
2026	$5,225,000	$2,656,125
2027	$5,225,000	$2,482,360
2028	$5,225,000	$2,319,962
2029	$5,225,000	$2,168,189
Total	**$136,015,000**	**$93,860,591**

Table 33 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 34 provides a comparison of this data.

Table 33. Costs and Present Value Costs for OEMs and Operators Over 10-Years, Partial Compliance Recommendations

Calendar Year	Costs in 2016 Dollars	Present Value Costs at 7%
2015		
2016		
2017		
2018		
2019		
2020	$89,610,840	$68,363,681
2021	$6,466,680	$4,610,653
2022	$7,087,519	$4,722,713
2023	$7,708,359	$4,800,379
2024	$8,329,199	$4,847,670
2025	$8,950,039	$4,868,228
2026	$9,570,879	$4,865,349
2027	$10,191,719	$4,842,012
2028	$10,812,558	$4,800,905
2029	$11,433,398	$4,744,454
Total	**$170,161,190**	**$111,466,045**

Table 34. 10-Year Total Projected Costs and Present Value Costs, Partial Compliance Recommendations

Calendar Year	Costs in 2016 Dollars	Present Value Costs at 7%
OEM Costs	$136,015,000	$93,860,591
Operator Costs	$34,146,190	$17,605,453
Total	**$170,161,190**	**$111,466,045**

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 post-crash thermal injuries would be offset by an increase in accidents and their associated (non-thermal) injuries. Unfortunately, it was not possible to provide a meaningful dollar estimate for the benefit reduction due to the accident rate concerns outlined above. However, the ROPWG believes these factors 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 partial-compliance estimates discussed in the previous appendix were developed without the costs associated with the recently-discontinued model, the partial-compliance 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 and partial-compliance, 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 partial-compliance 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 also 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 partial-compliance recommendations. Therefore, rather than detailing the methodology again, only the revised cost/performance penalty tables for full compliance with 27/29.952 are included here.

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

Table 35. Industry Total Non-Recurring Costs (USD) of Compliance for Models Still in Production, Revised Estimates for Full Compliance

Rotorcraft Groups	Non-recurring Cost, CRFS (.952)
Part 27 - Single Piston	$4,700,000
Part 27 - Single Turbine	$9.791,000
Part 27 - Twin Turbine	$0
Part 29	$78,080,000
All Groups Combined	**$92,571,000**

Table 36. 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 (.952) (per aircraft)**	**Total Annual Unit Costs (.952)**	**10-Year Total Unit Cost Increase (.952)**
Part 27 - Single Piston	85	$6,559	$557,500	$5,575,000
Part 27 - Single Turbine Models	84	$43,065	$3,617,500	$36,175,000
Part 27 - Twin Turbine	3	$0	$0	$0
Total Part 27	172	N/A	$4,175,000	$41,750,000
Total Part 29	13	$110,077	$1,431,000	$14,310,000
All Groups Combined	**185**	**N/A**	**$5,606,000**	**$56,060,000**

Table 37. 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	**CRFS: .952**
Single Engine Piston	$85,719
Single Engine Turbine	$295,750
Twin Turbine (Part 27)	$0
Part 29	$258,444
Total	**$639,912**

Table 38. 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	**CRFS: .952**
Single Engine Piston	$4,714,519
Single Engine Turbine	$16,266,261
Twin Turbine (Part 27)	$0
Part 29	$14,214,404
Total	**$35,195,184**

Table 39. Weighted Average Reduction in Effective Payload, Revised Estimates for Full Compliance	
Subcategory	**Avg. Payload Δ (lbs.) CRFS: (.952)**
Part 27 – Single Piston	8.5
Part 27 – Single Turbine	25.0
Part 27 – Twin Turbine	0.0
Part 29	72.4

Table 40. Weighted Average Reduction in Fuel Capacity, Revised Estimates for Full Compliance	
Subcategory	**Total Avg. Fuel Capacity Δ (lbs.)**
Part 27 – Single Piston	3.1
Part 27 – Single Turbine	2.4
Part 27 – Twin Turbine	0.0
Part 29	79.6

Table 41. Summary of 10-Year Industry Costs (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 (.952)	$14,491,000	$78,080,000	$92,571,000
10-Year Unit Cost Increase (.952)	$41,750,000	$14,310,000	$56,060,000
Total 10-Year OEM Costs	$56,241,000	$92,390,000	$148,631,000
10-Year Operator Cost Increase	$20,980,780	$14,214,404	$35,195,184
Total 10-Year Estimated Industry Cost	**$77,221,780**	**$106,604,404**	**$183,826,184**

Table 42. 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	$98,177,000	$74,898,763
2021	$5,606,000	$3,997,001
2022	$5,606,000	$3,735,515
2023	$5,606,000	$3,491,135
2024	$5,606,000	$3,262,743
2025	$5,606,000	$3,049,293
2026	$5,606,000	$2,849,806
2027	$5,606,000	$2,663,370
2028	$5,606,000	$2,489,131
2029	$5,606,000	$2,326,291
Total	**$148,631,000**	**$102,763,047**

Table 43. 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	$98,816,912	$75,386,949
2021	$6,885,825	$4,909,498
2022	$7,525,737	$5,014,717
2023	$8,165,650	$5,085,156
2024	$8,805,562	$5,124,917
2025	$9,445,475	$5,137,712
2026	$10,085,387	$5,126,899
2027	$10,725,299	$5,095,513
2028	$11,365,212	$5,046,290
2029	$12,005,124	$4,981,700
Total	**$183,826,184**	**$120,909,351**

Table 44. 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	$148,631,000	$102,763,047
Operator Costs	$35,195,184	$18,146,304
Total	**$183,826,184**	**$120,909,351**

Table 45. 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**
					.952	**.952**	**.952**
Single Engine Piston	85	$201	298	632	8.5	1.3%	$68,179
Single Engine Turbine	84	$463	338	1199	25.0	2.1%	$273,501
Twin Turbine (Part 27)	3	$950	500	3125	0.0	0.0%	$0
Part 29	13	$1,114	627	3646	72.4	2.0%	$180,202
						Total	**$521,882**

Table 46. 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 (US gallons)**	**Weighted Average Reduction in Fuel Capacity (US 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**
					.952	**.952**		**.952**
Single Engine Piston	85	$201	298	43	0.5	1.2%	20.0%	$12,188
Single Engine Turbine	84	$463	338	127	0.4	0.3%	20.0%	$7,383
Twin Turbine (Part 27)	3	$950	500	146	0.0	0.0%	20.0%	$0
Part 29	13	$1,114	627	323	11.7	3.6%	20.0%	$65,853
							Totals	**$85,424**

Table 47. 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**
					.952	**.952**
Single Engine Piston	85	298	0.005	$4.99	8.5	$5,352
Single Engine Turbine	84	338	0.005	$4.20	25.0	$14,866
Twin Turbine (Part 27)	3	500	0.005	$4.20	0.0	$0
Part 29	13	627	0.005	$4.20	72.4	$12,389
					Totals	**$32,606**