This White Paper outlines a strategy to reduce fatal helicopter accidents by facilitating IFR operations in lieu of VFR when conditions do not support safe flight under VFR. The paper also details a proposal to facilitate an economically viable IFR certification plan for single-engine helicopters.

14 CFR 27 Single-Engine IFR Certification Proposal

Association and Industry White Paper
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Prepared in cooperation with Helicopter Association International, American Helicopter Society International, General Aviation Manufacturers Association, and Aircraft Electronics Association.

Normal-Category (Part 27) Operational Safety Enhancement by Enabling Single-Engine Rotorcraft IFR

1.0 INTRODUCTION

It is generally accepted that an increase in rotorcraft Instrument Flight Rule (IFR) operations would provide a significant safety improvement. Currently, Inadvertent flight into Instrument Meteorological Conditions (IIMC) or Controlled Flight into Terrain (CFIT) while attempting to fly under weather conditions continues to be a major contributor to the accident statistics for rotorcraft – especially single-engine rotorcraft.

Over the period of 2001 to 2013[1] for Part 27 single-engine helicopters world-wide there were:

- 194 accidents related to IIMC or CFIT due to low-level flight to avoid weather.
- 133 of these accidents involved fatalities.
- 326 people lost their lives in these accidents.
- 57 of these accidents occurred in the United States.

None of these rotorcraft were IFR equipped. In fact, IFR-certified single-engine rotorcraft are virtually nonexistent in the current fielded fleet. Of the few that do exist, none are recent certifications employing the current state-of-the-art technology that is now commonly used for IFR systems in other aircraft.

For multi-engine, Part 27 or Part 29 rotorcraft world-wide there were:

- 54 accidents related to IFR, IIMC, or CFIT due to low-level flight in bad weather.
- 46 of these accidents involved fatalities.
- 40 involved rotorcraft attempting to fly by Visual Flight Rules (VFR), only 7 were conducted under IFR.
- 12 of these accidents occurred in the United States.

In most cases the multi-engine rotorcraft were IFR equipped, but often either the pilot had no instrument rating, was not current, or had minimal instrument experience and was not confident in IFR procedures. In addition, most of the rotorcraft involved were models with older “steam gauge” style IFR instrumentation. These require a much greater degree of skill to interpret than modern displays, and therefore require a greater degree of practice in order to remain proficient.

The Associations believe the above accident data only shows a portion of the problem. Figure 1 below shows the year-to-year distribution of these accidents. What is not captured in the accident data are the near misses of obstacles and terrain that occurred trying to avoid weather, or the near losses of control that occurred attempting to exit IIMC. The erratic year-to-year data is indicative of a broader issue where a high risk practice of “scud running” is prevalent and what is captured in the data are the aircraft that failed in the gamble.

[1] Based on major OEM safety department accident data base covering all accidents /incidents for all rotorcraft manufactures and types. Data excludes military operations.

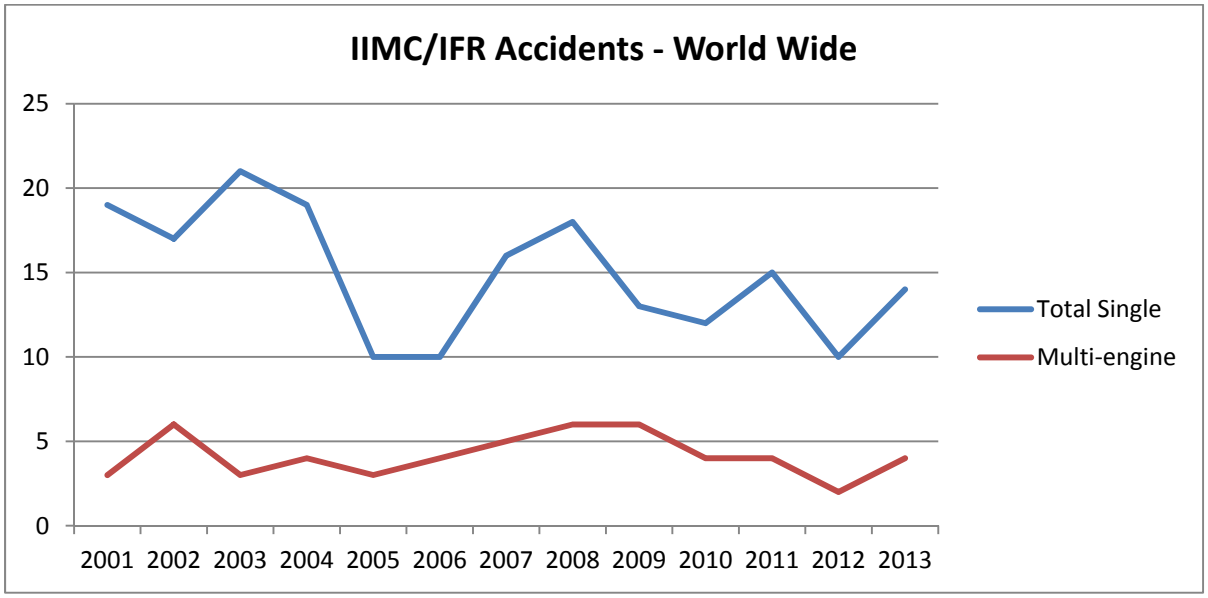

Figure 1. Yearly IIMC/IFR Accidents

This issue has been recognized by both the National Transportation Safety Board (NTSB) and the Legislature. Helicopter Operations were included in the NTSB's "10 Most Wanted" list of 2014. Many of the recommendations were focused on measures to reduce IIMC and CFIT accidents especially for Helicopter Air Ambulance (HAA) operations, which in the United States are predominantly conducted using single-engine rotorcraft.

Because of the accident rate, the Legislature recently took action to impose the HAA rules which took effect starting April 2015. VFR minimums for all helicopters were raised, and instrument ratings are required for pilots involved in HAA operations. In addition, yearly IIMC recovery training is required for pilots operating under Part 135 certificates.

In 2015, public-use rotorcraft operations remain on the NTSB's "10 Most Wanted List", largely due to the same pressures that exist in the HAA community, where the decision to continue operation into marginal or deteriorating weather conditions is affected by the knowledge that lives hang in the balance. Enabling these operations through the safety of practical IFR rotorcraft is far preferable than simply encouraging the decision not to fly.

A culture of IFR operation cannot be cultivated where the largest population of rotorcraft, and almost all training rotorcraft, are not IFR certificated. In comparison, most single-engine airplanes used in initial flight training are IFR equipped and certified. IFR training and opportunities to remain proficient through normal use are prevalent for the airplane pilot. In

contrast, the number of single-engine rotorcraft IFR certifications has dropped from several in the 1980s and 90s to virtually none since 1999. This is in spite of technology such as Global Positioning System (GPS) area navigation and Wide Area Augmentation System (WAAS) GPS approach procedures which make IFR flight more relevant to helicopter operations than they were in the 1980s and 90s.

Figure 2 shows the interrelationship of issues which must be addressed to produce a shift of rotorcraft operational culture to a more "IFR as normal operation" mind set. The lack of affordable and practical single-engine IFR rotorcraft will continue to inhibit the desired safety improvements if not addressed.

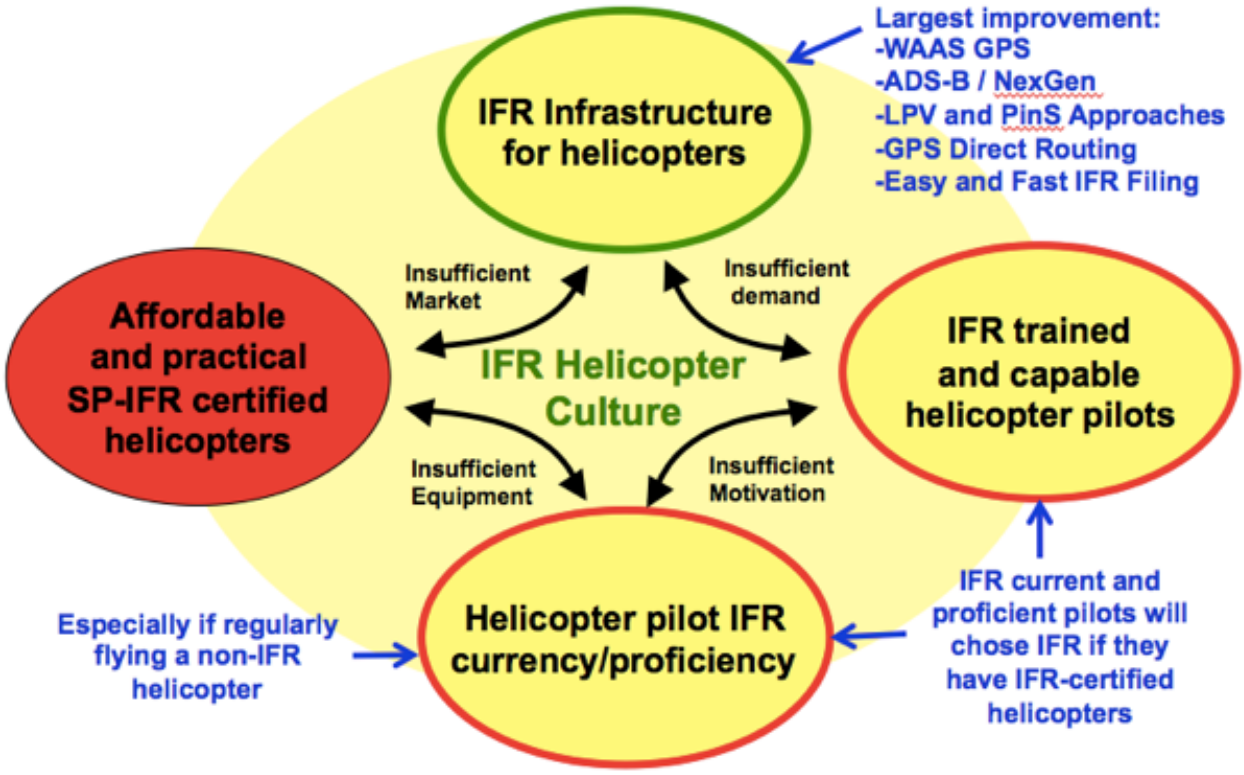

Figure 2. Changing the Rotorcraft Operational Culture

Enabling IFR certification alone is not sufficient, as the data indicates. Even IFR equipped aircraft have difficulty when older systems requiring greater skill and interpretation are used. The FAA Capstone program, which operated from 1999 to 2006, demonstrated a 38% fatal accident rate reduction from the benefits of modern technology. This was in a fleet of aircraft which, prior to the program, was mostly IFR equipped with conventional “steam gauge” indication systems. Therefore the expected safety benefits for this action with rotorcraft would be the compounded benefits of both providing the ability to fly IFR and general lowering of certification barriers for modern technology that then reduces the workload and interpretive skill level required to fly IFR.

In summary, certifying single-engine helicopters for IFR with systems that are ergonomic and confidence inspiring will lead to increased use of the IFR system and improved situational awareness during VFR operations. It is a reasonable to speculate that as pilots choose to conduct operations IFR instead VFR, fatal IIMC, CFIT and certain accidents attributable to loss of control will be eliminated. Successful and safe completion of missions under IFR will have a snowball effect throughout the industry. It is likely that single engine operators will begin to mandate operations under IFR when conditions do not support safe VFR operations once a practical means-of-compliance for IFR certification is established.

2.0 Impediments to Part 27 Rotorcraft IFR Certification

The IFR certification rules contained in Appendix B of 14CFR Part 27 and general systems and equipment requirements contained in 14CFR 27.1309 have not significantly changed since 1983. However in 1999, numerical safety analysis methods for means-of-compliance were incorporated into AC 27-1. These defined the term "extremely improbable" as less than 1 event in a thousand million hours (1/1,000,000,000 hours or $1E^{-9}$) of flight operation. The analysis also requires that subordinate hazard conditions are identified and these are also given numerical probability requirements.

The methodology and numeric values chosen made the standards for certification of normal category helicopter systems equivalent to those of Part 25 and 29 transport category airplanes and rotorcraft. In 2001, AC 27-1 was again revised to specifically state that loss-of-function or hazardously misleading indication of attitude, airspeed, and barometric altitude in IFR were individually "catastrophic", and that these events must be substantiated to be "extremely improbable" when seeking IFR certification. In general, substantiations of such low probability require the installation of triplex systems.

At the same time, certification requirements for Part 23 airplanes were changed in order to ***reduce*** the barriers and redundancy requirements for new technology certification. The sound reasoning contained in the introduction to AC 23.1309-1C explains the justification for this advisory circular. These words apply precisely to the current situation in the Part 27 rotorcraft community (**emphasis** added):

> *The certification standards being changed were incorporated by using the standards developed for transport airplanes. Incorporation of these standards into Part 23 resulted in a significant increase in equipment reliability standards. That is, they required much lower probability values for failure conditions than the existing operational safety history of different airplane classes.* ***Current data indicates that these probability values were not realistic. Since most aircraft accidents are caused by something other than equipment failures, increasing the reliability of the installed systems to try to improve safety will have little positive effect on reducing aircraft accidents when compared with reducing accidents due to pilot error.*** *If systems are required to meet safety and reliability parameters much greater than the operational environment, the cost of the improved systems are driven to a level that makes them impractical.*

Table 1 below provides a summary comparison of the ***existing*** Part 23, Part 25, Part 27 and Part 29 hazard classifications and system requirements.

Since the issuance of these divergent advisory circulars, the number of type certifications issued (including supplemental certifications) for single engine IFR rotorcraft has fallen to a level of insignificance. However, systems and safety equipment unavailable in 1999 are now readily

available at reasonable cost, thanks largely to the strength of the small airplane market. These systems are mature, highly reliable and dramatically reduce pilot workload while markedly increasing a pilot's situational awareness. The rotorcraft community remains unable to make practical use of these systems to enable IFR.

Table 1: Current Requirements for Probability and Development Assurance Levels as a function of Aircraft Type and Class

Aircraft Type		*Failure Hazard Classification (Note 2)*				
		No Safety Effect	*Minor (Note 3)*	*Major (Note 3)*	*Hazardous/ Severe Major*	*Catastrophic (Note 1)*
Part 23 Airplane	*Class I (typically SRE < 6000lbs)*	No Probability or Development Assurance Level Requirements	Prob <1E-3 Prim = D	Prob <1E-4 Prim = C Sec = D	Prob <1E-5 Prim = C Sec = D	Prob <1E-6 Prim = C Sec = C
	Class II (typically MRE or STE < 6000lbs)		Prob <1E-3 Prim = D	Prob <1E-5 Prim = C Sec = D	Prob <1E-6 Prim = C Sec = C	Prob <1E-7 Prim = C Sec = C
	Class III (SRE, MRE, STE, or MTE ≥ 6000lbs & < 12,500 lbs)		Prob <1E-3 Prim = D	Prob <1E-5 Prim = C Sec = D	Prob <1E-6 Prim = C Sec = C	Prob <1E-8 Prim = B Sec = C Ter = C
	Class IV (Commuter Class 12,500 to 16,000 lbs & < 19 passenger)		Prob <1E-3 Prim = D	Prob <1E-5 Prim = C Sec = D	Prob <1E-7 Prim = B Sec = C	Prob <1E-9 Prim = A Sec = B Ter = B
Part 25 and Part 29 Transport Airplane/Rotorcraft (>12,500/7,000 lbs)			Prob <1E-3 Prim = D	Prob <1E-5 Prim = C Sec = C	Prob 1E-7 Prim = B Sec = B	Prob <1E-9 Prim = A Sec = A Ter = B
Part 27 Normal Helicopters (≤ 7000 lbs)			Prob <1E-3 Prim = D	Prob <1E-5 Prim = C Sec = C	Prob <1E-7 Prim = B Sec = B	Prob <1E-9 Prim = A Sec = A Ter = B

SRE = Single reciprocating Engine
MRE = Multiple Reciprocating Engine
STE = Single Turbine Engine
MTE = Multiple Turbine Engine

Prob = probability requirement for functional failure condition
Prim = Primary path development assurance level (note 2)
Sec = Secondary path development assurance level (note 2)
Ter = Tertiary path development assurance level (note 2)

Note 1: At the aircraft function level, no single failure will result in a Catastrophic Failure Condition.

Note 2: The letters A, B, C and D denote the Software and Complex Hardware Development Assurance Levels (DAL) required for the Primary, Secondary and Tertiary System. Secondary and Tertiary systems are indicated where they are typically required to achieve the probability requirements for "loss of function." Note that 1E-9 notation for probability is equivalent to 1×10^{-9}

Note 3: For Part 23, specific probability analysis is not required to support certification for Minor or Major Hazards; a qualitative analysis is allowed and numbers are for reference. For Part 25,27 and Part 29, specific probability analysis is required for hazard levels "Major" and above. No specific relief is given in Part 27 (as in Part 23)

Compounding these effects is the fact that the relatively small rotorcraft market has traditionally relied on Part 23 airplane derivative systems and equipment to achieve financial practicality. But, as certification requirements for Part 23 airplane systems and equipment are reduced (especially in terms of Design Assurance Levels (DALs) and equipment qualification), adapting low-cost, Part 23 technology to the Part 27 helicopter market becomes impossible in some cases, and in others, impractically costly.

3.0 Regulatory Foundation

14CFR 27.1309 is the general rule for the installation of systems and equipment. This rule draws a clear distinction between the safety requirements for single-engine rotorcraft systems and differentiates them from multi-engine rotorcraft in the following paragraphs (emphasis added):

> *(b) The equipment, systems, and installations of a multi-engine rotorcraft must be designed to prevent hazards to the rotorcraft in the event of a probable malfunction or failure.*
>
> *(c) The equipment, systems, and installations of single-engine rotorcraft must be designed to minimize hazards to the rotorcraft in the event of a probable malfunction or failure.*

The means-of-compliance in AC 27-1 is incongruous with the regulation in that it specifies only a single means of compliance for systems and equipment. Clearly there should be two distinct means-of-compliance to match the two distinct provisions contained in the rule. It is also clear that the currently-specified means-of-compliance, which is equivalent to transport category aircraft, is geared towards preventing hazards. Therefore it is apparent that AC 27-1 lacks a means-of-compliance related to paragraph (c) of §27.1309.

The preamble to the Notice of Proposed Rulemaking (NPRM) in the Federal Register: August 26, 1982 (Volume 47, Number 166) Docket No. 23266; Notice No. 82-12 explains the FAA's intent of this provision in the regulation:

> *Explanation: This proposal would relax equipment, systems, and installations design requirements for single-engine rotorcraft. It also would require that all rotorcraft equipment, systems, and installations designs consider the effects of lightning strikes on the rotorcraft.*
>
> *Sec. 27.1309 currently requires that all rotorcraft equipment, systems, and installations be designed to prevent hazards to the rotorcraft if they malfunction or fail. This proposal would continue the requirement that multiengine rotorcraft must prevent hazards in case of a probable malfunction or failure. Single-engine rotorcraft would have to be designed to minimize hazards in case of a probable malfunction or failure.*
>
> *A majority of Part 27 rotorcraft are single-engine rotorcraft and designs for those models are currently required to prevent hazards under probable failure conditions. The FAA is not aware of any justification for more stringent equipment, systems, and installation requirements for single-engine rotorcraft. It is therefore proposed to provide relief for the large majority of small rotorcraft designs consistent with the [sic] currently provided for airplanes in Sec. 23.1309. The proposed wording for Secs. 27.1309 (b) and (c) is consistent with Part 23.*

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It is clear that in 1983, the regulation contained in §27.1309 was specifically changed to provide relief for single-engine rotorcraft through the regulatory process. The NPRM makes it clear that the intent of this relief was to provide parity with Part 23 systems and equipment requirements. It is also clear that this intent was negated by the singular means-of-compliance for §27.1309 introduced in AC 27-1 in 1999. Although the extinction of single-engine IFR rotorcraft is the most apparent consequence of this incongruity, it can be assumed that the installation of other safety enhancing technologies has also been hindered by the provisions of AC 27-1.

4.0 Proposed Solution

4.1 General

The following proposal provides a generic "additional means-of-compliance" for meeting the requirements of 14CFR 27.1309 (Equipment, Systems, and Installations) and Appendix B (Airworthiness Criteria for Helicopter Instrument Flight) for the purposes of certifying Normal Category Single-Engine Rotorcraft. The desire is that the FAA adopt policy or issue guidance based on the contents of this section in order to facilitate the cost-effective IFR certification of single-engine rotorcraft – which would in turn promote enhanced safety by facilitating the use of the IFR system by these helicopters, enabling the IFR training of helicopter pilots in Instrument Meteorological Conditions (IMC), and helping to advance the general professionalism of helicopter operations in the United States.

4.2 Establishing a Definition for "Extremely Improbable"

This proposal outlines that for Part 27 single-engine rotorcraft the definition for "extremely improbable" should be adjusted to be consistent with the existing rules and requirements of Part 23 airplanes with similar engine configuration, weight class, and passenger carrying capability. Specifically those for Class I and Class II airplanes certified under 14CFR Part 23.

It is the definition of "extremely improbable" that becomes the defining requirement for the "catastrophic" failure condition, and precipitates all other probability requirements for the lower hazard classifications. The term "extremely improbable" is specifically cited in several Part 27 rules, particularly those related to supporting systems and displays for IFR.

The Part 23 definitions for "extremely improbable" for Class I and II airplanes are consistent with prescriptive requirements contained in the Part 27 IFR rules. For example, attitude presentation is widely recognized to be the most critical indication for IFR flight, and complete loss of attitude is considered "catastrophic." This is consistent with 14CFR Part 27 Appendix B section VIII (b)(5)(iii) which requires that loss of the indications "*essential to the safety of flight"* must be *"extremely improbable."* However, 14CFR Part 27 Appendix B section VIII (a) also clearly establishes that dual attitude indicators are sufficient to meet this requirement[2].

This interpretation of the regulation – that dual attitude indicator systems are allowed by the rule – is also supported by the configuration of existing single-engine, single-pilot IFR rotorcraft certified after 1983 and prior to 1999. These were typically equipped with two traditional independent attitude indicators.

[2] The rule states that in addition to the attitude indicator as required in 29.1303, section VIII(a)(2) requires, "a standby attitude indicator which meets the requirements of §§29.1303(g)(1) through (7)"…" For two-pilot configurations, one pilot's primary indicator may be designated for this purpose." So when a second indicator is added for a second pilot, a separate standby indicator is not required – this clearly indicates a total of 2 indicators is adequate.

When we analyze the reliability of two traditional, independent attitude indicators, they can at best support a functional probability for loss of 1E-6 to 1E-7 failures per flight hour.

Analysis of other typical systems approved for rotorcraft IFR between 1983 and 1999 also show results consistent with the current requirements for Class I and Class II Part 23 airplanes.

Therefore there are three justifications for the reliability requirements contained in Table 2: (1) The stated FAA intent for Part 23 parity contained in the NPRM, (2) consistency with the prescriptive rules calling for dual rather than triplex critical systems, and (3) analysis of the safety level provided by rotorcraft certified between 1983 and 1999 which were compliant to the rule.

4.3 Demonstrating Compliance with §27.1309

Table 2 provides the proposed probability and development assurance levels (DALS) that would be required for Class I and Class II helicopters. Numeric values and DALS are based on providing consistency with Part 23.

Table 2: Proposed Probabilities & Development Assurance Levels

Part 27 Aircraft Type	***Failure Hazard Classification (Note 2)***				
	No Safety Effect	*Minor (Note 3)*	*Major (Note 3)*	*Hazardous/ Severe Major*	*Catastrophic (Note 1)*
Class I: Typically Single-Reciprocating Engine (SRE) Normal Category Rotorcraft	No Probability or Development Assurance Level Requirements	Prob <1E-3 Prim = D	Prob <1E-4 Prim = C Sec = D	Prob <1E-5 Prim = C Sec = D	Prob <1E-6 Prim = C Sec = C
Class II: Typically Single-Turbine Engine (STE) Normal Category Rotorcraft		Prob <1E-3 Prim = D	Prob <1E-5 Prim = C Sec = D	Prob <1E-6 Prim = C Sec = C	Prob <1E-7 Prim = B Sec = C

SRE = Single reciprocating Engine
STE = Single Turbine Engine

Prob = probability requirement for functional failure condition
Prim = Primary path development assurance level (note 2)
Sec = Secondary path development assurance level (note 2)

Note 1: At aircraft function level, no single failure will result in a Catastrophic Failure Condition.

Note 2: The letters A, B, C and D denote the Software and Complex Hardware Development Assurance Levels (DAL) required for the Primary and Secondary System. Secondary systems are indicated where they are typically required to achieve the probability requirements for "loss of function." Note that 1E-9 notation for probability is equivalent to 1×10^{-9}

Note 3: In order to provide parity with equivalent Class I and Class II airplane requirements, a qualitative analysis should be allowed to support certification of minor and major hazards –probability analysis are for reference only.

Note 4: The proposed development assurance levels match those for the equivalent probability classifications for Part 23 with the exception of the primary system for Class II Catastrophic. Primary system in this case is DAL Level-B. This recognizes a need to preserve a DAL level difference between Hazardous/Severe Major and Catastrophic since there is no Class III rotorcraft to provide further gradual transition to multi-engine Part 27 and Part 29.

Like the equivalent table in AC 23.1309-1, Table 2 already includes architectural considerations for the relief of DALs, as such SAE ARP-4754A methodology cannot be used to provide additional relief when this guidance is used. Appendix 1 provides an example Functional Hazard

Assessment (FHA) similar to that provided in AC 23.1309-1 and provides additional guidance on typical acceptable architectures and mitigations.

Table 2 maintains a distinction for reciprocating engine rotorcraft versus turbine-powered similar to what is done for small airplanes and for similar reasons. The classification (Class I or II) is not absolutely based on engine but is based on the traditional assumption that reciprocating engine aircraft are smaller, less sophisticated, lower-cost machines where the economic impact of these electronic systems in relation to the aircraft cost is even more prevalent, and so additional relief is provided. This methodology has worked for Part 23 airplanes, and is echoed in the proposed rotorcraft requirement.

With the acceptance of the proposed Table 2, wherever the term "extremely improbable" is called out elsewhere in 14CFR 27 related to systems and equipment (i.e. for the provisions of Appendix B), then the requirements of Table 2 would apply: For example, values of 1E-7 would be applied for Class II rotorcraft and 1E-6 would be applied for Class I rotorcraft.

A specific provision of §27.1309(c) is that hazards are "minimized" as opposed to "prevented". This implies specific recognition of mitigation through other functions. Recognition of some established mitigations are included in this proposal (such as the prominence of visual cues as mitigation for reduced stability). Others are included in the example FHA contained in Appendix 1. Where mitigation through other features, systems, or pilot actions is considered to set the hazard level, the mitigation should be described within the FHA.

When considering mitigations, there are additional considerations for the equitable comparison of the risks of Part 27 and Part 23 aircraft certifications:

- Helicopter pilots have more options to safely exit IMC and execute controlled and safe landings off-airport – this factor being clearly recognized in 14CFR 91 as it relates to fuel requirements, VFR weather minimums, and relaxed IFR approach minima.

- Part 27 aircraft can be operated at lower speeds than Part 23 aircraft.

- Part 27 aircraft have lower inherent stability than Part 23 airplanes, therefore mitigation of failure conditions where stability is a factor must be considered specifically for the rotorcraft and Part 23 aircraft may not provide analogous mitigation (see section 4.5).

4.4 Demonstrating Compliance with Appendix B Section VIII

4.4.1 General requirements of Section VIII(b)(5)

Interpretation of 14CFR Part 27 Appendix B section VIII(b)(5) is key to establishing many of the areas for which this means-of-compliance is sought. The regulation which must be satisfied states (emphasis added):

(5) For systems that operate the required flight instruments at each pilot's station—

(i) Only the required flight instruments for the first pilot may be connected to that operating system;

(ii) Additional instruments, systems, or equipment may not be connected to an operating system for a second pilot unless provisions are made to ensure the continued normal functioning of the required instruments in the event of any malfunction of the additional instruments, systems, or equipment which is not shown to be extremely improbable;

(iii) The equipment, systems, and installations must be designed so that one display of the information essential to the safety of flight which is provided by the instruments will remain available to a pilot, without additional crewmember action, after any single failure or combination of failures that is not shown to be extremely improbable; and

(iv) For single-pilot configurations, instruments which require a static source must be provided with a means of selecting an alternate source and that source must be calibrated.

Given that several rotorcraft were certified for single-pilot IFR between 1983 and 1999 with a single pilot/static system and a single set of pneumatic instruments (e.g. the MD Explorer[3], certified in 1995), it is clear that a different interpretation was applied than is provided in AC 27-1 – not only for "extremely improbable", but also for "required instruments" as referenced in item (ii) and the instruments that are "essential to the safety of flight" referenced in item (iii).

Examination of the FAA response to comments from the original NPRM clarifies the intent of these paragraphs and supports compliance of these earlier configurations (comments on Appendix B VIII(b)(5)(iii) - originally VIII(b)(6)(ii) in Notice 80-25). In response to the issue of requiring independent copilot systems to achieve "extremely improbable", the FAA states that this rule was intended for dual pilot IFR systems only, where the requirement to fly with dual pilot at all times allows the longitudinal stability requirements to be significantly relaxed. In this case, for an aircraft only meeting the minimum stability requirements for dual pilot IFR, the continuous display of airspeed and altitude would be required to maintain basic control of the aircraft. This is what makes the indicators for a second pilot "required." The FAA continues in the response to state (emphasis added):

> *This low initial level of stability makes it mandatory that accurate airspeed, altitude, and attitude information remain available to the required crew complement during both normal and reasonably anticipated failure conditions. This requirement is much more vital to a helicopter which barely meets two-pilot helicopter instrument flight criteria than it would be for small or transport airplane applications or for single-pilot IFR helicopters.*

The comments explain that, for an aircraft meeting the single-pilot IFR stability requirements, the attachment of a second set of instruments for the copilot "*would not be 'required*

[3] The MD Explorer actually had 2 altimeters. One altimeter was electronic and combined with the vertical speed indicator, the other was stand alone. These, along with an airspeed indicator, were all supported by a single pitot/static system.

instruments' and could be powered from existing sources" (i.e., work from a single pitot/static system).

Therefore, the FAA response effectively says that in paragraphs VIII (b) (5) (ii) the "second pilot" means a *required* second pilot in a dual-pilot IFR aircraft. In VIII (b) (5) (iii) the statement "essential to the safety of flight" allows for a lesser criticality of individual airspeed or altitude failures for installations that meet single-pilot IFR longitudinal stability requirements. This goes back to the familiar "partial panel" training for loss of a single instrument when only one such instrument was provided, and was not considered "catastrophic".

4.4.2 Examples of Acceptable Flight Instrument Installations

The following are examples of IFR instrument installations that would comply with the above provisions and the specific provisions of Appendix B section VIII listed below:

a. Flight Instruments for Single-Pilot IFR: Attitude (Pitch & Roll)

Dual independent attitude indicators will normally meet the requirement of 14CFR Part 27 Appendix B section VIII (a) provided probabilities and development assurance levels from Table 2 are met.

b. Flight Instruments for Single-Pilot IFR: Airspeed, Altitude and Vertical Speed

A single pitot/static system with alternate static port and heated pitot tube will normally be considered sufficient to meet requirements in accordance with 14CFR Part 27 Appendix B section VIII (b)(1) and (b)(5)(iv), so long as the rotorcraft otherwise meets the single-pilot stability performance requirements of Appendix B. If a stability augmentation system is used to achieve the required stability performance and is dependent on air data, its basic SAS function must not be dependent on the same pitot/static system.

An internally vented alternate static port can be used in lieu of heated static ports as a means of protection from ice as required by 14CFR Part 27 Appendix B section VIII (b)(1).

Traditional, single-function pneumatic instruments for airspeed, altitude, and vertical speed provide a degree of independence of failure modes. Rarely is more than one indicator affected at a time. These indicators are also not subject to failure modes caused by loss of common electric power. Mechanical failures of these indicators are generally progressive and give the pilot adequate warning of degraded performance. As such a set of these instruments will generally support the requirement as described in Appendix 1.

When traditional pneumatic instruments are replaced by electronic integrated displays supported by a common electronic air data computer, a redundant indication of airspeed and altitude is generally required. These redundant indication systems may utilize the same common pitot/static system that would otherwise be used by independent traditional pneumatic indicators.

A second independent pitot/static system is required when the 14CFR Part 27 Appendix B allowance for relaxed stability requirements is employed for a dual-pilot IFR certification. In this case the additional indicators for airspeed and altitude are considered "required" indications

at the copilot's station and the additional considerations of Appendix B section VIII (b)(5)(ii) and (iii) must be considered.

Designs must be assessed for the loss of independence which occurs when indicators or sensor units are combined into integrated systems with common displays, processors or power supplies. For example, common failure modes which would simultaneously affect attitude, airspeed, and altitude indications, or would affect common sensors supporting both flight displays and stability augmentation. In these cases the simultaneous failure condition should be specifically identified and assessed in the FHA.

c. Flight Instruments for Single-Pilot IFR: Heading

A magnetic gyro-stabilized direction indicator is required, and a non-stabilized magnetic compass is typically provided as a back-up in case the primary system fails. This is generally sufficient to meet the requirements.

Special consideration is required when installing some stabilized magnetic heading systems as many systems do not provide the option of an un-slaved directional gyro mode and the option to manually set heading. In addition, many of these systems have the ability to detect when a field other than the earth's magnetic field is influencing the magnetic field sensor. In these cases, the magnetic sensor generally disconnects automatically from the heading indicator to prevent the display of misleading data. After a period of time, if a valid earth's magnetic field is not restored, the heading information is flagged as invalid thereby reducing the probability of misleading data. However, this also presents challenges particular to helicopter operations operated on steel structures and hospital helipads in close proximity to Magnetic Resonance Imaging (MRI) equipment.

Although typically these systems will free-gyro-operate long enough to complete a normal landing, the primary concern is that without a valid earth magnetic field, these systems cannot perform their required start-up alignment procedure. As a result, the heading indicator or even the entire horizontal situation display may remain invalid until the area of magnetic disturbance is exited. This can have the unintended consequence of a helicopter landing in a location, and then not being able to then take-off into IMC conditions due to an apparent heading system failure. If the system uniquely identifies this condition as opposed to other failures of the heading system or magnetic sensor, then special procedures might be acceptable to allow departure (e.g., based on track) so long as there is sufficient indication that the heading system is otherwise operational and will recover once out of the area of magnetic disturbance.[4]

Therefore installation of a heading system that does not support a Directional Gyro (DG) mode or similar option for aligning and initially operating the heading system independent of the

[4] Commentary:
AC 23.1309-1E for small airplanes states loss of all heading indication is "Major." The difference is that AC 23.1309-1E states that "navigation is assumed to be operating." The Part 23 guidance was written with recognition that modern GPS systems can continue to provide display of ground track information independent of a heading source and that this is sufficient to continue flight. Navigation by GPS ground track in the case of a gyro-stabilized heading failure is a simple and reflexive response for today's pilots, however use of ground track as mitigation for loss of heading has not generally been accepted for rotorcraft under the "prevent hazards" interpretation of the 27.1309 rule.

magnetic sensor must address how operations will be conducted from areas of severe magnetic disturbance before approval for IFR can be granted.

4.5 Stability Augmentation and Boosted Controls

Most modern rotorcraft require Stability Augmentation Systems (SAS) to achieve the required stability performance for IFR specified by 12CFR Part 27 Appendix B. Additionally, in most cases, SAS actuators require the benefit of hydraulic boosted controls in order to operate. As a result, the reliability of the boosted controls must exceed the minimum reliability required for the SAS, since failure of the hydraulic control boost generally also results in loss of SAS.

Consequently, the establishment of reliability requirements in accordance with the "prevent hazards" methods of AC 27-1B often drives a requirement for dual boosted controls for IFR certification in a rotorcraft that normally requires only single boost for VFR. Providing redundant SAS and redundant hydraulic boost increase the cost and complexity of the typical single-engine helicopter beyond what is practical and therefore merit the additional consideration outlined below.

The actual rules concerning SAS for IFR are established by 14CFR 27 Appendix B VII. The key areas addressed by the rule are as follows:

- The rule states: *"If a SAS is used, the reliability of the SAS must be related to the effects of its failure."* In accordance with §27.1309(c) for single engine rotorcraft, this should be judged differently than for a multi-engine rotorcraft, and as such it should be acceptable to "minimize" the effect of the loss of SAS through mitigating means.
- The rule states: *"Any SAS failure condition that would prevent continued safe flight and landing must be extremely improbable."* Provided the definition of "extremely improbable" used for single-engine rotorcraft is defined as $1E^{-6}$ or $1E^{-7}$ with commensurate DALs, such rules could be practically complied with.
- Part (a) of the rule further requires that for other failures that are not extremely improbable, the aircraft must be flyable "*without undue pilot effort"*, but in any event, the aircraft stability should not deteriorate below VFR flight requirements. Judgment of what constitutes "undue pilot effort" becomes the focus of an objective flight evaluation as described in this section.

For rotorcraft with established VFR-compliant flight performance capability without SAS, if boost is required and loss of such boost is not determined to be extremely improbable, then loss of such boost must be established to allow continued safe flight and landing with a workload commensurate with VFR flight. Therefore, the quality of artificial visual cues (Primary Flight Display (PFD) and Multi-Function Display (MFD)) provided by cockpit displays and the level of automation provided by the avionics systems to reduce workload should be considered as mitigation for loss of stability augmentation and hydraulic control boost when necessary.

Where this mitigation is used, acceptable compliance can be demonstrated through flight testing. Demonstration should include the ability of a representative group of at least 3 IFR-trained pilots to complete procedures sufficient to exit IMC following loss of SAS and loss of control boost if applicable. Such a test should be performed in simulated IMC conditions (view limiting device) with the FAA certification pilot or appropriate delegate serving as the safety pilot.

The above evaluations should only require flight test above V_{MINI} and for approximately 30 minutes as may be required to exit IMC. The ability to continue flight and land after exiting IMC is adequately addressed by the VFR certification process and §27.695 compliance. IFR procedures evaluated should include the allowance to change destination or request special handling from ATC following the failure.

Given the above method of establishing required reliability of the SAS, this provides more options in preventing malfunctions through monitoring and shut-down of the SAS where necessary to prevent hazardous erroneous control inputs. This can be accomplished by allowing cross-comparison between dual attitude sensors to eliminate the probability of a single errant attitude sensor from precipitating a hazardous control input. Independent actuator rate and position monitoring equipment to detect errant operation relative to commanded operation can be used to shut down the actuator. If failure modes remain that are not "extremely improbable", then demonstration can be used to show that the effects are appropriate to their probability in accordance with Table 2 above.

When redundant attitude sources and cross-comparison monitoring is used to achieve "extremely improbable" and a single source has failed, continued flight on the remaining source may be allowed if there is clear annunciation of the condition and appropriate precautions are outlined in the aircraft procedures.

If large format flight displays mitigate the loss of stability augmentation, then common failure modes should not cause the loss of both SAS and the mitigating flight display. Use of a common sensor system may be acceptable if automatic reversion of either the flight display or SAS to an alternate sensor is provided in the case of failure or if it is demonstrated that the standby flight display is also usable to provide sufficient mitigation for loss of SAS.

4.6 Navigation and Communications Systems

For single-engine rotorcraft, the total unrecoverable loss of navigation and communications systems is Hazardous/Severe-Major. This hazard level appropriately matches the level in AC 23.1309-1 for small airplanes, since the same considerations exist for both types of aircraft.[5]

The hazard level assumes a source of heading information remains available and that the rotorcraft will perform emergency procedures similar to those used by Part 23 Class I or II airplanes for the same failure condition. These may include navigating by dead-reckoning to a

[5] Commentary:
In-flight IFR capability of a rotorcraft is generally similar to a Class I or Class II airplane in terms of range, speed, and altitude. The ability of a helicopter to avoid obstacles during exit from IMC and to find a suitable landing site should be considered better than that of a Class I or Class II airplane. Therefore the rotorcraft should be assessed a hazard level no worse than that for a Class I or Class II airplane.

location of Visual Meteorological Conditions (VMC) or where descent from IMC is least likely to encounter obstacles and then seeking a suitable emergency-landing site.

4.7 Electrical Power

Reliability and development assurance level requirements for electrical power systems should be in accordance with Table 2 in this document.

AC 27-1B Appendix B paragraph (b)(13)(i)(B) currently requires that the electrical design ensures an IFR rotorcraft "*can continue flight to its destination and alternate airports*" following any single failure of the electrical system. This requirement has traditionally driven the installation of dual generators in IFR rotorcraft.

AC 27-1B Appendix B paragraph (b)(13)(i)(H) allows for a single engine rotorcraft to be fitted with an increased capacity battery in lieu of a second generator provided:

a) The battery capacity provides for half the time of its worst case maximum flight duration consideration; and,
b) A separate battery of at least 30 minutes duration is provided for the standby attitude display.

Paragraph (H) provisions, as stated, echo the requirement of paragraph (B) for no single failure to prevent the ability to reach the destination and alternates. However in this case it allows the alternate power source to be a battery so long as it has the capacity as stated. (Note the requirement states "and" alternate airports, not "or" alternate airports). The required capacity in AC 27-1B does not allow for the probability of other available landing sites other than the planned destination and alternates. This requirement is therefore considered to be overly restrictive.

In comparison, Part 23 airplanes with a maximum altitude capability of 25,000 feet or less are only required to provide assured battery power for 30 minutes following a loss of the primary electrical generating system (per 14CFR 23.1353(h)(1)(i)). This requirement is far less stringent than AC 27-1B Appendix B (b)(13)(i)(H).

Therefore, in lieu of item (a) above, the single-engine rotorcraft should be allowed to provide a battery that provides at least 30 minutes of operation similar to the requirement for airplanes. In addition, the Rotorcraft Flight Manual (RFM) should include a statement in the Emergency Procedures section as to the aircraft capability to continue IFR flight on battery following loss of the generator (including any qualifying requirements with regards to configuration, etc.) and that suitable emergency landing sites within this duration, and any additional requirements of operating rules, should be considered during IFR flight planning.

4.8 High Intensity Radiated Fields (HIRF)

With the exception of §27.1317 (a) (4) for critical VFR functions in rotorcraft, the High Intensity Radiated Fields (HIRF) rules for Part 23 airplanes (§23.1307) and Part 27 helicopters (§23.1317)

are for all practical purposes identical. Therefore, from the point of view of display systems, there should be equal consideration.

However, a recent revision to AC 20-158 (Certification for HIRF) specifically limited the ability to use generic attenuation based on general construction for establishing the HIRF environment for Level-A and some Level-B rotorcraft cockpit "display units". The limitation (appendix 1(2)(6)) comes with the exception unless "*specific shielding is provided in the bulkhead, glare shields, panels, and doors.*" This revision created ambiguity in the guidance for rotorcraft cockpits because, unlike the other guidance provided, there are no statements made as to what constitutes "specific shielding" or what level of attenuation credit is allowed. Effectively this requires the certifying authority to render judgment on a case-by-case basis to obtain credit for the attenuation of the rotorcraft in the cockpit area. Without clear guidance, this effectively eliminates credit for airframe attenuation in the cockpit area for most applicants unless specific airframe testing is performed.

Another issue has been the requirement within AC 20-158 for an integrated system HIRF test for the level-A functions using aircraft representative harnesses and installation features. This is burdensome because it tends to force construction of a special test set-up for each platform, sometimes with multiple configuration options, which may often have to be revisited for re-test as components are upgraded or replaced for obsolescence (depending on the classification of the change). There is relief within AC 20-158 section 9(e)(9) for what is considered a simple system. AC 20-158 is still guidance material providing a means-of-compliance applying across the transport category aircraft as well as rotorcraft and does not have to be the only allowed means-of-compliance, especially where the intent is to minimize rather than prevent.

The following guidelines are provided to help with this issue noting that the intent is to **minimize** the hazard rather than **prevent** it. The idea is to apply some proven techniques without having to specifically prove their effectiveness by testing the specific installation (similar to the philosophy applied for other generic attenuations). Therefore it is recommended the following should apply to finding compliance to HIRF requirements for Part 27 single-engine rotorcraft:

- Use of generic attenuation and transfer functions as allowed by AC 20-158A based on the construction guidelines. For radiated susceptibility, cockpit-mounted equipment such as displays may specify HIRF environments separately for the face of the unit and for the rear of the unit with its associated wiring. Each environment may be specified using AC 20-158 guidance (e.g., a metal-enclosed pedestal in a bubble cockpit with no doors or full non-conductive transparencies – the front of the display may have little or no attenuation while the back of the display and associated wiring may have 12dB or more).

- Given adequate enclosure of the instrument panel, 6 dB attenuation can be afforded to the face of the instrument-panel-mounted display units if any if the following features exist:

    - Cockpit doors comprised of mostly conductive material (i.e. metal or carbon fiber) extending to approximately the height of the base of the instrument panel. Similar door construction for cabin doors unless some form of conductive bulkhead provides equivalent obstruction between the cabin and the cockpit; or,

  - An extended glare shield made of conductive material that wraps the instrument panel to either side so as to obstruct a large percentage of the line-of-sight view of the displays through non-conductive transparencies. The inclusion of an average pilot can be included in the consideration. However if the second pilot's seat is not assured to be occupied, the blockage afforded by that pilot cannot be considered; or,
  - Conductive coating on non-conductive transparencies or significant portions of the transparencies at low-angle (i.e., down from the instrument panel level). These coatings should provide 100 ohms-per square inch or less.

- Provided that the face of the display unit in the cockpit does not include wiring interfaced to other units, qualification of the equipment for the levels at the face may be provided by unit level testing in accordance with RTCA DO-160() section 20 equivalent categories. The rationale is that without exposed wiring in the cockpit environment, susceptibility through the face of a display unit is primarily in the radiated susceptibility range (100MHz to 18GHz). This frequency range will not carry very far through aircraft wiring to other units. Any disturbance to internal electronic operation will most likely appear as anomalous operation of the display equipment itself or its outputs (which would be monitored during unit test) This allows display manufactures to qualify displays for a cockpit HIRF environment applicable to many aircraft without having to repeat an integrated system HIRF test for each installation.

- Level-A system elements which provide direct digital interface outputs to user systems (such as via ARINC-429 or via RS-422. RS-232, or RS-485 with similar protocol and parity checks), and where the data is a simple repetition of broadcast parameters are considered "simple systems" under AC 20-158 section 9.e.(9) and may be qualified by unit level testing alone per RTCA DO-160( ) section 20. Typical examples of such system elements would be independent flight sensors such as Attitude and Heading Reference Systems (AHRS), Air Data Computers (ADCs), or standby flight displays with digital outputs of flight parameters. Digital output is specified since analog interfaces are more susceptible to the effects of varying system interconnections. Digital data with inherent error checking is primarily susceptible to loss due to detectable signal corruption as an effect of varying installation, and known installation practices will limit these occurrences. The repetitive nature of the data assures recovery from momentary data lapses. For this provision to apply, performance of the system element's level-A functions which are susceptible to HIRF cannot be dependent on external system devices which were not included in the equipment testing (e.g. remote air data sensing elements, etc.). Also for this provision to apply, strict adherence to the installation manual with regards to shielding, bonding, and shield termination must be applied. This then allows typical IFR flight sensors such as Attitude and Heading Reference Systems (AHRS) and Air Data Computers (ADCs) to be separately HIRF qualified from the display systems – reducing the cost of repeated integrated HIRF tests for each installation variant.

- Level-A display systems which rely on direct digital interface inputs from supporting system elements to support level-A functions (such as via ARINC-429 or via RS-422. RS-232, or RS-485 with similar protocol and parity checks), and where the received data

is a repetitive broadcast of parameters from the supporting system, and where the display system does not provide supporting data back to the Level-A source that may lead to corruption of the Level-A supporting data from that source, then these display systems may be HIRF qualified by unit level or display subsystem testing per RTCA DO-160( ) section 20 with these inputs externally simulated. Testing should include consideration of the effects of variations input data rate (bit, parameter, and frame), and the allowed tolerance for these should be specified and an installation consideration for acceptable supporting sensors. This then allows displays systems to be qualified independent of supporting sensors provides they are using a direct, one-way digital interface.

- When an IFR SAS/Autopilot system is not required for VFR certification, and only has potential catastrophic failure conditions as a result of malfunction as opposed to loss, then for the sake of HIRF certification, due to the consideration that the pilot is still in-the-loop in this form of control system, Level-A HIRF certification may be done using the same considerations as a Level-A display system. This then allows generic attenuation and transfer functions to be used to establish the HIRF environment without requiring aircraft level HIRF testing, and also allows the considerations for external supporting sensor systems providing data via digital interface to be qualified in separate testing. However, the SAS/Autopilot system itself should be HIRF tested in an integrated system test with all its interacting components such as flight computers, actuators, control and/or actuator position sensors, etcetera.

4.9 Lightning

The lightning protection rules for Part 23 airplanes (§23.1306) and Part 27 helicopters (§27.1316) are for all practical purposes identical. Rotorcraft have an advantage over airplanes in that lightning attachment points tend to be better defined than for an airplane. Typical attachment points exist through the rotor system, mast, landing gear, nose and tail.

Like HIRF, use of the generic assessment of lightning waveforms based on aircraft construction is very important in maintaining the viability of IFR certification. In the case of lightning, the effect is expected to be damage and loss of function. For SAS/Autopilot functions, for most designs, the effect of lightning is potential loss of function as opposed to hazardous malfunction. As a result, the lightning protection requirement can be assessed on the basis of loss. Credit for the pilot as a mitigating factor in the safety analysis should allow the effect of any SAS/Autopilot failure to be treated in the same manner as a display system. Minimizing, not preventing the hazards, is the objective of the safety analysis.

5.0 Safety Cost/Benefit of the Proposed Solution

The following section discusses the "safety costs" versus the "safety benefits" of this proposal to the fielded single-engine rotorcraft fleet. Section 1.0 makes it clear that if IFR helicopters made up a larger percentage of the single-engine helicopter fleet – and broader use of the IFR system by helicopter pilots and operators was the norm, most of the accidents noted in section 1.0 could be prevented. The question is whether this proposal will help achieve those results.

The proposed lowering of certification and redundancy requirements is the safety cost – in that a higher risk of equipment failure accidents or incidents is accepted in order to provide an expected safety benefit of fewer fatal IIMC and CFIT accidents. If only a small number of helicopters achieve IFR certification as a result of this proposal, then the safety cost was not worth the realized safety benefit. So the question becomes what is the realistic effect of this proposal in terms of equipment safety impact, and is the incentive to equip and field IFR rotorcraft sufficient to significantly impact the ratio of IFR versus non-IFR rotorcraft – especially among those most at risk for IIMC accidents.

The FAA has often used limited test fleet programs (e.g. the FAA Capstone program) to study the effect of changing requirements before authorizing them for general use. In this case, the MD Explorer serves as an effective study for the expected "safety cost" of allowing the proposed levels-of-safety recommended in this white paper. The MD Explorer was certified in 1995 – just prior to the 1999 change in AC 27-1. Over 100 Explorers have been fielded and a primary market for this aircraft is air ambulance operations. Although this rotorcraft is multi-engined, its single-pilot IFR systems are at a safety level[6] which would not satisfy current means-of-compliance in AC 27-1, but which would be allowed again under the provisions of this white paper: (a) It has dual attitude indicators: a primary with an independent standby, (b) It has a single heated pitot/static system with alternate static, and (c) It has a single attitude heading reference system (AHRS) supporting both the pilot's primary attitude indicator and a single-lane stability augmentation and autopilot system.

To date with 20 years in service, there is not a single accident or incident that could be found related to failure or malfunction of the IFR systems on the MD Explorer[7]. In addition there have been no IFR related accidents for this type to date - so there is no possibility that an undetermined failure of an IFR system may have contributed to an accident in IFR conditions. This establishes that the "cost of safety" to systems and equipment in adopting the Associations' proposal is extremely small – largely because the current requirements imposed on equipment are far more conservative than necessary.

With regards to the development assurance levels proposed in this white paper: These are typically assigned commensurate with probability requirements. In the white paper's case these map directly to equivalent levels as used in AC 23.1309-1 revision C through E for equivalent probabilities. So in this area the Associations cite the 15+ year history of Part 23 airplanes certified since 1999 as the validation that the DAL levels are appropriate. The FAA has not changed the DAL level assignments through subsequent revisions from C to D to E of this

[6] With regards to probability of loss or malfunction and the level of redundancy.
[7] Using the same OEM accident /incident data base used to establish the accident data in section 1.0

advisory circular. Therefore the Associations infer that the FAA has found the DAL level correlation appropriate with the hazard and probability levels.

It is noted the Associations were unable locate the safety basis used to support the introduction of the current reliability and DAL requirements for normal rotorcraft established in AC 27-1 in 1999. As such this report is unable to provide analysis of impact relative to that safety basis.

With regards to the safety benefit, the increase in IFR use in single-engine rotorcraft will be measured from its current state of essentially zero aircraft.

Between 1983 and 1999 several single engine rotorcraft were FAA certified for single-pilot IFR. During this period, GPS navigation was not yet prevalent, and helicopter IFR operations were essentially limited to airports serviced by VHF Omni-directional Range (VOR) radio navigation, Instrument Landing Systems (ILS) facilities, and fixed-wing IFR procedures. Even with limited usability, there was sufficient demand for IFR systems in helicopters that the industry produced type certificates which included IFR kits and IFR Supplemental Type Certificates (STCs). By restoring equipage requirements to something commensurate with these levels, the desire to equip and certify for IFR is expected to be far stronger than that realized prior to 1999.

Today the helicopter can benefit more from the IFR infrastructure than ever before: GPS area navigation, WAAS LPV approaches, WAAS LPV helicopter steep approaches, Point in Space (PinS) approaches, and the potential for ADS-B supported low-level route systems allow even the smallest airport or heliport to have access to IFR without the costs of maintaining airport-based navigation facilities. Based on the operational benefits, there is more reason now for a helicopter to be IFR certified than ever before.

The market already has a large number of rotorcraft with most of the components in place for IFR. The popularity of recent lower-cost, single-lane autopilots is further indication that the market is already moving in this direction. At this point, the impact of achieving an IFR certifiable configuration in accordance with this proposal is minimal with huge benefits in aircraft versatility. It is logical to conclude the market will respond strongly if this proposal is accepted.

Further Incentives for Equipage:

The Helicopter Air Ambulance (HAA) rule which took effect April 2015 will provide additional incentive to equip. The rule increases VFR minimums for all rotorcraft and requires instrument rated pilots for Helicopter Air Ambulance operators. The rule is one of several pressures moving rotorcraft to increased IFR operation.

The Associations' position is that it is natural for the Part 27 single-engine rotorcraft community to want to have IFR capability and be IFR current – if it is affordable. Most helicopter operations are commercial, and being limited by weather prevents the rotorcraft from being consistently employed. Contracted services currently pressure operators into "pushing" the weather situation. The situation is especially difficult for EMS and public operations where it is known lives are in the balance with the weather decision. The Associations feel it is the FAA's duty to the rotorcraft industry to provide a practical option for IFR conditions other than "don't

fly" – especially when that practical option previously existed. Once Part 27 single-engine IFR becomes viable, it will be demanded by hospital organizations as a condition of EMS contracts - much in the way IFR capability is a demanded today for twin engine rotorcraft in EMS. The safety, liability concerns, and expanded usability will produce the demand.

Again, the Part 23 experience serves as the model. When Part 23 reduced the barriers to affordable glass cockpit technology following the FAA Capstone program, private and corporate owners very quickly adopted the technology. No special mandates were required. The common Part 23 airplane is typically IFR equipped without mandates or incentives other than the convenience of flying IFR and the fact that IFR provides value: The additional cost of equipment, the additional empty weight of the aircraft, the additional maintenance costs are offset not only by the additional safety, but the additional ability to fly and generate revenue. Training is available because IFR aircraft are common and available. Part 61 and Part 135 initial and recurrent training then become commonly available and ideally performed on the same aircraft type regularly flown by the pilot. Restoring affordable IFR to rotorcraft will provide its own incentives to equip and provide the assets for training.

The following table is provided to assist in establishing Functional Hazard Assessments and considerations with respect to single-engine rotorcraft IFR systems:

Hazard Classifications and Considerations – Single Engine Rotorcraft in IFR/IMC		
Failure Condition	**Hazard Classification**	**Considerations**
Loss of all attitude displays	Catastrophic	Pilot has insufficient means to maintain safe flight attitudes.
Display of misleading attitude on both displays	Catastrophic	Pilot will likely follow one or the other indication to an unrecoverable attitude.
Loss of the attitude display in the pilot's primary field of view	Major	Traditional stand-alone attitude indicator reliabilities are generally unable to support "Major" (1E-5) for failure in a rotorcraft environment. For single-pilot IFR, close placement of the standby indicator to allow continued flight with limited workload increase is an acceptable mitigation. Electronic displays, or display pairs with automatic reversion can generally support an overall compliance with "Major." Where mitigation is used, reliable operation of the primary attitude display should be maximized through the use of dual independent power sources and similar provisions.
Display of misleading attitude on the primary display without warning	Major to Hazardous	Similar to considerations for Part 23, hazard classification is dependent on the availability of cues to rapidly recognize the condition and resolve which attitude indicator to follow. Recognition is generally a case of incongruity with other indications such as airspeed, altitude, and heading changes and assumes these indications remain available. Stability augmentation may be a mitigating factor in promoting recognition if the SAS uses either an independent attitude source, or annunciates in some way for a miscomparison in dual or primary + standby attitude sources. Part 23 includes "catastrophic" which has been clarified by SAD (Small Airplane Directorate) as applicable to cases of single attitude installations which are not allowed by rule in Part 27.
Loss of all airspeed indication	Major to Hazardous	For a rotorcraft with no other means to maintain IFR speed between V_{MINI} and V_{NE}, the hazard is "Hazardous.". Typically the hazard can be

Hazard Classifications and Considerations – Single Engine Rotorcraft in IFR/IMC		
Failure Condition	**Hazard Classification**	**Considerations**
		mitigated to Major depending on other speed cues. These may include handling, auditory, vibration and other cues. Power setting versus changing altitude can also be a cue. In addition, prominent display of GPS groundspeed is a mitigating factor, allowing the pilot to monitor for speed changes, and estimate airspeed based on expected wind conditions. The pilot is expected to fly conservatively between V_{MINI} and V_{NE} following the loss of airspeed until able to exit IMC and use ground cues.
Misleading airspeed indication without warning	Major to Hazardous	Potential mitigations are the same as noted for total loss of airspeed. The concern is whether the other cues are sufficiently dominant to prompt the pilot to check other indications rather than follow the misleading airspeed to below V_{MINI} or above $V_{NE.}$
Loss of all barometric altitude indication	Hazardous to Catastrophic	AC 23.1309-1E allows a classification of Hazardous for airplanes, but this classification assumes the ability to maintain a degree of altitude control using other indications (airspeed, power setting, attitude, and if available, vertical speed) until a descent from IMC can be cleared and initiated. If the same ability can be demonstrated for the helicopter, it should be allowed the same hazard level classification. However failures which produce loss of both altitude and airspeed (e.g. dual ADC failures) would have to be considered Catastrophic unless otherwise mitigated. Other mitigating considerations are the availability of a GPS/HTAWS altitude readout, GPS digital map, and/or the availability of a radar altitude display. GPS altitude is sufficient to provide for a controlled let down. For radar altitude, a means to get to the radar altimeter indicating range must be considered. All these mitigations would include informing ATC of the inability to maintain altitude clearance to avoid conflicting traffic.
Misleading altitude indication without warning.	Catastrophic	Traditional pneumatic airspeed and independent vertical speed indicators on a static system with alternate static to address a clogged port will typically support the 1E-6 to 1E-7 requirement, given that an operational

Hazard Classifications and Considerations – Single Engine Rotorcraft in IFR/IMC		
Failure Condition	**Hazard Classification**	**Considerations**
		vertical speed indicator is a warning means for a pneumatic altimeter with less than the required probability of misleading indication. Typical electronic displays using a common sensor for altitude and vertical speed must otherwise support the requirement. (e.g. by utilizing an independent standby indicator).
Loss of the primary means (but not all means) of indication for either altitude or airspeed	Minor	Loss of the primary means with an available alternate means of indication is considered Minor. This is consistent with other AC material, e.g. AC 23.1309-1E
Loss of all heading and track indication.	Catastrophic	"All heading" includes a standby magnetic compass (unstabilized) if provided. Track indication is typically provided by GPS or similar area navigation systems which determine ground speed and ground track angle.
Loss of primary magnetic gyro-stabilized direction indication	Minor	Other sources of heading (non-stabilized compass) and navigation track information assumed to remain available. In order to be considered "Minor" the display of track information with the heading gyro heading information unavailable must be presented in the pilot's primary or secondary field-of-view.. Some integrated primary flight displays will suppress or "X" the entire horizontal situation presentation if gyro-stabilized heading information is invalid or unavailable. In this case, proximate alternate displays (i.e. GPS with map displays) can be used to maintain a "Minor" classification.
Loss of primary magnetic gyro-stabilized direction indication without track information available	Major	The non-stabilized compass is the only means readily available to establish and maintain direction for continued flight. Optional navigation track information, if available, is considered in this case not to be presented in a way that is readily usable. Workload is increased as navigation deviations must be monitored more closely with more frequent corrections made.

Hazard Classifications and Considerations – Single Engine Rotorcraft in IFR/IMC		
Failure Condition	**Hazard Classification**	**Considerations**
Misleading heading indication without warning	Major	A hazardously misleading heading is usually when the accuracy error is greater than 10 degrees on the primary heading instrument and it is an undetected error. (Same definition as for AC 23.1309-1E) Error will eventually become evident through incongruity with navigation indications (e.g. VOR or GPS) and/or the standby compass. Assumes installation of a single stabilized heading system and only a non-stabilized magnetic compass to operate under IFR for 14CFR part 91.
Loss of or Misleading Vertical Speed	Minor / Minor	Minor for loss / Minor for misleading
Loss of or Misleading Slip / Skid	Minor / Minor	Minor for loss / Minor for misleading
Loss of Turn Rate	No Safety Effect	No safety effect for loss since turn rate indication is not a requirement given redundant attitude indication for IFR.
Misleading Turn Rate	Minor	Due to the redundancy provided by other indications and the fact that the turn rate indicator is not a required instrument, misleading turn rate information will likely result in momentary distraction only.
Combined loss of Primary Flight indications and/or information provided by an integrated display	Variable	Needs to be assessed to the degree which multiple failures are susceptible to common device failures or supporting systems, and where indications have been identified in the mitigating considerations for loss or misleading presentation for another. Loss here means apparent or annunciated malfunction. Blanking of the entire display, display flags, or corrupted presentation to the degree where it is apparent that a failure has occurred are all cases of apparent loss. An apparent failure in this case is assessed on the basis of the workload induced by having to continue flight on the remaining alternate or standby indications.

Hazard Classifications and Considerations – Single Engine Rotorcraft in IFR/IMC		
Failure Condition	**Hazard Classification**	**Considerations**
Combined misleading display of multiple parameters on a primary flight display	Variable	Needs to be assessed to the degree of common elements within the design. Once detected as erroneous, the failure condition becomes the equivalent of loss. The issue is the additional hazard to which the aircraft is exposed until the erroneous condition is detected. Presentation of highly incongruous combined misleading data becomes apparent leading to checks with standby instruments (e.g. high rate of climb with no altitude change, large bank with no heading change or slip rate). The considerations are failures that can lead to multiple misleading yet congruous indications. The most common form of this is a frozen integrated display, or a display where large portions of the data set are severely stale. Displays with independent watch-dog timer circuits, or displays with assured dynamic data (e.g. prominent display of time or moving maps features that stop moving, etc.) can be factors in establishing the scope of failure modes that need to be considered.
Unrecoverable loss of all radio communications and navigation	Hazardous	Assumes a heading display, time indication, and map remains available in order to navigate via dead reckoning. Procedure would be to attempt to navigate to an area where let down from IMC would be possible and an off-airport landing could be performed. Classification is consistent with AC 23.1309-1E.
Loss or mis-operation of all communication	Minor / Major	Navigation systems and potentially transponder continue to operate.
Loss of all radio navigation means	Major	Communications systems continue to operate. Agrees with AC 20-138.
Misleading of primary navigation means	Major	This is typical and corresponds with AC 20-138 and TSO requirements.

Hazard Classifications and Considerations – Single Engine Rotorcraft in IFR/IMC		
Failure Condition	**Hazard Classification**	**Considerations**
Misleading primary navigation means for precision approach	Hazardous	Agrees with AC 20-138. Some older TSO'd ILS receivers were certified with DAL level-C and are still considered acceptable for aircraft with higher DAL requirements for this function. Others systems, such as flight displays presenting this information should meet the appropriate minimum DAL for hazardous, unless they qualify for lower DAL under the provisions of AC 20-138D paragraph 15-2.
Loss of or misleading Surveillance (Transponder operation)	Minor / Minor	This corresponds with TSO requirements for normal use of these functions
Loss of Surveillance ADS-B	Minor	Minor for loss
Misleading Surveillance ADS-B	Major	Major for erroneous reporting of data to ATC. This corresponds with TSO requirements for normal use of these functions.
Loss of Stability Augmentation	Variable	Hazard Classification depends on the aircraft. For fly-by-wire, the classification is catastrophic. However, for an augmented mechanical flight control system, if the un-augmented aircraft meets VFR stability requirements, then mitigation can include artificial cues such as a larger attitude presentation and/or reduction in need to perform tasks with view away from instruments due to automated navigation and radio management, electronic charts, etc. Demonstration would be required.
Erroneous operation of stabilization	Variable	The primary concern here is the hard-over consideration. In some systems the authority is mechanically limited for high rate actuators, and is rate limited for large travel actuators. This can reduce the potential impact to the flight path of an errant actuator or actuator command. Also monitors can be used to detect and disconnect from erroneous actions before they create large deviations in the flight path. A typical example would be a parallel processing path (possibly from a separate attitude source) to determine a bound of expected actuator movement, with the ability to disconnect the actuator if out of range. In other cases a simple rate

Hazard Classifications and Considerations – Single Engine Rotorcraft in IFR/IMC		
Failure Condition	**Hazard Classification**	**Considerations**
		limiting monitor on the actuator is all that is needed to achieve the design requirements. In any case of an electronic monitor, however, failure of the monitor must also be considered as well as erroneous action of the monitor contributing to loss of stabilization.
Loss of coupled autopilot modes	Minor	Manual flying to raw data is a typical IFR pilot skill. Ease of flying from raw data is typically done as a flight demonstration.
Erroneous operation of coupled / un-coupled flight guidance	Typically Minor en-route, Major during precision approach	Assumes authority of coupled inputs limited by autopilot. Limiting function DAL needs to be to worse-case autopilot response capability (e.g. erroneous stabilization). Also assumes available display of raw data (airspeed, altitude, heading, deviations) in the pilot's scan for recognition and response to erroneous commands.