

# A PERSPECTIVE ON THE FAA APPROVAL PROCESS: INTEGRATING ROTORCRAFT DISPLAYS, CONTROLS AND WORKLOAD

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## ABSTRACT

The FAA is responsible for making the determination that a helicopter is safe for IFR operations in the National Airspace System (NAS). This involves objective and subjective evaluations of cockpit displays, flying qualities, procedures and human factors as they affect performance and workload. After all of the objective evaluations are completed, and all Federal Regulations have been met, FAA pilots make the final subjective judgement as to suitability for use by civil pilots in the NAS. The paper uses the flying qualities and pilot workload characteristics of a small helicopter to help examine the FAA pilot's involvement in this process. The result highlights the strengths of the process and its importance to the approval of new aircraft and equipments for civil IFR helicopter applications. The paper also identifies opportunities for improvement.

## NOMENCLATURE

|                   |                                      |
|-------------------|--------------------------------------|
| AFCS              | Automatic Flight Control System      |
| CAS               | Calibrated Airspeed                  |
| c.g.              | Center of Gravity                    |
| FAR               | Federal Aviation Regulations         |
| IFR               | Instrument Flight Rules              |
| IMC               | Instrument Meteorological Conditions |
| MCP               | Maximum Continuous Power             |
| NAS               | National Airspace System             |
| OEI               | One Engine Inoperative               |
| PRs               | Pilot Ratings                        |
| T&E               | Test and Evaluation                  |
| VFR               | Visual Flight Rules                  |
| VMC               | Visual Meteorological Conditions     |
| V <sub>MINI</sub> | Instrument Flight Minimum Speed      |
| V <sub>NE</sub>   | Never Exceed Speed                   |
| V <sub>NEI</sub>  | Instrument Flight Never Exceed Speed |
| V <sub>Y</sub>    | Climb Speed                          |
| V <sub>YI</sub>   | Instrument Climb Speed               |

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## INTRODUCTION

The engineering and operational criteria contained within the Federal Aviation Regulations (FARs) have evolved as the result of operational experience and flight research. Yet these regulations alone can not absolutely guarantee the suitability of an aircraft, principally because the quantitative criteria do not address the integrated aircraft system. So as the final check, FAA pilots are assigned to fly the aircraft and make a determination as to the suitability of the total system.

More than any other measures, suitability is determined by gauging the performance which is achieved in return for the spectrum of workload required to achieve this performance. In short, the workload that the pilot is required to accept must never exceed the capability of the minimum qualified pilot. In addition, the performance should never fall below an acceptable level during periods when the pilot is required to operate at the maximum tolerable workload.

The role of the FAA pilot during flight evaluations is similar to the role of the military T&E pilot. That is, while a civil helicopter may meet all of the FARs (References 1 and 2) for IFR flight (or meet Military specifications in the case of a military aircraft), the FAA pilot may find that the aggregate of performance and workload is not good enough to recommend the aircraft for approval. As a result, an unsatisfactory evaluation often includes a finding that the workload is too high.

It is also possible for both civil and military helicopters to fail to meet the demonstration requirements of the relevant specifications (FARs) yet still be found suitable for normal operations. This highlights the uncertainty of the preliminary design specification process. The manufacturer needs design guidance (criteria) but the Government can only provide its best estimate of what is required. It can only provide best estimate because: (1) technology and changing missions often change faster than the criteria can be updated, and (2) it is extremely difficult to predict the performance of the resultant system.

Finally, while the intent of the criteria or regulations is rarely in error, it is often difficult to demonstrate compliance of new automatic flight control systems (AFCS), workload relief equipment, and displays to existing objective criteria. In some cases, there are no objective criteria. In the case of helicopter approvals for civil use, Advisory Circulars 27-1 and 29-2 (References 3 and 4) recognize this situation and provide the applicant with the opportunity to use a variety of means to demonstrate compliance. Never-the-less, it is the FAA pilot team that determines the suitability of the aircraft for operations in the NAS. This is as it should be.

This paper focuses on the aggregate of workload and pilot-aircraft performance. It presents a joint perspective to examine the process which is used by the FAA to insure that only safe aircraft are approved for operations in the National Airspace System (NAS). It explores the alternative approaches available to applicants and strives to increase the rotorcraft community's understanding of how the FAA defines adequacy, and how adequacy can be predicted by the applicant with confidence.

### **RELIABILITY**

Before considering the impact of displays, flying qualities, control characteristics, and various workload relief equipment, one must appreciate the need for reliability of function. If the quality (or correctness) of a function is not sufficiently reliable, the FAA pilot will often evaluate the aircraft as though the function is never available.

Suffice it to say that if the helicopter incorporates a workload relief feature which is not extremely reliable (or does not include redundant elements), the FAA pilots will treat the feature as a "nice to have". Such "nice to have" features will not normally figure prominently in the determination of suitability for IFR operations in the National Airspace System (NAS).

The same constraints apply to displays. If the attitude display and its power supply are not adequately reliable, a standby display is required to insure the availability of an attitude display under the most adverse failure mode condition. In such a case, the standby attitude indicator will often be evaluated as the primary attitude reference during evaluation of cockpit management workload and flying qualities.

### **FAILURE MODES**

The failure modes of components of the total system are also extremely important. The transient condition associated with the introduction of a failure must not introduce an "upset" condition which will require unusual pilot skill to avoid a dangerous situation during the period subsequent to the failure.

The multi-layered systems available in the more expensive aircraft generally exhibit fail-operate or fail-passive characteristics (sometimes accompanied by a

modest but very acceptable degradation in capability). Smaller, less expensive aircraft are typically less able to afford the same degree of redundancy and the transient introduced by a flight control or related subsystem failure can be very significant to the suitability of the aircraft in the eyes of the FAA evaluation pilot.

### **THE MINIMUM QUALIFIED PILOT**

Unless otherwise stipulated by the applicant, FAA pilots must evaluate the suitability of a helicopter for IFR operations based upon their personal perception of the capabilities of the least qualified pilot that can legally be expected to fly the aircraft. This recognizes the fact that FAA approves pilots with as little as 150 hours of first pilot time in helicopters and airplanes. That is, the "worst case crew" could involve one or two pilots with these minimal qualifications. This suggests that every helicopter approved for instrument flight must be suitable for operation by a pilot with immature piloting skills and an under developed appreciation for the potential hazards of instrument flight in the NAS.

### **PILOT TECHNIQUE AND PROCEDURES**

The FAA recognizes that tandem helicopters and single rotor helicopters do not fly alike, nor will a 3000 pound and a 30,000 pound helicopter fly alike. The FAA's evaluation pilots recognize that these configuration and size differences dictate unique operating procedures and techniques. The addition of series and parallel automatic flight control systems can also dictate configuration unique procedures and piloting techniques. These equipment and related techniques may make the direct comparison of an aircraft to the objective requirements of the FARs difficult if not irrelevant. The installation of a sidearm control stick is a case in point.

Regardless of the configuration, the evaluation pilots understand the intent of all of these requirements and they understand that they have a responsibility to evaluate existing flight control characteristics against the intent of the requirements, as explained in Advisory Circulars 27-1 and 29-2A. As noted earlier, this means that some issues are resolved during the inflight determination of the overall suitability.

While the FAA pilot has a responsibility to understand the techniques developed by the applicant, the evaluation pilot(s) may not find all of the procedures acceptable. Some may be found to be too difficult and require special training or a periodic demonstration of proficiency, or both to obtain approval for operations in the NAS. The applicant has the option either to accept such findings or to alter the aircraft in ways which improve the aircraft and eliminate the need for special skills.

### **EVALUATION ENVIRONMENT**

Implied in any FAA evaluation of a helicopter for IFR operations is the need to evaluate the aircraft in an adverse environment. An extensive evaluation in a variety of adverse environments is most likely to be

conducted if: (1) the margin of suitability is perceived to be small, or (2) innovative control techniques or equipments are incorporated which introduce uncertainties because of the lack of precedent or the lack of hands on experience on the part of the FAA pilot(s). In the case of an IFR application, the FAA pilot is likely to include an evaluation flight in a building cumulus cloud formation and, or a night flight profile in frontal weather. If this is not a practical choice, other evaluation tasks are executed to build an understanding of the aircraft which is sufficient to accurately predict its suitability in bad weather. The duration of flights in adverse weather is also important to the determination of suitability. The evaluation pilot must deal with the workload for an appropriate period to be able to answer the question: does a pilot at the controls need either a co-pilot or a highly reliable workload relief system to make it through the flight?

### **ONE PILOTS VS. TWO PILOT**

The applicant must request approval of an aircraft with a crew of one or a crew of two.

### **SINGLE PILOT FLYING QUALITIES**

A helicopter is said to exhibit single pilot flying qualities, when one pilot is able to fly the aircraft for a period of time equal to the endurance of the aircraft without being relieved by a second pilot. Implicit in this definition, is the concomitant ability of the pilot to accomplish essential non-piloting, cockpit management duties such as communication, navigation and typical emergencies.

### **AUTO PILOT VS. CO-PILOT**

If an auto pilot is employed, the pilot is free to perform the co-pilot's duties. This is an acceptable alternative if the auto pilot never fails, but what if it does fail? If the auto pilot fails, the flying qualities and the non-flying workload must be managed by one pilot.... on a bad night.

### **DUAL PILOT FLYING QUALITIES**

A helicopter is said to exhibit dual pilot flying qualities, when the pilot in command is unable to fly the entire flight (for a period equal to the endurance of the aircraft) without being relieved from time to time by a second pilot. The pilot who is not at the controls normally handles the cockpit duties attendant to the flight. This includes tasks which the pilot at the controls does not desire to perform or can not perform.

### **WORKLOAD**

Workload during instrument flight is the result of one or a combination of the following: (1) task complexity including the cockpit management tasks and the control required to accomplish the maneuvers which in turn produce the desired flight trajectory, (2) residual flight path errors and the time dependent growth of these errors due to the control and flying qualities characteristics of the aircraft (including the AFCS), (3) the volume and quality of the flight

instrumentation situational awareness displays. The display equipment either facilitates the control of the aircraft (and aids the pilot in efforts to eliminate errors), or the displays are inadequate; degrading situational awareness and, or frustrating the pilot's efforts to trim, suppress gust responses, and accomplish a variety of compensatory control inputs, and (4) the pilot's experience and familiarity with similar equipment, vehicle responses, and environmental conditions, as well as proficiency in any given situation.

### **EXCESSIVE WORKLOAD**

When a single pilot can fly the aircraft for the duration of the flight without relief, but can not accomplish all of the cockpit management duties in a timely fashion, the aircraft is exhibiting an excessive workload characteristic. When an excessive workload situation exists, the flying qualities can be improved to make more time available to accomplish cockpit management duties, or the cockpit management workload can be decreased, or a combination of ameliorating changes can be incorporated. For example: (1) A crew of two can be substituted for the desired single pilot crew, or (2) An extremely reliable flying workload relief system (auto pilot) can be incorporated, or (3) The flying qualities of a helicopter can be augmented through electro-mechanical or electro-hydraulic means, or (4) The display system can be improved, or (5) Workload intensive equipment can be eliminated or replaced, or (6) The flight envelope of the aircraft can be tailored to include only that portion of the flight envelope which is suitable for the desired flight operations.

### **FLYING QUALITIES BOUNDARIES**

Figure 1 provides a characterization of a hypothetical helicopter which has been evaluated for IFR flight using the Cooper Harper pilot rating scale. Such scales are not utilized by FAA pilots during the evaluation-approval-reporting process, but since all FAA pilots use the Cooper-Harper scale during research evaluations, it seems appropriate to use this scale here. Assume, for the sake of this discussion, that the pilot ratings in Figure 1 were developed as the result of conducting precision standard rate turns during level, climbing and descending flight. In addition, precision approaches were conducted at a number of airspeeds on each of the three glide slopes. Precision performance criteria was also established and observed in the normal way provided for in the associated literature (Reference 5).

This figure reflects the fact that there is a band of airspeed within which a helicopter will fly best (each helicopter has its own set of boundaries). It also illustrates the gradual degradation in flying qualities which occurs if the aircraft slows down, or if power is added and the aircraft climbs. Also note that the typical single rotor helicopter becomes easier to fly as the aircraft descends. But at some speed, an acceleration will also cause a degradation in flying qualities.

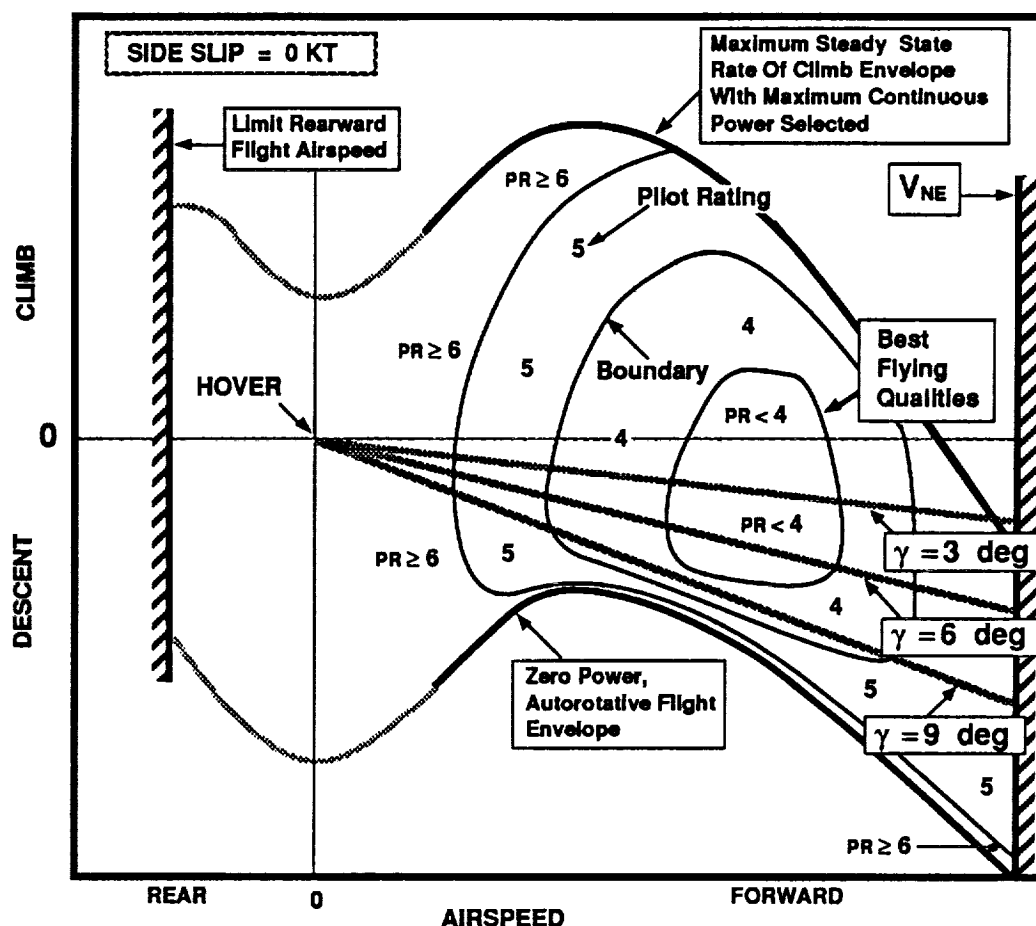


Figure 1: A Generalization of the Flying Qualities Of A Small Modern Unaugmented Helicopter Evaluated During Level Flight, Climbs, Descents and Precision Approaches Under Night IMC-IFR Conditions

It is important to realize that the pilot comments associated with a given pilot rating change as the flight conditions change from slow-level to slow-climb to fast-climb to fast-level to fast-descent to slow-descent. That is, while the rating of "5" may be assigned to many different flight conditions, the pilot's comments which explain the rating "5" may differ substantially throughout the envelope.

#### THE BASIC FLIGHT ENVELOPE

The flight evaluations conducted by the FAA are accomplished within the bounds of a proposed IFR envelope. The boundaries of this envelope coincide with, or fall within the boundaries of, the previously approved VFR envelope. The VFR envelope is determined by the performance capability of the aircraft and the limitations established due to structural considerations (component fatigue lives), stability and controllability (see boundaries in Figure 1).

All of today's civil IFR operations assume that pilots will utilize Visual Meteorological Conditions (VMC) to accelerate to some minimum airspeed which is approved for Instrument Meteorological Condition (IMC), before entering IMC. That is, the low speed end of the IFR approved flight envelope must support

climbing, level and descending transitions into an IMC airmass during day and night operations. The minimum airspeed approved for instrument flight is referred to as  $V_{MINI}$ . This is an extremely important airspeed limit for it typically precludes helicopter unique IFR flight, constraining helicopter IFR operations to "airplane like" flight.

Typically,  $V_{MINI}$  is equal to or less than  $V_Y$ , the speed for best rate of climb. Alternately, an applicant can establish a best climb speed for instrument flight  $V_{YI}$  in which case  $V_{MINI}$  is equal to or less than  $V_{YI}$ .

In principle,  $V_{MINI}$  defines the speed above which the pilot will not encounter any troublesome non-linearity, dynamic instability, or strong adverse collective control coupling. These are characteristics that can cause the aircraft to become difficult or even unsafe to fly during IMC. For this reason, inadvertent flight substantially below  $V_{MINI}$  can be expected to require the pilot to concentrate on the retention of attitude control and flight path management to the exclusion of other tasks.

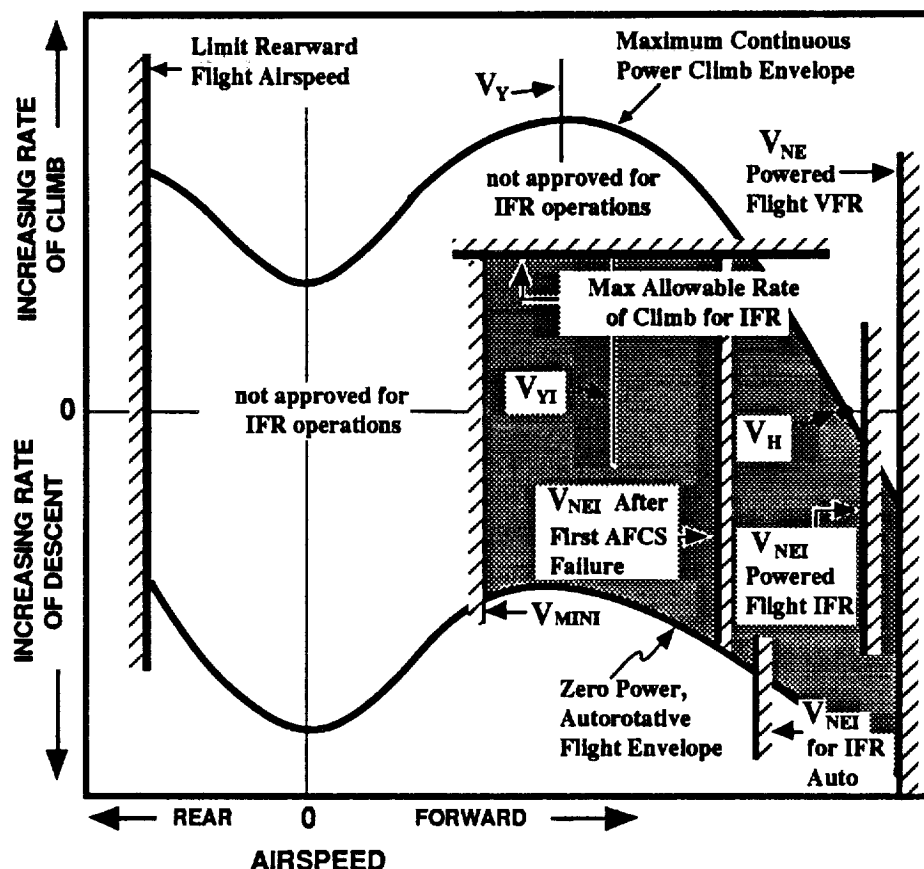


Figure 2: Typical Flying Qualities Envelopes Of A Small To Medium Size Helicopter

The applicant may also choose a speed for  $V_{MINI}$  which is based on considerations other than the flying qualities of the aircraft. For example, the low limit of an airspeed transducer in the AFCS may define  $V_{MINI}$ . In general,  $V_{MINI}$  can be established at a speed which is as high or as low as the applicant desires, as long as the aircraft exhibits adequate flying qualities, is capable of adequate climb performance, and has a practical operating speed envelope.

#### BASIC CONFIGURATION FOR EVALUATION

As mentioned earlier, the approval of an IFR envelope is based on the characteristics exhibited by the aircraft while it is being operated at the most adverse combinations of c.g., gross weight, etc., for which an approval is sought by the applicant. These adverse configurations will include the disengagement of all workload relief systems which have not met the requirements of the FAA for reliability. In some cases, a failure mode is acceptable if the pilot can be reasonably expected to observe the limits of a smaller envelope after a failure occurs.

#### TAILORING THE ENVELOPE

Typically there is an airspeed below which any given helicopter can no longer be easily flown under IMC, on airways. The actual airspeed defining the

lower limit of the suitable flight envelope typically varies as a function of climb rate. For example, the boundary between the PRs of 5 and PRs of 6 in Figure 1 could define the minimum safe airspeed for IMC operations. Note that such an approach would produce a limit which varies as the function of rate of climb. Since a variable minimum limit speed would be relatively difficult to observe, the FAA has adapted the practice of selecting a single airspeed for all allowable climb rates (see Figure 2).

Typically a minimum airspeed for IFR operations ( $V_{MINI}$ ) is proposed by the applicant and the flying qualities are investigated at the limit climb capability of the aircraft, or the maximum rate of climb proposed by the applicant (the FARs stipulate a minimum climb of 1000 ft/min, or a climb at maximum continuous power, whichever is less, while trimmed at  $V_Y$ ). The shape and location of the boundary between PRs of 5 and PRs of 6, as depicted in Figure 1, provides the reader with an insight into the alternative combinations of minimum airspeed ( $V_{MINI}$ ) and the maximum allowable rate of climb for instrument flight which the applicant can choose from. In most past cases, the applicant has had an opportunity to increase  $V_{MINI}$  to obtain approval of a higher maximum allowable climb rate. Alternately, the applicant might agree to decrease the maximum

allowable climb rate to gain approval of a lower  $V_{MINI}$ . In the latter case, the resultant limit climb rate must provide a practical capability on airways.

In a similar way, the IFR operational envelope of a civil helicopter is often reduced to insure the availability of good flying qualities by limiting the maximum gross weight or minimum gross weight, and/or by limiting the range of the center of gravity (c.g.). Sometimes the envelope is limited in autorotative flight, and sometimes it is limited after a failure. For example, in Figure 2, the maximum forward speed has been limited after an AFCS failure (the speed is limited to protect the crew against a second failure). These are now limitations to the scope of the FAA evaluation and the envelope available for operational use. Any time an envelope is reduced in this way, it is said to have been tailored. The FAA now investigates the objective or the subjective requirements of the FARs within the envelope defined by these new boundaries.

### STEEP APPROACHES AND $V_{MINI}$

The authors realize that there is current interest in the potential of reducing  $V_{MINI}$  to facilitate low speed, steep approaches into metropolitan vertiports. Such approaches will require the applicant to propose a relatively low  $V_{MINI}$  in combination with an indication of airspeed which is reliable at (and below)  $V_{MINI}$ , and the minimum airspeed for a Category A approach -- to insure the ability to execute a one engine inoperative (OEI) balked landing. (Note: The definition of  $V_{MINI}$  will need to be revised to accommodate instrument approach and balked landings under instrument conditions.)

### FLIGHT DISPLAYS, FLYING QUALITIES, WORKLOAD

A search of past explanations of the relationships between displays, controls, task, performance and workload produced the AGARD Advisory Report No. 51 on "Displays for Approach and Landing of V/STOL Aircraft" (Reference 6). Figures 3 through 5 have been adapted from this reference to help us examine the complex but long recognized relationships which are an integral part of the FAA's evaluation-approval process. These figures illustrate the interdependence between display capability, aircraft handling qualities, automated flight control systems and well designed or automated cockpit management functions.

The adapted AGARD graphic presented in Figure 3, tells us that it is possible to trade-off display sophistication (capability) with control sophistication (capability) in a way which produces about the same performance for the same crew effort (pilot rating). This common capability is depicted as a single curved line in Figure 3. Each line is referred to here as a continuum of capability. To improve the pilots evaluation or pilot rating of an aircraft, the display-control combinations must improve. In Figure 3, this incremental improvement is illustrated by the inclusion of three lines representing three individual continua of capability.

Two continuum lines have been drawn in Figure 4 to consider the issue of workload. Lines (a) and (b) both represent acceptable performance and workload during the execution of an identical task. Observe that the pilot ratings are the same for the two lines but the distribution of the workload is different.

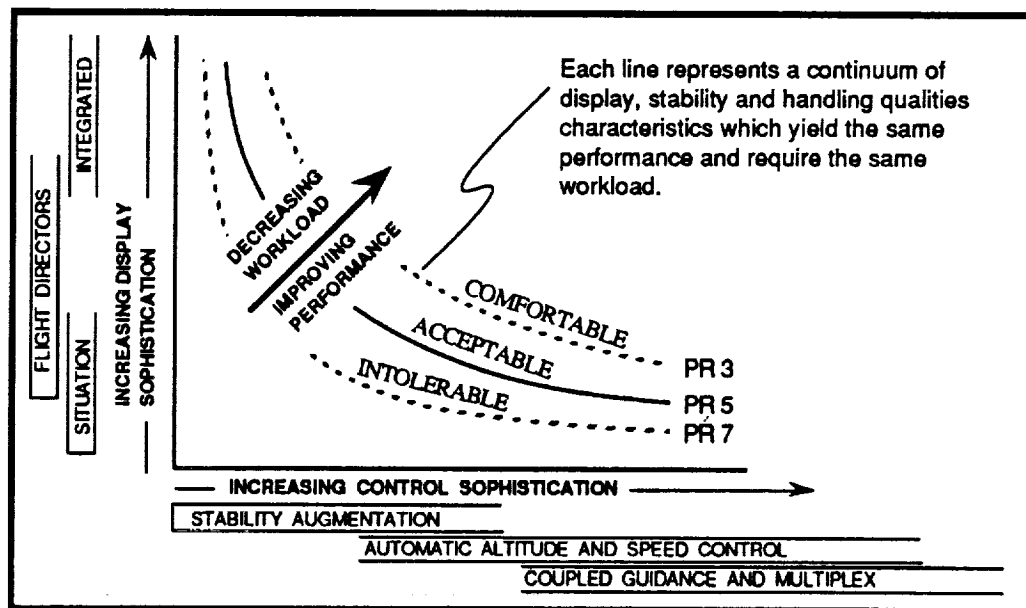


Figure 3: Tradeoff Between Display And AFCS Sophistication For An Instrument Approach

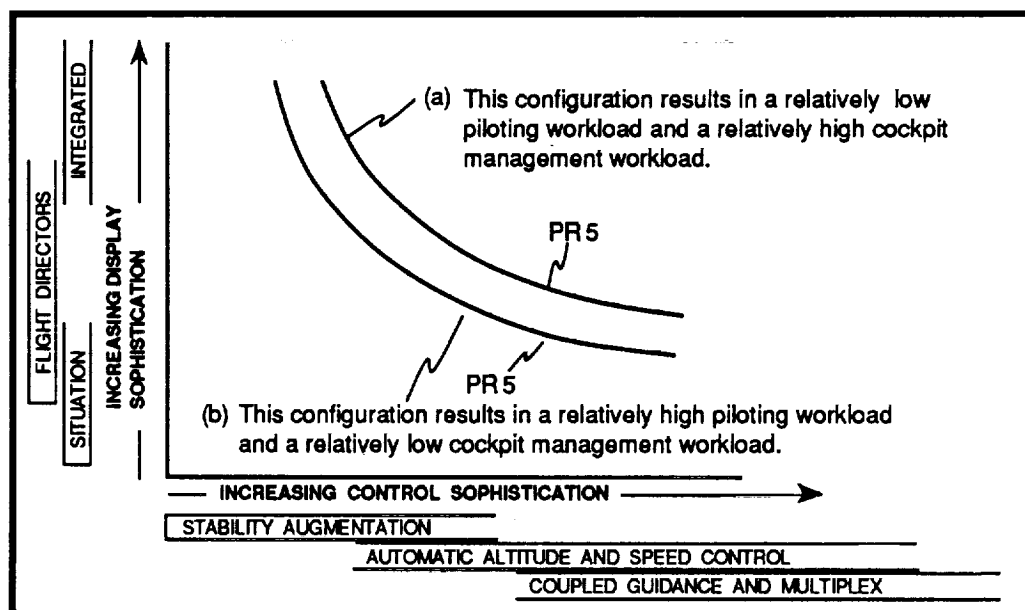


Figure 4: Enhanced Display And Control Sophistication Required For An Instrument Approach

The pilot's task to fly the aircraft is the least difficult when the display-control combinations of (a) are selected. When any of the combinations of displays and controls represented by continuum (b) are selected, the pilot effort to fly the aircraft is the greatest. The fact that the same pilot rating is assigned to both of these lines is explained by the fact that the pilot-aircraft performance (combined flight path management and cockpit management performance) is more or less equal and the total workload is more or less equal. Restated, while the total performance and workload are approximately the same for the two cases, the ratio of piloting workload to cockpit management workload are reversed. Once a satisfactory continuum of capability has been identified, the applicant is free to trade-off displays to find the most affordable and reliable combination of equipment.

#### MINIMUM EQUIPMENTS AND FLYING QUALITIES

An understanding of the workload relationships is very important when trying to understand the FAA's approval methodology. First, as a design guide, minimum display and flying qualities guidance is provided in the FARs and related Advisory Circulars. This guidance has been characterized by the VFR and the IFR limits included in Figure 5. That is, a minimum set of flight instruments (and related equipment) are stipulated by horizontal lines, and a minimum set of stability and handling qualities characteristics (vertical lines) are provided for the control side of the equation.

For the sake of discussion, assume the IFR limits in Figure 5 define the minimum stability, handling qualities and display requirements which will

support approval of a helicopter for non-precision approaches with a crew of two. The limits also include consideration of the workload which can be accepted by two pilots. If the crew is reduced to a single pilot, it follows that workload must be reduced by incorporating either improved cockpit displays or an improved flight control system (or both).

For example, an improvement in the flight control system and/or AFCS should reduce the flight path control workload and yield a more desirable aircraft. The resultant operating point, "b" in Figure 5 represents a significant handling qualities improvement over "a". Such a change should make the aircraft easier to fly and improve pilot-aircraft performance as well as reduce workload. Similarly, an improvement in the display configuration is illustrated in Figure 5 as operating point (c). This should also help reduce the workload as well as help a pilot achieve the objective performance.

When the combined effect of the display and AFCS improvements are considered, a new operating point (d) is defined. If both point (b) and point (c) produced an adequate single pilot IFR capability, then theoretically a failure of either addition would be acceptable. This inferred redundancy once again briefly illustrates the potential connectivity between displays and controls.

#### PROVISIONS FOR FAILURES

The FAA process also insures that no failure of the displays or controls will result in an operating condition where the workload is inappropriate for continued IFR operations, or the pilot-aircraft performance is unsatisfactory. For example, this need for redundancy typically requires a second attitude indicator

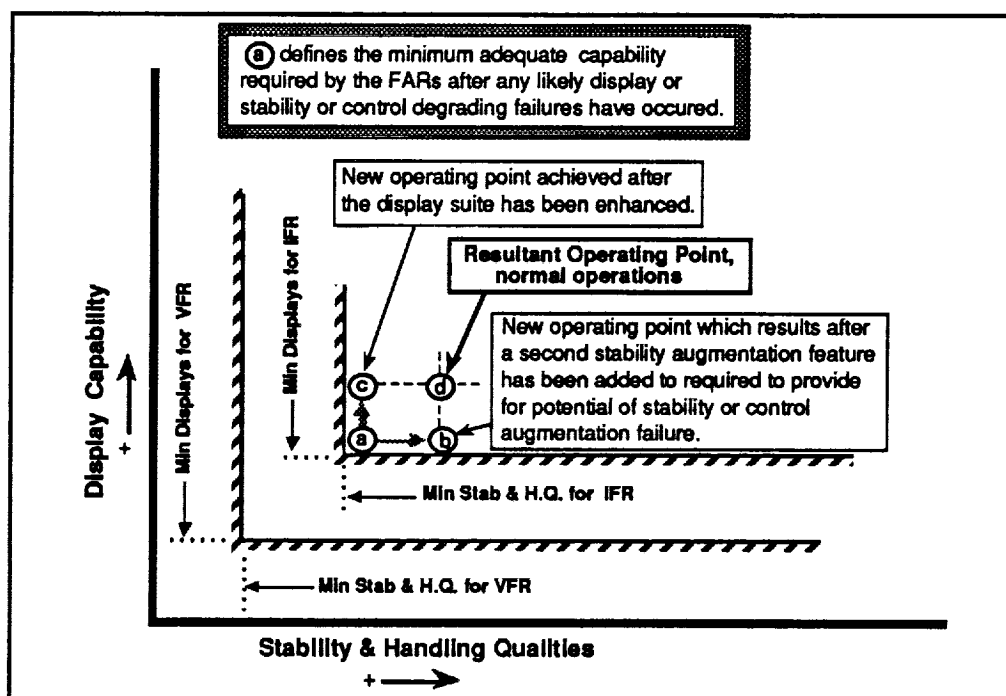


Figure 5: An Incremental Increase In Display Capability (or Redundancy) And Stability And Handling Qualities (or Redundancy)

to be installed in "single pilot" instrument panels. The addition of the redundant attitude indicator insures that the capability of the aircraft will not fall below that defined by operating point (a) in Figure 5.

Redundancy is also required to accommodate AFCS failures which degrade the stability or handling qualities of the aircraft. Sometimes, the addition of redundant AFCS channels allows the design to be altered in a way which simultaneously improves the flight characteristics of the aircraft (see path (a) to (b) in Figure 5) and provides the needed redundancy.

#### DISPLAYS COULD BECOME MORE IMPORTANT

Some argue that the (IFR enabling) credit assigned to displays and control system features of IFR helicopter systems tends to favor the use of AFCS. It can be argued that the development of display rich cockpits would be facilitated if the FAA allocated more credit to advanced electronic sensor-display systems with rotorcraft unique features. Such cockpits should decrease the need for multi-layers of stability and flight control augmentation. This might be especially true during a steep approach to a high pre-landing hover under IMC. Other less revolutionary yet equally important additions, such as display of ground speed and omni-directional low airspeed may substantially enable steep approaches to hovering flight. A powerful indication of yaw rate could also simplify pilot control of heading during slow speed flight without heading hold (subsequent to an AFCS failure).

A careful review of lessons learned during basic rotorcraft display research may be sufficient to justify

greater specificity in the allocation of credit to existing conventional displays such as large turn and slip indicators, and large attitude indicators, with less credit allocated to very small attitude indicators, and turn and slip indicators that have been integrated into attitude indicators (ADI). For example, the work reported in Reference 7 found the large turn and slip display was the preferred display for IFR helicopter operations on airways, while the small integrated turn and slip displays were judged inferior.

In addition, a review of past flight director projects suggests that flight directors are substantially under valued, especially in the small helicopter application. This data has been overcome by the widely held belief that flight directors can be expected to improve performance, but typically at the cost of an increase in workload. As a point in fact, there is little rotorcraft data which suggest that a mature flight director design increases workload when the performance objective is held constant.

Counter to conventional wisdom, Reference 8 presents data which seems to establish the fact that a good flight director will lower workload and improve performance when: (1) the flight director is installed in a helicopter with poor inherent flying qualities and, (2) no AFCS is operating. That is, the inclusion of a proper flight director should cause the operating point to move from (a) to (c) in Figure 5.

It is the opinion of the authors that early flight director successes which involved the use of simple contact analog displays were pursued on the military side but abandoned (by the civil community) in favor of the electronic reproductions of the current electro-



mechanical displays. In short, the perceived risk associated with customer acceptance and FAA acceptance of advanced electronic display formats has retarded advances in this area.

Similarly, most commercially available flight directors do not incorporate flight director laws which command the pilot to use the collective to maintain glideslope. The longitudinal control is used instead. This of course is not an acceptable solution for operations on the back side of the power required curve. The most important fact here is that this mechanization reflects a lack of concern for display techniques which could allow the pilot to enter the control loop in a way which might lead to the effective exploitation of the slow speed portion of the helicopter flight envelope. In summary, few seem to appreciate the display priority which should be allocated to the collective during operations on the back side of the power required curve, especially during steep approaches.

A future cockpit might incorporate an extremely powerful vertical situation display, with flight director capabilities which could enable the pilot to quickly and precisely trim the aircraft. The ability to trim precisely and quickly should do two things. It should significantly speed up the trimming process and delay the unattended departure from trim. This would allow a single pilot to spend more time with other flying and cockpit management tasks. This capability might prove to be most important as a safety enhancement feature subsequent to a stability augmentation failure or the failure of a work load relief system. Other improvements might include: airspeed displays, heading reference displays, and power management displays as suggested by Reference 9.

### **RISK AND AFFORDABILITY**

The more affordable an IFR system is, the greater the applicant's monetary risk during the approval cycle. A precedent setting expansion of the operational utility of a helicopter model, such as the first configuration offered for Category III B instrument approaches also has an associated high risk relative to the cost to obtain approval of an aircraft of interest to a very small initial customer base. The risk at both ends of the sophistication spectrum involves concern for the calendar time to achieve approval and the cost of the effort (including the improvements which may be inferred by the FAA). The larger the anticipated investment and the greater the uncertainty associated with approval, the greater must be the potential return on investment. The fact that demand for IFR helicopters appears to be low seems to exacerbate the potential applicants worst fears.

The key to progress seems to reside in the development of an improved vertical flight infrastructure, and an aggressive effort to integrate more small helicopters into the IFR portion of the NAS. This effort should probably focus on the large potential fleet of helicopters in the 3000 to 5000 pound class.

Such an effort would require a number of demonstration programs to evaluate the alternative display-AFCS-cockpit workload design improvements. The resultant alternative configurations must be both clearly safe and affordable. It seems logical that the FAA approval process should be used as the format for these demonstrations. Finally, none of the resultant data should be proprietary.

### **SPECIAL OPPORTUNITIES**

The following areas are identified as providing important enhanced capability to the rotorcraft community and the public it serves:

#### **Partitioned-Independent Systems**

Stability and control augmentation, autopilot and other workload relief systems should be designed so that the probability of total loss of a single system is unlikely and the loss of a partial system is not disabling. Failures could cause the pilot to retreat to the best portion of the flight envelope for the remainder of the flight.

#### **Velocity Sensors and Displays**

Doppler, airspeed and other speed measurement-display systems (not now in civil helicopters) will be required to allow approval of approaches to extremely low airspeeds or hovers during steep instrument approaches. A new family of logic can be developed which responds to the need to observe  $V_{MINI}$  and single engine minimum airspeed constraints (Cat A operations) while conducting steep approaches to a hover. Such a logic would be expected to address the practical attributes of currently available airspeed and ground speed sensor-display equipment in context with the air crew's need for the data under normal and failure mode operations.

#### **Special Flight Director Functions**

On the complex system end, flight director computers are required which incorporate relatively brilliant laws which in turn are able to provide steep approach guidance and hover or vertical descent/assent guidance. This might even respond to the need for flight directed Cat A takeoffs, rejected takeoffs, landings, and rejected landings.

On the low end, a new application of flight director logic could be used to direct the pilot to put the pitch attitude in the right place and the flight controls in the right place to steady the aircraft on trim in the shortest possible time, providing the pilot with more time to spend on navigation, communications, etc. In addition, there seems to be an opportunity for an improved display of commanded collective position.

#### **Attitude Indicators**

Attitude indicators come in a variety of sizes. Some are electro-mechanical, some are electronic. But what is their relative value? What is the benefit obtained with the largest practical display and the smallest emergency (two inch) display? The potential (or relative) advantage of the large display needs better definition.

## Enhanced Vision Systems

There is clearly a need for affordable first step applications of vision enhancing sensor-display systems. The need exists all across the spectrum of aircraft size and capability. The potential is virtually unexploited in the civil helicopter community.

## Helicopter Unique Displays

The slow and vertical modes of the helicopter are its principal attributes. Displays which facilitate pilot in the loop activity during slow and steep helicopter operations could make the helicopter more affordable and help the industry realize its potential. The current flight director, miniature turn needle, typical engine torque indicators, horizontal situation display (HSD) and pitot static airspeed indicator are five excellent examples of instruments which are not well suited to the helicopter during slow speed helicopter unique flight.

## OBSERVATIONS

The FAA pilot has the authority and responsibility to evaluate and approve the aggregate suitability of combinations of controls, displays and workload relief equipment to facilitate and expedite the expanded application of large numbers of IFR helicopters in the NAS.

Innovation is required to demonstrate: (1) Partitioning between the axes of an AFCS to provide a form of graceful degradation which can be applied to low cost stability augmentation and workload relief equipment suitable for IFR operations of small helicopters. (2) The relative value of robust displays and concepts for granting credit in the FAA IFR approval process. Such displays will help pilots compensate for some of the weaker flying qualities of some small helicopters. (3) The advantages and limitations of vision systems for credit during approaches to metropolitan vertiports.

In addition, there is a continuing need to better articulate the way modern helicopters fly and are flown in the civil environment. This is required to support a broader understanding of the issues and opportunities for improvement, so as to facilitate the development of and garner FAA approval of, affordable equipment sets with accommodating flight envelopes.

## SUGGESTIONS

Research and development should be encouraged to develop background data which will enable expeditious approval and encourage the intelligent applications of technology to develop affordable IFR equipment for a wide range of single and multi-engine helicopters.

The insight developed through R&D and FAA evaluations of aircraft offered for approval, should be used to enhance the guidance contained in Advisory Circulars 27-1 and 29-2.

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