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THE ROLE OF AUTOMATIC STABILIZATION EQUIPMENT IN ACHIEVING HELICOPTER IFR CERTIFICATIONS

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ABSTRACT

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The Federal Aviation Administration (FAA) of the United States has recently updated the airworthiness criteria for helicopter instrument flight. The new criteria clearly define the stability requirements for helicopter IFR. This paper summarizes the criteria, provides rationale for some of the requirements, and discusses the use of stability augmentation systems in achieving certification. The following areas are treated in detail:

- Trim
- Static longitudinal stability
- Static lateral-directional stability
- Dynamic stability
- Equipment redundancy and failures

The paper concludes by commenting on the new-generation helicopters and the current trend in the industry toward sophisticated avionics.

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1. INTRODUCTION

The airworthiness criteria for helicopter IFR flight in the United States have been somewhat unclear and incomplete. An FAA Helicopter IFR Task Force was therefore created with the intention of updating the criteria. The group coordinated suggestions made by industry, various FAA departments, and qualified technical societies, and generated a new regulations document in December 1978. That document was made available to the industry and to the various FAA regions in March 1979. The new standards have helped to clarify the FAA's position on helicopter IFR requirements particularly with respect to those related to aircraft stability.

The following paragraphs summarize the helicopter IFR airworthiness criteria, discuss the rationale behind them, and provide examples of how stability augmentation systems (SAS) can be used to help meet the requirements.

2. IFR STABILITY CRITERIA

Trim

The criteria state that all control forces in an IFR helicopter must be trimmable to zero. A force-trim button, beeper switch, or friction device may be used for this purpose. The cyclic control, however, must exhibit self-centering characteristics.

IFR operational requirements are primarily responsible for the trimmability criterion. An IFR pilot must remove his hands from the controls to perform routine duties such as radio tuning or chart unfolding. The control forces must be trimmed so as not to upset the aircraft when the controls are released. Any need to apply a steady force to the controls would prove to be an annoying, as well as tiring, task for the pilot.

Recent U.S. IFR certifications have all employed magnetic brake/force-feel techniques in the cyclic controls. Conventional friction has been used in the collective axis, while either magnetic brakes or friction has proven satisfactory in yaw. One variation to this has been the Sperry BO-105 certification where a trim motor and spring capsule configuration was selected to relieve steady control loads which develop due to the aircraft's lack of yaw boost. A beep switch located on the collective stick was used to make long-term pedal position changes.

Static Longitudinal Stability

The longitudinal stability criteria are different for single- and dual-pilot certifications. For the single-pilot system, the helicopter must possess substantial positive static longitudinal stability. The slope of the control force versus airspeed curve must indicate that any significant change in airspeed is clearly perceptible to the pilot through a resulting change in longitudinal cyclic control force. "Clearly perceptible" means that the pilot can recognize, by feel, a pilot-induced 20-knot speed change. Furthermore, when the control force is released, the helicopter must return to within 10 knots or 10 percent, whichever is less, of the trim speed.

The flight conditions of interest are:

Climb - Trimmed at best rate of climb airspeed and with power required to obtain 1,000 feet per minute rate of climb or maximum continuous power, whichever is less.

Cruise - Trimmed at 0.9 (V_h or V_{ne}) whichever is less.

Slow Cruise - Trimmed at 1.1 times the desired minimum IFR airspeed.

Descent - Trimmed at $0.8V_h$ or $0.8V_{ne}$, whichever is lower, and with power required to descend at 1,000 feet per minute.

Approach - Trimmed at recommended approach speed and with power appropriate to the landing approach aid being used.

For two-pilot certifications, it need only be shown that the control force stability of the helicopter should not cause objectionable handling qualities in any area of the flight envelope for which approval is requested.

An aircraft that has substantially positive airspeed stability relieves the pilot of having to make frequent longitudinal cyclic or collective position trim changes. The most recent revisions to FAR 27 and 29 require that all helicopters possess at least slightly positive airspeed stability to obtain even a VFR certification. This should be sufficient for a two-pilot IFR certification. For single-pilot IFR, however, the longitudinal cyclic versus airspeed gradient for most helicopters is much too shallow for certification. Two notable exceptions are the Aerospatiale Gazelle and Dauphin.

There are several ways to induce static airspeed stability. Bell uses a movable elevator in the 212 aircraft which is mechanically programmed as a function of longitudinal stick position. The S-76 employs a pitch bias series actuator which provides a longitudinal cyclic input to the swashplate as a function of airspeed and collective position. These two techniques affect the overall stick position/airspeed relationship of the helicopter. Since the IFR criteria, however, only require airspeed stability about a given aircraft trim position, a very simple technique may be employed to induce this stability. For example, the Bell 212, BO-105, and A-109 are all airspeed stable with respect to pitch attitude; i.e., for a fixed collective setting, there is one, and only one, airspeed which will be obtained at a given pitch attitude. As a result, a series actuator based augmentation system which employs pitch attitude feedback also induces airspeed stability about its attitude reference point. This technique has proven successful in the Sperry single-pilot IFR certification of those three aircraft.

Figure 1 is a typical example of the improvement in longitudinal cyclic/airspeed gradient which can be obtained using series actuator-attitude feedback. The BO-105 gradient improves from 0.1 to 0.9 percent of full travel per knot for the flight condition shown.

Static Lateral-Directional Stability

In straight and steady sideslips, the direction and magnitude of the lateral cyclic and pedal forces in an IFR helicopter should increase in stable directions as the angle of sideslip is increased up to 10 degrees. This stability feature must be present for cruise, climb, and descent over the entire IFR speed envelope.

Substantial lateral-directional stability is necessary for IFR flight from workload and safety standpoints. Without it, an aircraft is difficult to trim both in roll and in yaw. Furthermore, any sideslips which are either pilot or externally induced tend to compound, requiring the pilot to pay constant attention to the situation. Virtually all helicopters currently certificated for IFR flight have inherent lateral- directional stability. A notable exception to this is the Bell 212. One version of an IFR 212 employs a large fin located on the cabin roof forward of the rotor mast to compensate for this lack of stability. This device is located above the roll axis center of rotation, and thereby provides a stabilizing roll counter-moment in response to sideslip

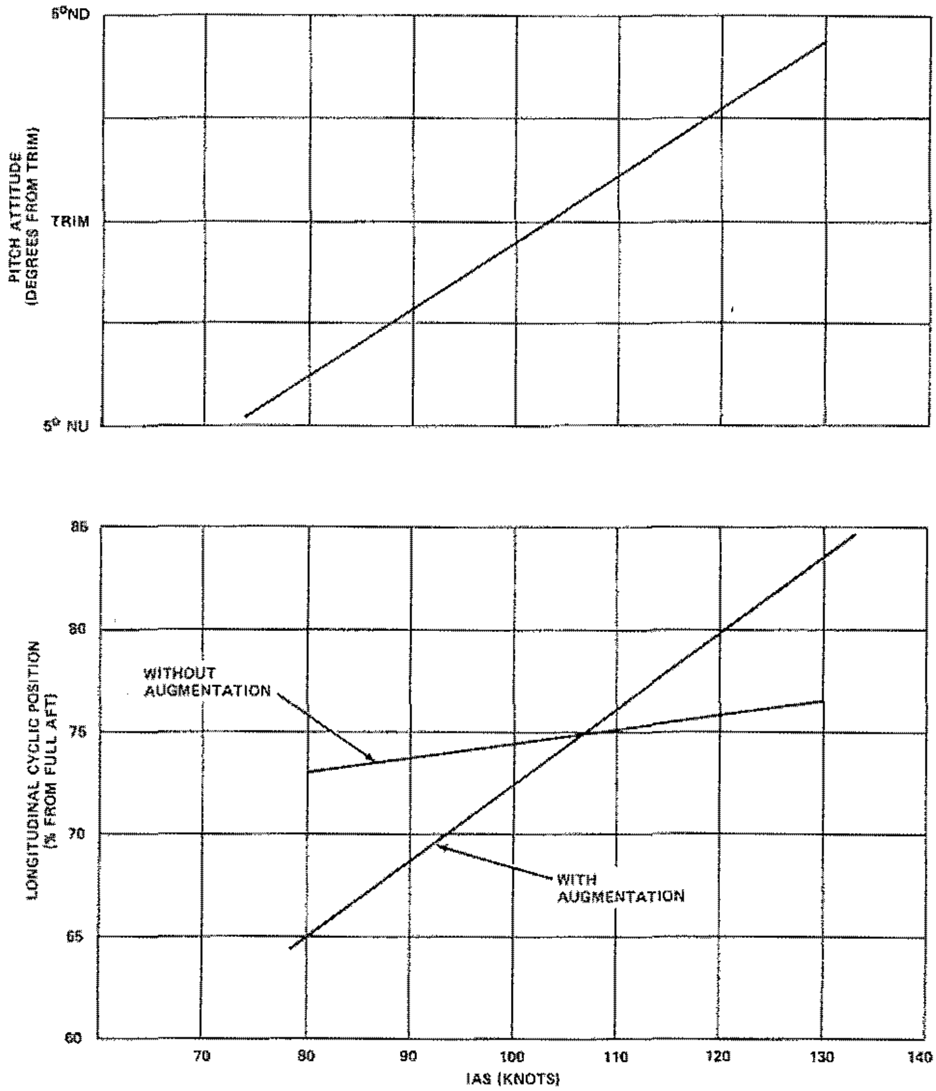

Figure 1
BO-105, Static Longitudinal Stability
105 Knots Cruise, 5070 lb Gross Weight, 129 Inch cg

forces. Another solution to the problem is the use of electronic stabilization using attitude feedback through a series actuator. The concept is best illustrated by the flight test data shown in figure 2 for a Bell 212 equipped with pontoon-type fixed floats. In performing a lateral-directional stability test, the pilot initiates a right sideslip by first applying left pedal pressure and then adjusting the roll attitude of the aircraft with the lateral cyclic control as necessary to maintain the same initial aircraft ground track. Without augmentation, approximately 8-percent left cyclic is required to hold the 15-degree sideslip at an 8-degree right bank. In the

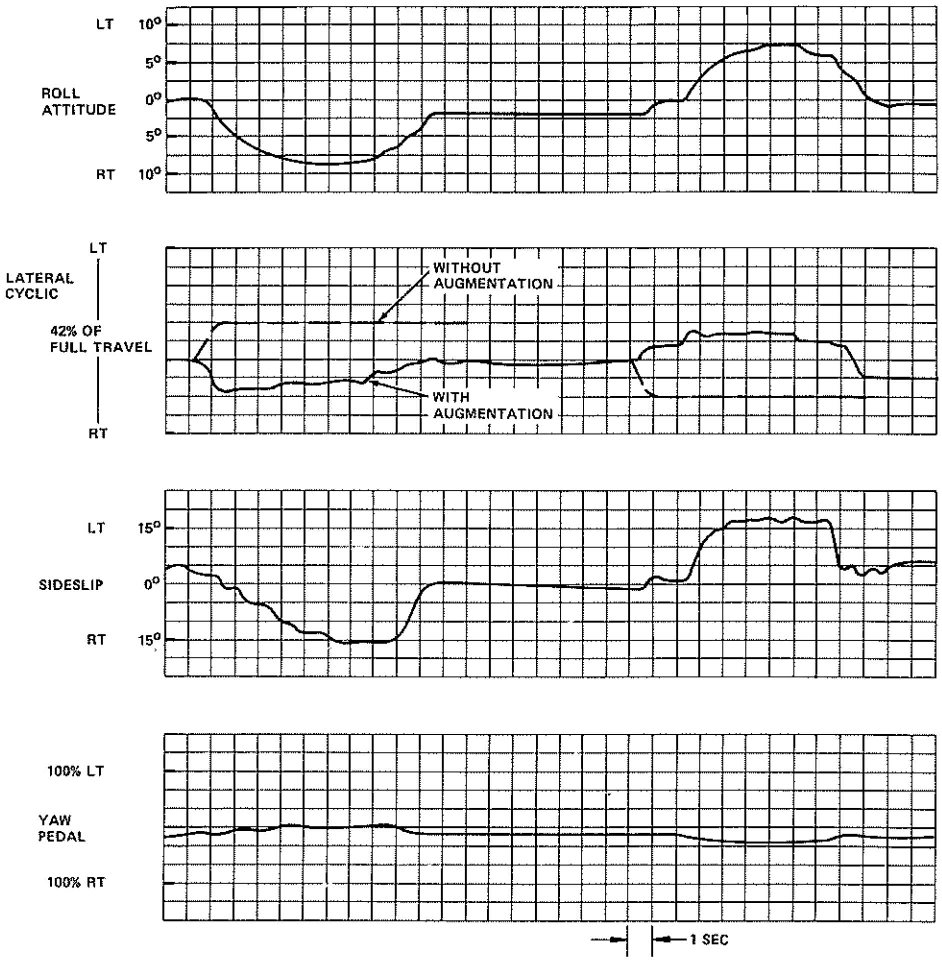

Figure 2
Bell 212 Lateral-Directional Stability
Fixed Floats, 1000 FPM Descent, 80 Knots,
8375 lb Gross Weight, 142.6 cg

case with stability augmentation, the 8-degree right bank results in a series actuator output equivalent to approximately 12-percent left cyclic. As a result, the pilot must use 4-percent right cyclic to hold the 8-degree right bank. This is the only technique that has been successful in the Bell 212 equipped with fixed floats.

Longitudinal-Lateral-Directional Dynamic Stability

The IFR airworthiness criteria set definite standards for any oscillatory tendencies an IFR helicopter might have. Oscillations are classfied by period and the specifications differ for single- and dual-pilot certifications. Table 1 summarizes the requirements.

TABLE 1
Dynamic Stability Requirements

Period	Single-Pilot Requirements	Dual-Pilot Requirements
5 seconds or less	Damp to half amplitude in one cycle	Damp to half amplitude in two cycles
5 to 10 seconds	Damp to half amplitude in two cycles	Shall be damped
10 to 20 seconds	Shall be damped	Time to double amplitude shall be greater than 10 seconds
20 seconds or more	Time to double amplitude shall be less than 20 seconds	Time to double amplitude shall be less than 20 seconds

Since the IFR pilot must occasionally turn his attention away from the controls, any high frequency (periods less than 20 seconds) oscillatory characteristics must dampen without pilot intervention. Longer period oscillations may be slightly divergent. These stability characteristics allow the pilot to divert his attention to other cockpit duties for periods of 10 seconds or more. Underdamped helicopter oscillatory modes (dutch roll, phugoid, etc.), as well as aperiodic modes (angle-of-attack divergence, spiral, etc.), can be stabilized by attitude and attitude rate feedback. The same pitch attitude feedback that induces static airspeed stability also stabilizes the aircraft phugoid mode and any angle-of-attack divergence tendencies. The roll attitude feedback used to augment static lateral-directional stability will also stabilize the spiral mode and, when coupled with a simple yaw rate damper system, dampens the dutch-roll mode. The BO-105 flight test data presented in figure 3 shows the effectiveness of a yaw rate damper. Pedal pulses are applied with the yaw damper first engaged and then disengaged. The improvement with damper engaged is quite dramatic.

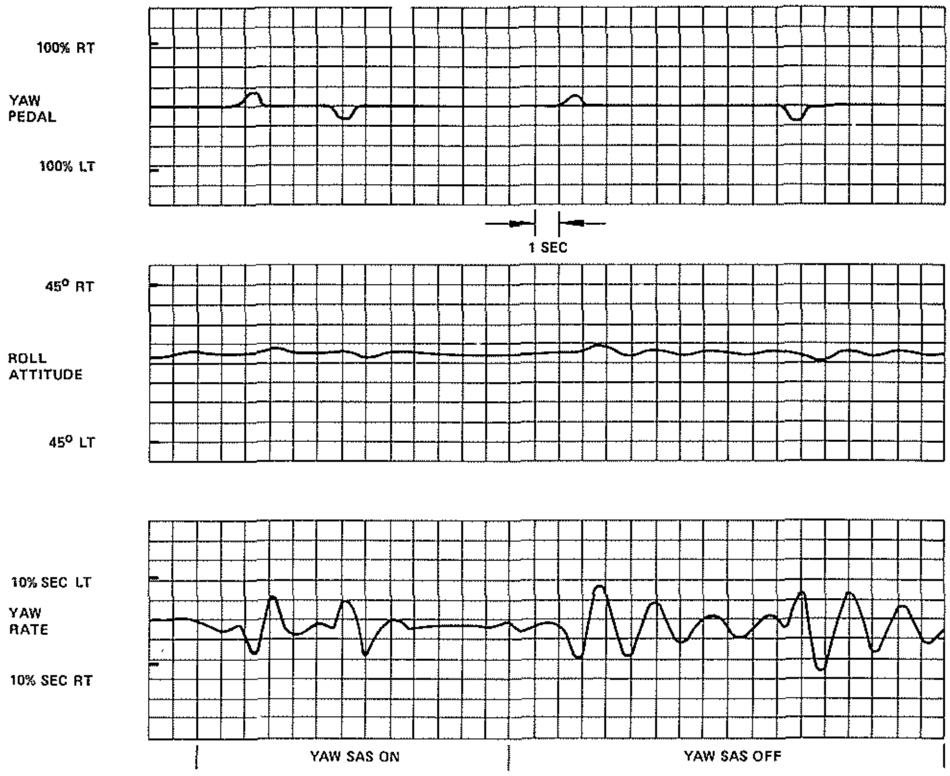

Figure 3
BO-105 Yaw Axis Dynamic Stability
122.8 Inch cg, 5070 lb, 100 Knots Cruise

3. SAS REDUNDANCY AND FAILURES

The IFR airworthiness criteria provide only qualitative statements concerning handling qualities in the event of a failure of a stability augmentation system. Four major points are emphasized:

1) The helicopter shall be safely controllable when the failure occurs.

2) The requirements specified in the applicable (FAR 27 or 29) airworthiness requirements must be met over a practical operational envelope.

3) Flight characteristics are not impaired below a level needed to permit continued prolonged instrument flight and landing in turbulence without exceptional piloting skill, alertness, or strength.

4) The effects of any subsequent unrelated failure should not be so severe as to preclude safe, continued instrument flight.

Statement 3 implies that a stability system does not have to be redundant if the unaugmented aircraft can be readily flown manually for the duration of the mission. This is the area where human factors, engineering, and nonstability-type riding qualities play an important role. A helicopter type which has low vibration levels, comfortable seats, and a well-engineered instrument panel layout might possibly be IFR certifiable with a nonredundant SAS. Another aircraft type with similar stability characteristics but with high cockpit vibration levels or a high workload cabin layout would require a dual system. Similarly, if an airframe met all the airworthiness criteria without stabilization, good riding qualities coupled with proper human factors engineering could lead to an IFR certification without any stability augmentation. The SA 360 Dauphin is currently certified for two-pilot IFR without a SAS or autopilot.

Prior to publishing the new airworthiness criteria, there was confusion concerning time delays that must be demonstrated prior to recovering from SAS failures. The new regulations are quite clear:

Flight Condition	Time Delay
Crew of One	
Hover	Normal pilot reaction
Takeoff and landing	Normal pilot reaction
Maneuvering and approach	1 second plus recognition
Climb, cruise, and descent	3 seconds plus recognition
Crew of Two (Same as Crew of One Except)	
Climb, cruise, and descent	1 second plus recognition (hands-on system)
Climb, cruise, and descent	3 seconds plus recognition (hands-off system)

The key point to be stressed here is that, if the SAS is acting as an autopilot (i.e., it offers hands-off modes such as attitude hold, heading select, airspeed/altitude hold, etc.,), the demonstrated time delay is 3 seconds for climb, cruise, and descent. This criterion holds true for both single- and dual-pilot certifications, and for both first and second failures if the stability system is redundant.

The effects of stability system malfunctions can be minimized by a number of techniques. Limiting the authority of the SAS actuator is the most straightforward way. Frequently, however, the actuator authority needed to meet the 3-second time delay criteria over the full operating range of the aircraft is too low to satisfactorily control the aircraft in gusting conditions. Some systems depend upon monitoring techniques to allow the use of greater authority actuators without compromising safety. Usually, these designs employ independent sensors and electronics to test the validity of the SAS commands as well as the reasonableness of the aircraft's attitude and rate. If a discrepancy is detected, the offending actuator is disabled or, in some cases, returned to a neutral position. Sperry has found that redundancy is most effective in minimizing the effect of a malfunction. This proven technique requires the use of two independent sets of sensors, actuators, and electronics. The two systems work simultaneously and, should one system malfunction, the operational system applies a countering input in response to aircraft motion. In addition, the remaining operational system provides backup operation once the malfunctioning system is disengaged. The hardover improvements gained by using a dual system are well illustrated in figure 4. For a 5-percent single system longitudinal cyclic hardover, the A-109 achieves a pitch attitude of approximately 23 degrees in 3 seconds at the flight condition shown. With a dual system, however, a hardover results in only an 8-degree change in attitude.

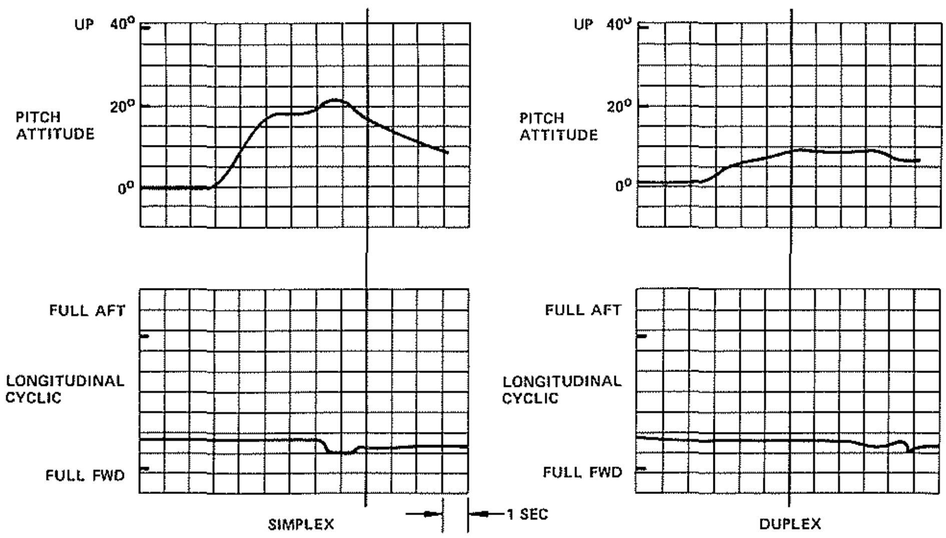

Figure 4
A-109 Pitch Hardover Response
Aft cg, 168 Knots, 2450 kg

4. SUMMARY AND CONCLUSIONS

The FAA airworthiness criteria for IFR helicopters are now quite clear. Ideally, the aircraft manufacturer should design sufficient stability into the airframe in order to meet these requirements. Should additional stability be required, however, a series actuator-based stabilization system can be tailored to the aircraft to assist in meeting the airworthiness criteria. The stability augmentation system can also be readily coupled to a flight director computer thereby providing the pilot with autopilot capability comparable to that of a commercial jetliner.

At least two of the new-generation helicopters meet the IFR airworthiness requirements without additional stability augmentation systems. The aircraft manufacturers, however, have elected to offer the IFR versions of these aircraft with sophisticated, fully coupled stabilization systems. The reason is twofold. Operators who must routinely work in a true IFR environment need and demand the capability those systems offer. Also, the foresighted airframe manufacturers and avionics companies refuse to compromise performance and safety by developing minimal systems which just barely meet the IFR criteria. Rather, they offer more comprehensive systems necessary to properly integrate the helicopter into commercial IFR operations.

REFERENCES

1) Federal Aviation Administration, Airworthiness Criteria for Helicopter Instrument Flight, AFS160, December 15, 1978.

2) Office of the Federal Register, Code of Federal Regulations, Title 14 - Aeronautics and Space, January 1, 1978.