System Suitability and Pilot Workload Assessments for Instrument Flight Certification of a New Utility Helicopter*

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This paper presents the instrument flight certification procedure for, and major flight test results of, a newly developed military helicopter. Instrument flight certification is achieved by combining the evaluation of aircraft system suitability, flight characteristics, and pilot workload assessments during flight tests. The suitability of the aircraft system is determined by whether or not the instruments and equipment required for instrument flight are mounted on the aircraft and if they are installed properly and protected. The performance of the equipment installed is verified through both ground and flight tests. In addition, it should be verified that the aircraft has sufficient static and dynamic stability with respect to longitudinal, lateral, and directional axes. The static stability is determined by the tendency to recover after disturbance. The dynamic stability is also evaluated. As another important study, a series of simulated IMC flight tests were conducted and the pilot workloads assessed using the Bedford rating scale. The pilot workloads are evaluated not only for normal aircraft flight conditions, but also for malfunction of the stability augmentation system or essential flight instruments. After completion of the simulated IMC flight tests, actual instrument flights were performed under real air traffic control.

Key Words: Instrument Flight, IFR, IMC, Workload Assessment, Flight Test

Nomenclature

- $V_{NEI}$: never exceed speed
- $V_{XEI}$: instrument never exceed speed
- $V_{H}$: maximum level flight speed
- $V_{MINI}$: instrument minimum speed
- $V_{YI}$: instrument best rate of climb speed

1. Introduction

Military helicopters are generally operated in mountainous regions at low altitudes and have a high possibility of encountering sudden torrential rain, heavy snow, clouds, or fog. Such weather conditions that limit the visual cues of the pilots and force them to rely on instruments are referred to as instrument meteorological conditions (IMC). Conversely, the conditions that allow visual flight are referred to as visual meteorological conditions (VMC). Additionally, the rules to be followed during instrument flight are called instrument flight rules (IFR). The official definitions for IFR and IMC can be found in the Instrument Flying Handbook.1) Sometimes, it is necessary to fly in accordance with IFR even in the weather conditions with adequate visual capability due to air traffic control or operational reasons.

In order to fly in accordance with IFR, appropriate instruments and equipment must be equipped in the aircraft. In addition, the aircraft must have controllability complying with related regulations and be verified to be capable of maintaining safe flight under various fault conditions. Furthermore, the pilot workload for the aircraft system under IFR flight conditions must be evaluated as well. This is because pilots who are overburdened tend to commit more errors and have poor situational awareness.2−6) Such abilities for civil rotorcraft are certified according to FAR Part 277) or 29,8) Appendix B. However, there is no military standard related to military rotorcraft. Therefore, FAR regulations are usually modified to fit the characteristics of military rotorcrafts and applied.9) IFR/IMC certification for Korean utility helicopters (KUH) is also based on FAR-29 Appendix B, but some of the requirements are modified in accordance with the specificities of military operations and aircraft characteristics.

The purpose of this study is to present the important procedures and actual test results required to verify the instrument flight capability of military helicopters utilizing the case of a KUH. This will contribute to establishing the procedures of instrument flight certification for military helicopters.

2. Test Aircraft

The KUH is a medium utility helicopter with a fuselage length of approximately 15 m, four composite main rotor blades, and two T700 series engines controlled by FADEC. Anti-icing and deicing equipment are installed at the rotor blades and engine inlets to protect the aircraft from icing conditions. A 4-axis automatic flight control system (AFCS) enhances the stability and control performance of the helicopter. It is based on a dual architecture composed of an auto pilot module (APM), an attitude heading reference system (AHRs), smart electro-mechanical actuators (SEMA), and parallel trim actuators. The AFCS offers a basic stabilization mode that enhances aircraft attitude maintenance and basic
control stability with respect to the pitch, roll, and yaw axes. The control system also offers higher mode functions that alleviate the workload of the pilot during hovering, long-range aviation, takeoff, and landing. Additionally, the KUH is equipped with navigation systems such as a global positioning system/inertial navigation system (GPS/INS), VHF omni-directional range/instrument landing system (VOR/ILS), and a radio altimeter. The pilot’s field of view is also secured utilizing a forward-looking infrared (FLIR) and a helmet-mounted display (HMD) for use at night and during severe weather conditions.

The front instrument panel of the KUH has been developed as a full-glass cockpit with two multi-function displays (MFDs) at the pilot and copilot seats. The basic instrument information, such as altitude, calibrated airspeed, attitude and heading, is displayed through the primary flight display (PFD) of the MFDs. In addition, a fuel indicator, integrated engine instrument, integrated standby instrument (ISI), and caution and warning panels are located at the center of the instrument panel. Every instrument is compatible with night vision goggles (NVGs). Figure 1 illustrates the arrangements of the main and standby instruments.

3. IMC/IFR Certification Process

Instrument flight generally has more limitations than visual flight. Therefore, in order to receive instrument flight certification, it must be confirmed whether or not the aircraft has sufficient flight capability in a limited environment. This includes not only the suitability of the instruments and equipment mounted on the aircraft, but also the flight characteristics of the aircraft itself. Additionally, the pilot workload should be maintained at an appropriate level even under conditions with a limited field of view. Therefore, step-by-step substantiations from the equipment level to the aircraft system level are required for instrument flight certification. The certification process applied to the KUH is summarized as follows.

3.1. Instruments and equipment

An aircraft must be equipped with instruments and equipment suitable for instrument flight. FAR-29 generally requires the following avionics and flight instruments:

- Standby attitude indicator
- Magnetic gyro-stabilized direction indicator
- Thunderstorm light
- Alternate static source
- Navigation systems
- Communication systems, etc.

The battery used in the standby instrument should be separated from the aircraft starting system, and supply electrical power for at least 30 minutes after total failure of the electrical power generating system. In addition to these instruments, a device that prevents overvoltage should be equipped in the electrical power system, and the pilot must be able to monitor the adequacy of the electrical power supply. Additionally, the pilot static probe must have anti-icing and deicing functions. The performance of all equipment and suitability for instrument flight are evaluated through ground and flight tests.

3.2. Handling quality

Even if an aircraft satisfies the handling quality requirements under the VMC, additional certification tests are required for IMC/IFR certification. For example, the positive velocity gradient with respect to the control stick displacement has to be checked in the range of $0.8V_{NE} - 10\text{ kts}$ to $0.8V_{NE} + 10\text{ kts}$ under visual flight conditions to satisfy longitudinal static stability. Under IFR conditions, however, the positive gradient must be maintained from $0.7V_H$ to $V_{NE}$ or $1.1V_H$, and the pilot has to clearly recognize the change in control loading. Additionally, the speed has to return to within 10% of the initial trim speed when the control stick is released. Unlike visual flight, IMC/IFR certification includes requirements regarding low-speed cruise and descending flight. The KUH was verified to comply with each of the FAR-29 requirements through flight tests.

3.3. Stability augmentation system (SAS)

When a SAS is installed in an aircraft, such as the AFCS of the KUH, evaluation of the SAS failure conditions has to be conducted over the entire operation boundary unless the possibility of failure is extremely low. Even if the SAS fails, FAR-29 requires that the increase in pilot workload, which threatens flight safety, should be minimized or flight path deviation should not occur.

In order to ensure compliance with the requirements, primary failure modes possible in the KUH have been identified, and the pilot’s workload is evaluated for each of the conditions with intentional failures. Trim and SAS functions with respect to the pitch, roll and yaw axes are intentionally suspended for the tests. This test is conducted under simulated IMC with the pilot wearing a hood, and the workload of the pilot is assessed according to the Bedford Workload Rating Scale. The important advantages of the Bedford Workload Rating Scale are that it is easy to implement and the descriptions themselves represent the interpretations of the ratings scored by the pilots. Rules such as FAR do not specify explicit criteria for...
workload assessment. However, the criteria presented in De-
lucien et al. are worthy of reference, as follows.
1.1 Minimal pilot compensation. Control techniques are re-

laxed. Continual pilot involvement in short- and long-term flight control tasks.
1.2 Moderate pilot compensation. Pilot is moderately in-

volved in flight control tasks, and must continually correct the short-term state of the aircraft.
1.3 Considerable pilot compensation. Pilot is heavily in-

volved in flight control tasks. The pilot would not inten-

tionally plan to encounter this level of effort for more than 5–10 minutes.
1.4 Extensive pilot compensation. Pilot is very heavily in-

volved in flight control tasks. The pilot would not inten-

tionally plan to encounter this level of effort.
1.5 Maximum pilot compensation. Pilot is totally involved 

in flight control tasks. The pilot would not intentionally plan to encounter this level of effort.

For two-pilot operation, the pilot’s workload should be not greater than “1.3 Considerable pilot compensation” when landing in normal mode. When landing in failure mode, it should be not greater than “1.4 Extensive pilot compensation.” In the case of one-pilot operation, the criteria become “1.2 Moderate pilot compensation” for normal mode and “1.3 Considerable pilot compensation” for failure mode.

In terms of aircraft operation, the KUH is not allowed to be flown by a single pilot in both instrument flight and visual flight; that is, the KUH is a ‘two-pilot aircraft.’

3.4. Other failure modes

When a failure occurs in a rotorcraft, the rotorcraft aban-

don the mission or attempts an emergency landing according to the severity of the failure. Under the IMC, however, an immediate landing is impossible even if a failure occurs, and the aircraft must be able to continue to fly. Therefore, an aircraft must be able to fly safely with a certain degree of failure for IMC/IFR certification.

In addition to normal conditions, possible failure condi-

tions for KUHs are defined, and it is verified that there is no excessive increase in pilot workload under the corresponding conditions. However, failures that require declaring an emergency are excluded, and only reasonably probable failures are considered.

3.5. Flight manual and constraints

The pilot’s field of view is limited under the IMC, and there could be additional constraints compared to the VMC. For example, 60 degrees bank turn is possible during visual flight, but a bank turn over 30 degrees is difficult during an instrument flight. That is, a common maneuver during the visual flight could be a dangerous maneuver during the instrument flight. For this reason, additional flight constraints should be established for the IMC, and be included in the flight manual. The items that require additional constraints as compared to the VMC are the minimum speed, rate of climb, maximum never-exceed speed, and maximum angle of approach. The operation constraints reflected in the flight manual have to be verified through a flight test under simulated or actual IMC.

3.6. IMC/IFR demonstration and evaluation

An instrument flight under actual IMC has to be conducted according to air traffic control to finally verify the suitability of the aircraft for IMC/IFR certification. This flight is composed of instrument take-off (IT0), climb out, enroute, VOR/ILS approach, missed approach, etc. The previously used Bedford Workload Rating Scale is also used in evaluation of the IMC demonstration.

4. Test and Evaluation Results

4.1. Instruments and equipment

The design suitability of the instruments and equipment installed in the KUH should be confirmed prior to the IMC/IFR flight test. Especially, backup instruments, electrical systems, air data systems, and communication systems are important for safe flight under emergency conditions.

The standby instrument equipped in the KUH is an integrated standby instrument (ISI) that provides information on airspeed, altitude, and attitude. Figures 2 and 3 show the flight test results for the ISI to verify the accuracy of the data displayed. The airspeed and altitude of the ISI are compared with the data from air data computer (ADC) and the attitudes are compared with the data from the AHRS. The information from the ISI shows good agreement with that from the primary instruments, such as ADC or AHRS. Regarding the pitot static pressure measuring system, the KUH has a redundant design and is equipped with an anti-icing function. Such anti-icing ability has been verified through an icing wind tunnel test.

Regarding the power system, when a short circuit occurs in
AC or DC power, it is automatically cut off by the electrical master box (EMB). Rig tests have been conducted to confirm whether or not the power supply is automatically separated when it is intentionally short-circuited. The functions and performance of navigation and communication equipment are also verified through avionics simulations and flight tests.

### 4.2. Handling quality tests

The IMC/IFR handling quality test is conducted according to FAR-29 Appendix B. Longitudinal and directional stability tests are performed at low altitude, a high altitude of 10,000 ft or above, low and high speeds, and under climb and descent conditions. Figure 4 illustrates some of the longitudinal static stability test results at the maximum takeoff weight and most aft center-of-gravity (CG), which are the most severe conditions in static stability. As illustrated in the figure, the positive gradient with respect to control stick displacement verifies the static stability of the test aircraft. Figure 5 shows the lateral and directional static stability test results. These tests are performed in the same configurations as Fig. 4. The sideslip angle of the aircraft is linearly varied beyond ±20° with respect to the pedal and lateral control stick input. This means that the rotorcraft is statically stable in the directional and lateral axes. The static stability test above was conducted with respect to the severest weight and CG combinations at low, medium, and high altitudes, low- and high-speed level flight, climb, descent, and autorotation conditions, and every test yielded stable results.

Figure 6 shows the dynamic stability flight test results in accordance with the longitudinal axis at $V_H$ speed, which is related to the maximum takeoff weight and most aft CG. In this figure, the short period oscillation induced by rapid control stick input to forward or aft is mostly attenuated within one cycle. Figure 7 illustrates the dynamic stability flight test results with respect to the lateral axis. The amplitude of oscillation along the lateral axis also decreased to less than 50% within one cycle. Figure 8 shows the yaw response after doublet pedal input to verify the directional stability of the rotorcraft and the response also decayed rapidly. As with
the Simulated IMC tests. As shown in Table 1, the Simulated IMC tests include level flights at low and high speeds, and deceleration, acceleration, bank turn, climb, descent, approach and landing maneuvers. The test cases are as follows. A baseline test should be performed to evaluate the basic instrument flight ability and acquire a reference value to identify the increase in pilot workload under failure conditions. In an unusual attitude test, a safety pilot, who is sitting next to the test pilot, creates an unexpected change in roll or pitch attitude and checks whether or not the test pilot wearing the hood can easily fix the attitude. A trim malfunction test is conducted by sequentially stopping the operation of trim functions for the pitch, roll, and yaw axes.

In the AFCS off test, every function of AFCS including the SAS is turned off. A back-up instrument test is conducted to verify if IMC/IFR flight only using standby instruments without the support of basic flight instruments is possible. For this test, the displays on the test pilot side are turned off and the displays of the safety pilot are also dimmed. As shown in Table 1, the approach is not included in the back-up instrument test because it is too dangerous. An engine failure test is conducted with the assumption that one engine failure test is conducted with the assumption that one engine is stopped during IMC/IFR flight. To simulate this condition, the safety pilot suddenly moves the torque lever of one engine to the idle power position.

The workload of the pilot during the Simulated IMC tests could affect the control characteristics of the rotorcraft in the event of a failure. AFCS, engine, hydraulic and display failures are included in such conditions.

Table 1 summarizes the Simulated IMC tests. As shown in Table 1, the Simulated IMC tests include level flights at low and high speeds, and deceleration, acceleration, bank turn, climb, descent, approach and landing maneuvers. The test cases are as follows. A baseline test should be performed to evaluate the basic instrument flight ability and acquire a reference value to identify the increase in pilot workload under failure conditions. In an unusual attitude test, a safety pilot, who is sitting next to the test pilot, creates an unexpected change in roll or pitch attitude and checks whether or not the test pilot wearing the hood can easily fix the attitude. A trim malfunction test is conducted by sequentially stopping the operation of trim functions for the pitch, roll, and yaw axes.

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was evaluated using the Bedford Workload Rating Scale, as shown in Fig. 9. All workload evaluations were performed by a group of four pilots. The group consisted of three Army pilots and one Air Force pilot. Two of them were highly experienced pilots with more than 2,000 h of flying experience, and the other two pilots had an average level of experience of less than 1,000 h.

The assessment results are summarized in Fig. 10. As shown in this figure, the pilot workload at the baseline, which is the condition when every system works properly, satisfies the rating of 3.1 on average. In this case, acceleration and deceleration maneuvers are only rated at level 4. The other maneuvers in Table 1 are rated at level 3. Under the trim malfunction conditions, the increasing level of the workload is different according to the malfunction axes. For the roll trim malfunction, there is no significant difference between malfunction and normal conditions in all maneuvers. There is also no significant increase in workload, with the exception of approach, for the pitch trim malfunction. Pilots reported that approach under the pitch trim malfunction condition was more difficult than under the roll trim malfunction condition. This is because the pitch trim function affects maintaining the glide slope during approach. The workload during the yaw trim malfunction is relatively higher than the workload during the roll or pitch trim malfunctions. In conclusion, the workload increases in the order of roll, pitch, and yaw axes during trim malfunction. When the AFCS is turned off, the average workload rating increases to 4.8. According to the Bedford Workload Rating Scale, a mission is slightly restricted at a rating of 5. Considering the AFCS-off condition is when every function of SAS has been turned off and the aircraft is flying only with its basic flight characteristics, the rating of 4.8 is determined to be acceptable.

On the contrary to expectations, there is no significant increase in workload during standby instrument flight. This result seems to arise from the fact that the workload increases the most when a failure occurs during approach, but approach conditions couldn’t be included in the back-up instrument test.

4.4. IFR flight demonstration and evaluation

IFR flight demonstrations should be performed utilizing actual day and night IMC to verify IMC/IFR suitability. An overview of the test procedure is illustrated in Fig. 11. The tests are conducted within V\text{y} and the maximum instrument flight speed in the order of ITO, enroute, VOR hold, ILS approach, and missed approach. In addition, IMC/IFR flight ability under the condition of OEI is verified by changing the power of one engine to idle when enroute. Test flights were conducted at Sacheon and Gimhae airports. Night IFR flight tests were conducted under clear weather conditions. At the time, the wind varied at 7–15 kts. However, actual day IMC flights have been performed under moderate and heavy rain conditions. Based on the Bedford Workload Rating Scale, the pilot workload was evaluated to be 2.5 on average.

One of the important procedures of instrument flight certification is verifying whether or not main flight constraints related to instrument flight are appropriately reflected in the flight manual. Unlike visual flight, additional constraints can be required such as instrument minimum speed (V\text{MINI}), instrument never exceed speed (V\text{NEI}), instrument best rate of climb speed (V\text{YI}), the rate of climb, and maximum angle of approach. For this rotorcraft, the minimum speed certified for the air data system is used as the V\text{MINI}. The V\text{YI} and V\text{NEI} are also established as the same speed used for visual flight. However, V\text{NEI} is limited to the slower speed when AFCS fails. The rate of climb was also limited to 1,500 fps.
5. Conclusion

This research summarized and presented the instrument certification process and major test results for the KUH. The suitability of the instruments and equipment installed were first reviewed, and their performance was verified through ground and flight tests. The aircraft was evaluated in terms of whether or not it has handling quality suitable for instrument flight. For this, flight tests for static and dynamic stabilities of the aircraft were conducted according to the requirements of FAR-29 Appendix B. Once the suitability of instruments and equipment, and the handling quality of the aircraft had been verified, the workloads of the pilot were assessed through simulated IMC flight tests. Possible failure conditions for flight control and instrument systems were considered in the pilot workload assessments. Instrument flight demonstration was also conducted in an actual IMC environment with real air traffic control after completion of the Simulated IMC flight tests. Through the tests, the KUH was evaluated as suitable for IMC/IFR flight.

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