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EVALUATION OF A FLIGHT CONTROL LAW FOR CIVIL HELICOPTERS

FM10

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In order to accelerate the wide use of commuter helicopter, Advanced Technology Institute of Commuter helicopter Ltd. (ATIC) was established in March 1994, and started its 7-year-long research activity. ATIC is performing the research to solve two biggest problems of helicopter commuting, "Flight safety" and "External noise" which prevent the commuter use of helicopter.

We, ATIC Research Dept. No.2, pursue "Flight safety technology for helicopter", and aim to reduce pilot workload by FBW flight control system and sophisticated control law.

After introducing the outline of whole "Flight Safety study", this paper mainly describes the flight control law for civil helicopter, including the recent results of piloted simulation.

1.ABBREVIATIONS

ATIC	Advanced Technology Institute of Commuter helicopter
FBW	Fly By Wire
VMC	Visual Meteorological Conditions
IMC	Instrument Meteorological Conditions
GPS	Global Positioning System
ADC	Air Data Computer
IRS	Inertial Reference System
MFD	Multi-Function Display
FCC	Flight Control Computer
CPU	Central Processing Unit
FMS	Flight Management System
SPICE	Stick & Pedal Interface & Control Electronics
ACC	Actuator Control Computer
RCAH	Rate Command Attitude Hold
ACAH	Attitude Command Attitude Hold
ACVH	Attitude Command Velocity Hold
CP	Collective Pitch

2. INTRODUCTION

Helicopters first achieved flight at the beginning of the 20th century, almost concurrently with airplanes. However, they are not yet commonly used for carrying passengers, partly because they require high-grade aerodynamic and mechanical technology.

In the 21st century, a transportation network of trunk lines will likely be configured for high-speed mass transportation, as will Super Sonic Transports, etc. Peripheral transportation networks will be required in addition to the trunk lines network to globally connect each location so that the transportation network can be utilized effectively. Helicopters are the most suitable means for peripheral transportation and should be more widely used.

Helicopters, however, have a lower dispatch reliability than airplanes and there are many factors that prevent their widespread use, such as flight safety problems due to excessive use to compensate for the low dispatch reliability, and noise emission problems from flying at a low altitude over residential areas. These problems must be solved promptly.

The Advanced Technology Institute of

Commuter helicopter (ATIC) was established in March 1994 with investments from the Japan Key Technology Center (organ of the Ministry of International Trade and Industry and the Ministry of Posts and Telecommunications) to address these technical aspects of helicopter flight.

There are two research themes in the ATIC - noise reduction and flight safety improvement. Research into external noise-reducing technology is being undertaken by ATIC Research Dept. No. 1, while research into helicopter flight safety technology is being conducted by ATIC Research Dept. No. 2.

This paper pertains to the research on helicopter flight safety technology. We briefly introduce the flight verification system, which is now being manufactured. We then describe the development of flight control law for civil helicopters, which reduce the pilot workload by simplifying control operation, including the results of pilot evaluations obtained using the newest piloted simulations.

3. *CONFIGURATION OF THE ON-BOARD SYSTEM*

An overall configuration diagram for the on-board system is shown in Fig.1. The on-board system consists of a flight control system and a flight management - information display system. The flight control system is used to improve the flying qualities and simplify the control operation. This system utilizes a full-authority Fly-By-Wire (FBW) control system to achieve both the response required in Visual Meteorological Conditions (VMC) and high stability required for instrument flights under Instrument Meteorological Conditions (IMC).We can thus adopt sophisticated flight control law, which enable great improvements in flying qualities. The flight management - information display system guides the helicopter and helps the pilot's judgments. The flight management computer guides the helicopter using positional information obtained from the Global Positioning System (GPS) receiver. In addition, during take-off and landing, the Differential GPS (DGPS) offers more accurate positional information by using compensation information obtained through a data link. With this information helicopter can track an accurate flight path that extracts the helicopter's capabilities, such as a curved approach and landing path.

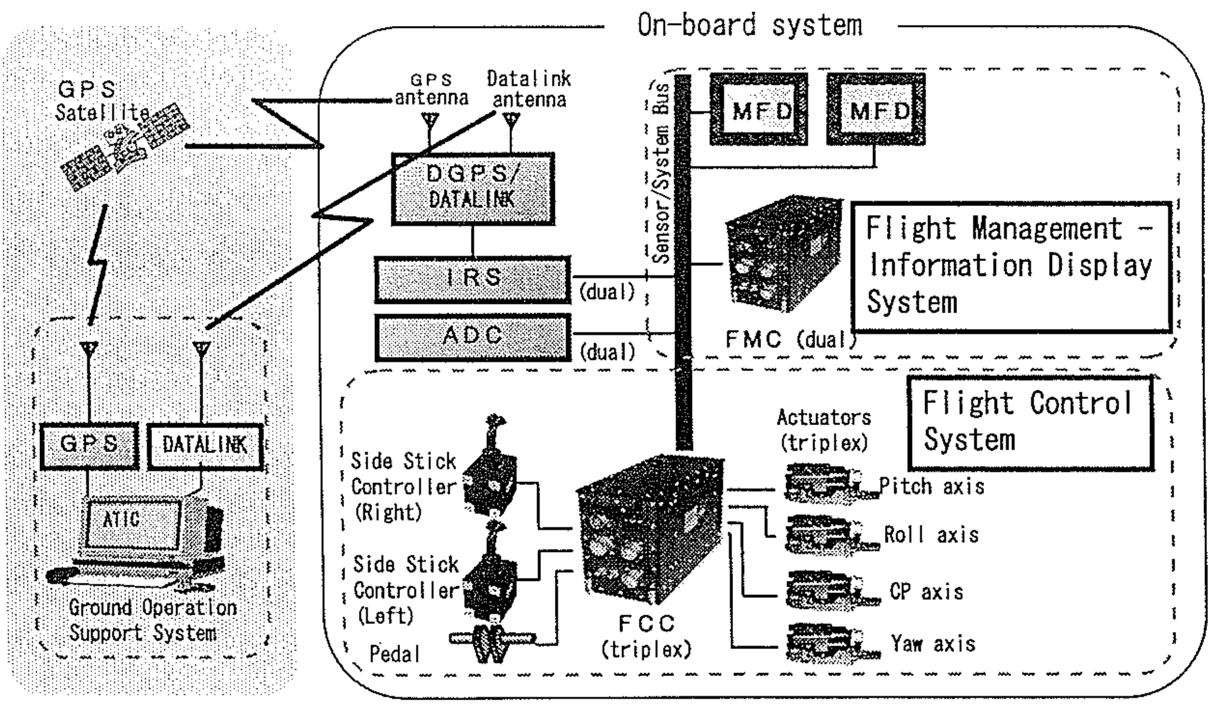

Figure.1 Configuration of the on-board system

The information display function helps the pilot make decisions by displaying information required during flight in an integrated and optimized form using two Multi-Function Display (MFD) units. Thus, the flight control system and flight management - information display system together reduce the pilot workload in piloting and other non-piloting operations.

4. *FLIGHT CONTROL SYSTEM*

The on-board flight control system executes the flight control law. We designed the flight control system using two objectives for civil helicopters:

1. A compact, light weight system that can be mounted on-board
2. A highly reliable system that qualifies for a civil aircraft certificate.

Based on these objectives, we configured the flight control system as a triplex FBW system, as shown in Fig. 2, to be as two fail operational as possible. Although a study of the FBW system for helicopters was conducted by using the BK117 FBW research helicopter [1, 2, 3, 4] in Japan, our system offers the following features which are different from that system; these features make our flight control system more practical.

1) Highly reliable Flight Control Computer (FCC)

Dissimilar computer technologies come to be generally used to overcome software errors in a FBW system. This flight control system demonstrates the monitoring and reconfiguration technology required to configure dual dissimilar technologies using two identical CPUs.

2) Analog backup system

Mechanical systems are not suitable for backups (against unpredictable events) of the FBW system in practical use with civil helicopters. Therefore, our system uses an analog backup system.

3) Combination with the Flight Management System (FMS)

Because of the flexibility of a digital system, this system can implement various functions in combination with the FMS.

5. *DEVELOPMENT OF THE FLIGHT CONTROL LAW*

5.1 Outline

The objectives of the flight control law are to achieve optimum flying qualities for each operation under VMC, to expand the flight envelope under IMC, and to enable a low speed/steep approach by improving low-speed flying qualities. We investigated various specifications and literature

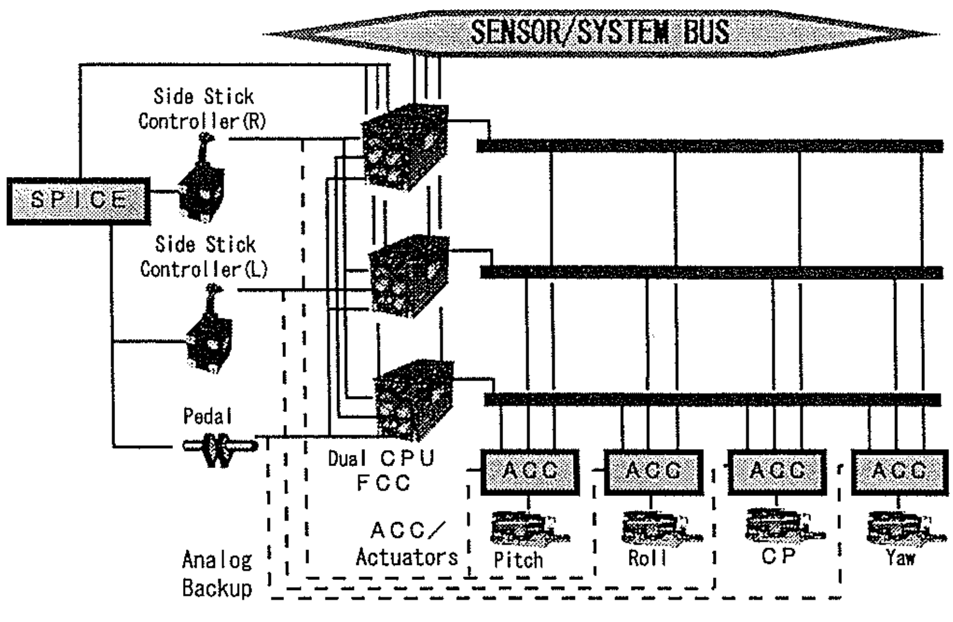

Figure.2 Coniguration of the flight control system

concerning flying qualities, prepared design requirement for designing flight control law based on the results of our investigations, and developed the flight control law by confirming the results through analyses and piloted simulations. The overall flying qualities target is to achieve flying qualities level 1 in flights using normal flight control law.

Our study is in the verification phase. We have found that low-speed stability is important for the flying qualities under IMC and that it is possible to use the flight control law to expand the flight envelope under IMC. We will report the results of our studies on these themes in future.

The contents of the flight control law in this study are described below. While the control law for the above-mentioned BK117 FBW research helicopter was limited in terms of control functions and flight envelope, the flight control law in this study covers a wide range, including diversified functions to improve the flying qualities under IMC, such as the hold function and automatic flight functions.

5.2 Details of the Functions

Figure.3 shows an overall configuration of the flight control law. The main functions of the control law are described below.

1) Core function

The core function improves the basic flying qualities of the helicopter and uses the explicit model following method as the control law. The configuration is shown in Fig. 4. This system includes a command model as a reference in the flight control law and effects controls to make the craft to follow the model. By this method, the core function enables the following:

a. Enhanced stability

The stability of a helicopter depends largely on the flying speed. The core function enables good stability at every speed, including low speeds, and in particular affords sufficient stability during a flight under IMC, using the feedback gains those are scheduled by the flying speed.

b. Elimination of the cross coupling between control axes

Due to the flying characteristics of a helicopter, if a control input is applied to a control axis, airframe movements at the other axes also occur simultaneously. This phenomenon is called a cross coupling between control axes. The core function eliminates this coupling, mainly by using the feed-forward gains those are scheduled by the flying speed.

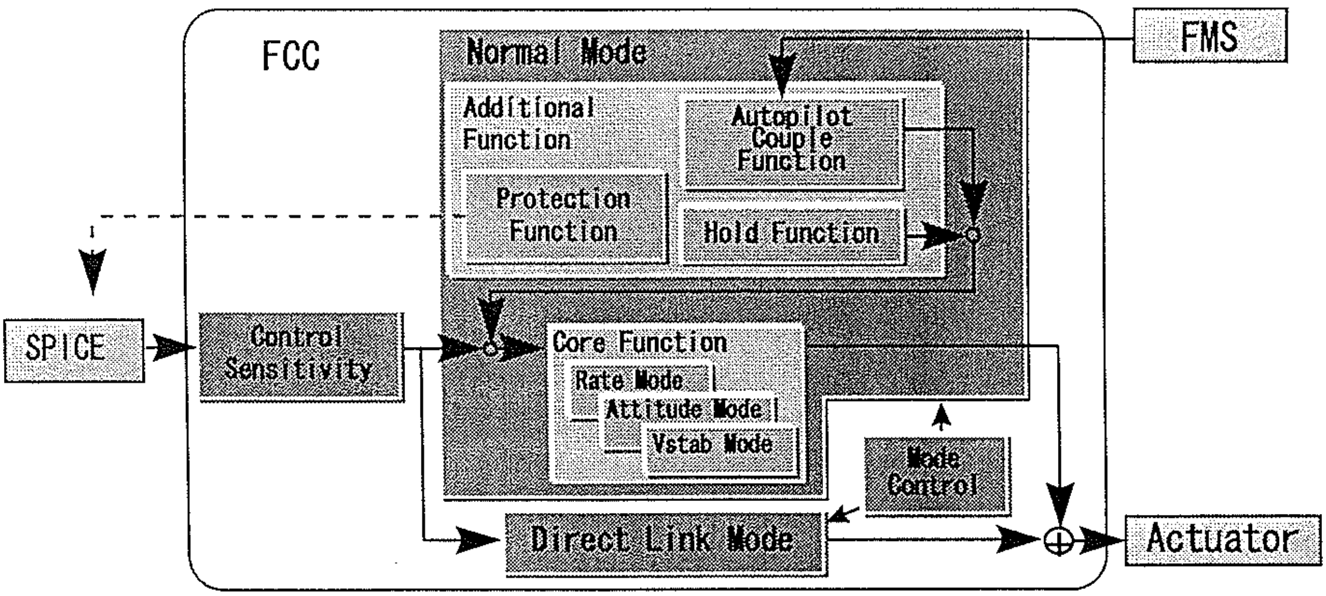

Figure.3 Function block diagram of the flight control law

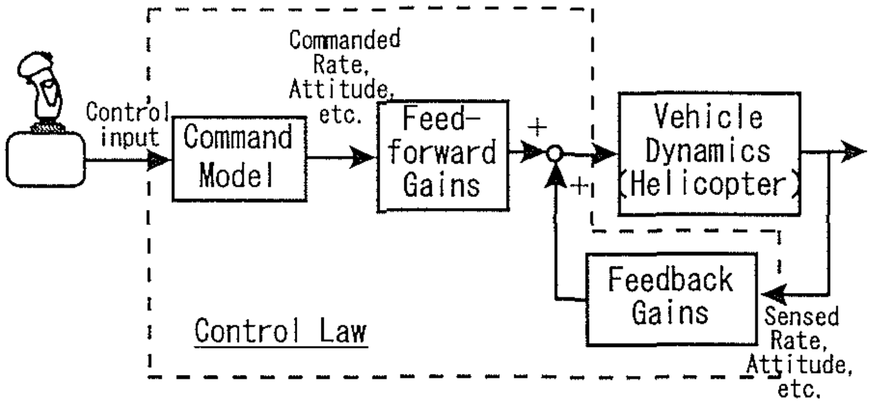

Figure.4 Configuration of the Core Function

c. Implementation of desirable response types

The core function has three control modes with different combinations of response types. The combination of response types for each axis in each control mode is shown in Table 1. The rate mode implements rate command attitude hold (RCAH); the attitude mode implements the attitude command attitude hold (ACAH); and the velocity stabilization mode (Vstab mode) implements the attitude command velocity hold (ACVH) and the attitude command attitude hold (ACAH). As shown in Fig. 5, each response type gives a different airframe response to the same control input. The different response types are compared here to determine which response type is suitable to operate civil helicopters.

Table.1 Combination of response types in Core Function

Mode	AXIS	LOW SPEED	HIGH SPEED
Rate	Pitch	Rate Command Attitude Hold	
	Roll	Rate Command Attitude Hold	
	Yaw	Rate Command	
	CP	Rate Command	
Attitude	Pitch	Attitude Command Attitude Hold	
	Roll	Attitude Command Attitude Hold	
	Yaw	Rate Command	
	CP	Rate Command	
Velocity Stabilization (Vstab)	Pitch	ACVH	ACVH
	Roll	ACVH	ACAH
	Yaw	Rate Command	Rate Command
	CP	Rate Command	Rate Command

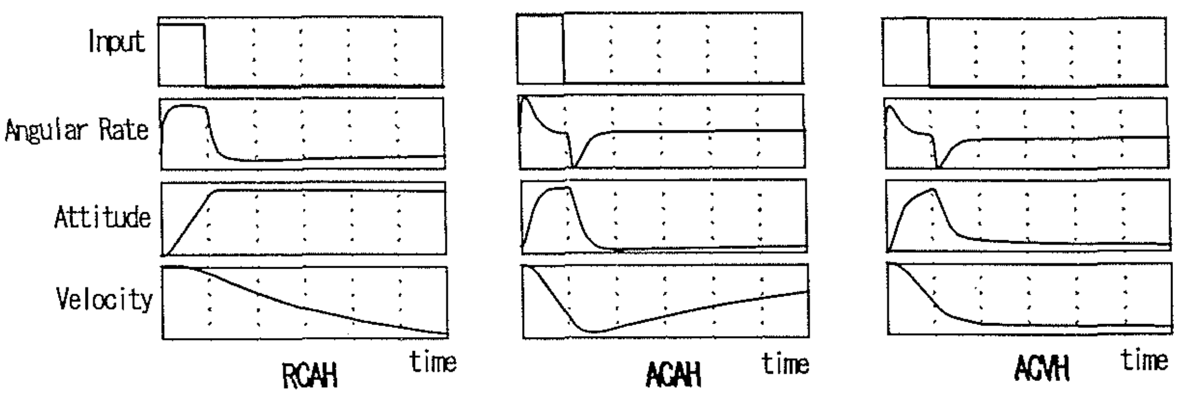

Figure.5 Control response of each response type in Core Function

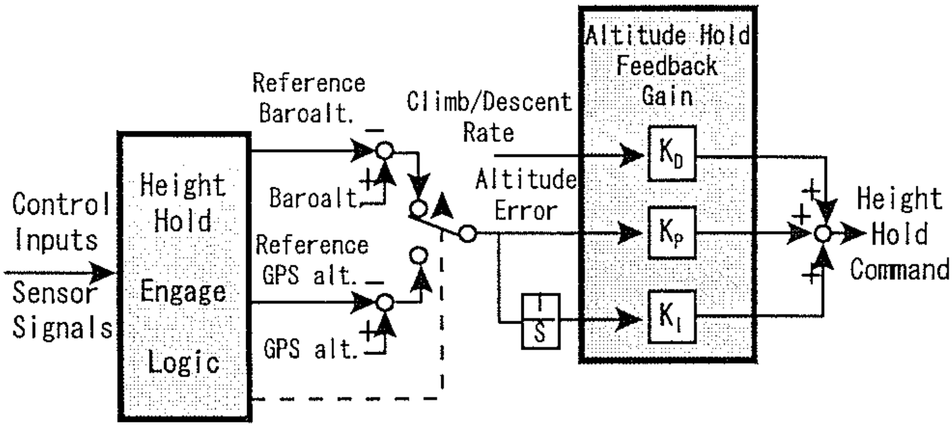

Figure.6 Block diagram of Hold Function

2) Hold function

The hold function, added to the core function to facilitate piloting further more, holds the flight conditions - heading, altitude, and the position during hovering. When they are engaged by switch input they holds those conditions as by feeding back deviation, deviation rate, and the integrated value of the deviation. Figure 6 shows a block diagram of height hold as an example of the control systems of the hold function.

3) Auto pilot couple function

The auto pilot couple function realizes automatic flight along a prescribed course by controlling the helicopter based on the reference values from the FMS. This function can be monitored intuitively from a back drive movement of the side stick according to the function output while the auto pilot couple function is in use. Furthermore, it is designed with an override that is activated when the pilot applies force to the control sticks; this function responds quickly to the pilot to avoid danger.

4) Protection function

The protection function sends an alarm to the pilot through a function of the side stick shaker which causes the stick to vibrate when flight conditions get near an operating limitation. The operating limitations that trigger alarms and the control axes are as follows:

a. Never-exceed speed (V_{NE}): Pitch axis
b. Main rotor torque: Collective pitch (CP) axis
c. Main rotor settling: CP axis

6. *RESULTS OF PILOTED SIMULATION*

The control law we designed includes various factors that cannot be evaluated by quantitative indices alone. In the piloted simulation, various data required for designing the control law were obtained by performing evaluations in pilot-in-the-loop simulations, where the pilot controls a helicopter in simulated condition. By performing sufficient piloted simulations prior to a flight demonstration, satisfactory performance, reliability, and safety can be established before starting the flight demonstration, which not only greatly reduces the duration of the demonstration but also ensures its efficiency.

The piloted simulations have been performed six times for this study, and the various data required to design the control law were obtained from the results of those tests. A simulated cockpit (Fig.7) for the piloted simulation was prepared and used in this study by connecting it to a dome-type flight simulator of Kawasaki Heavy Industries, Ltd. (KHI) (Fig.8).

Our primary evaluation results thus far are described below, based on the fourth to seventh basic piloted simulations.

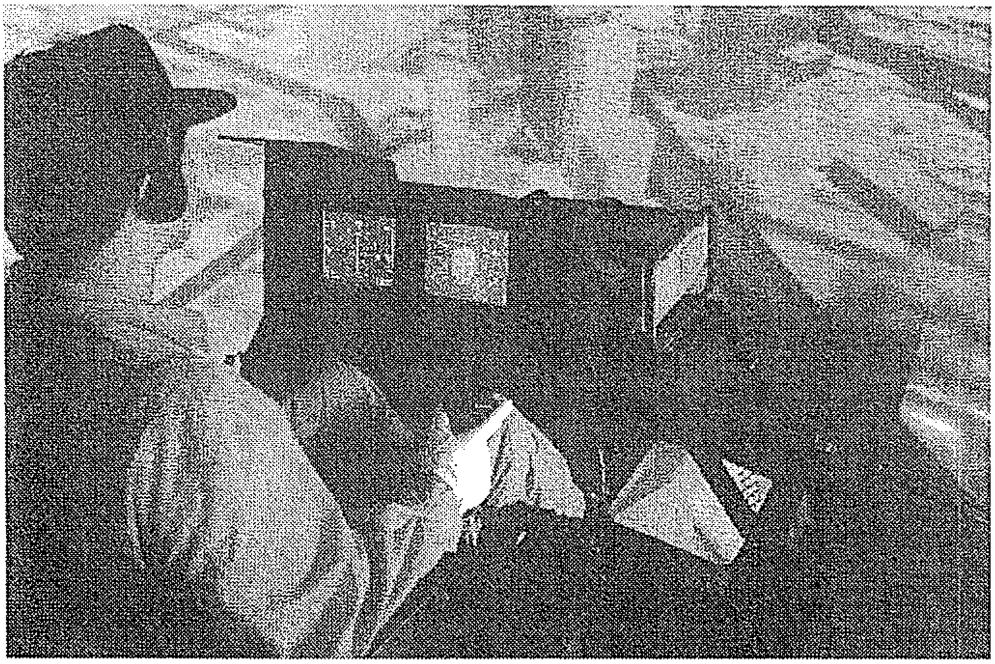

Figure.7 Simulated cockpit for piloted simulation

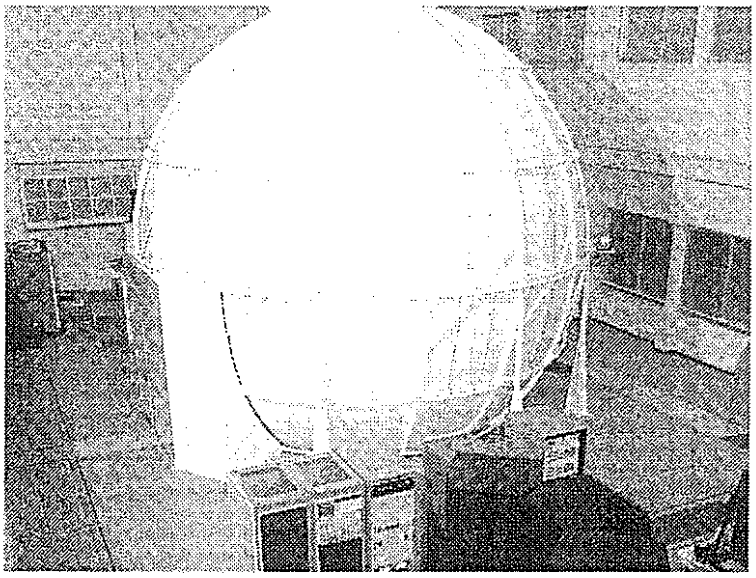

Figure.8 KHI dome-type flight simulator

6.1 Evaluation of the Core Function

To evaluate the core function, the same flight task was performed using each of the three control modes, and the features of those modes were compared. The contents and desired performance of the task were set based on the design requirements. We obtained the Cooper-Harper Pilot Rating, comments, and time histories of the flights from our evaluation results. The pilot rating and time histories from the core function evaluation results are shown in Figs. 9 and 10.These results indicate that the attitude and velocity-stabilization modes are more suitable for a low-speed flight task where precision control is required. A comprehensive evaluation, including the results from other tasks, suggested that the rate mode is more suitable for flight tasks that require high maneuverability; the velocity-stabilization mode is more suitable for tasks where stability, including speed hold, is required; and the attitude mode has an intermediate characteristic and is a control mode that is broadly applicable.

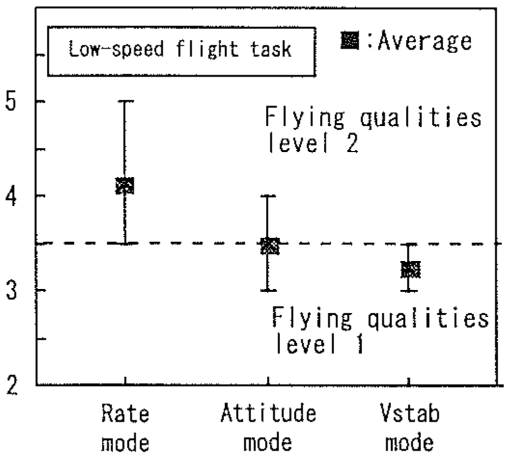

Figure.9 Pilot Rating of Core Function evaluation

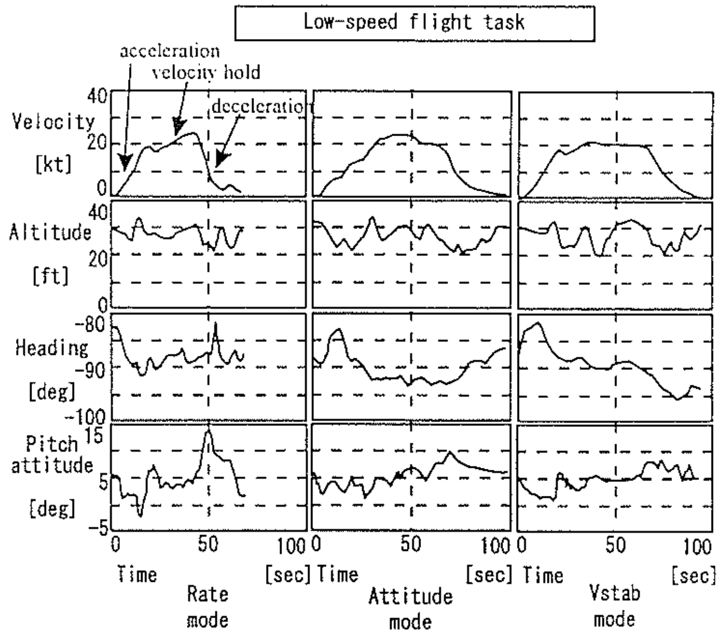

Figure.10 Time histories of the Core Function evaluation

6.2 Evaluation of the Hold Function

We evaluated the hold function by performing the same task in the same control mode of the core function with and without use of the hold function and then compared the results. The pilot rating is given in Fig. 11, and the time histories in Fig.12. Figure11 shows that while the flying qualities were between levels 1 and 2 in the flight without the hold function, the flying qualities rose to level 1 when the hold functions for direction and altitude were engaged. In addition, the time histories demonstrated that fluctuations in

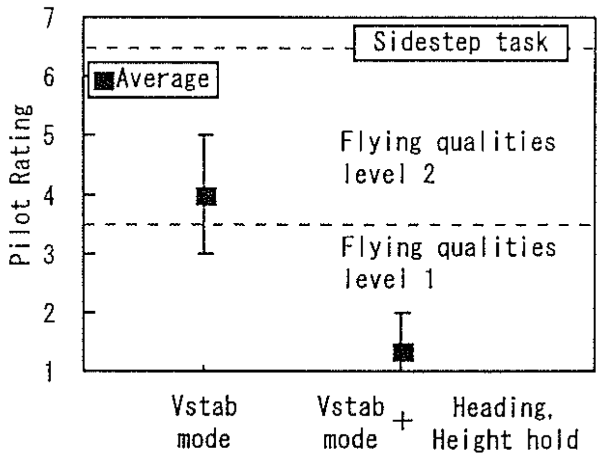

Figure.11 Pilot Rating of Hold Function evaluation

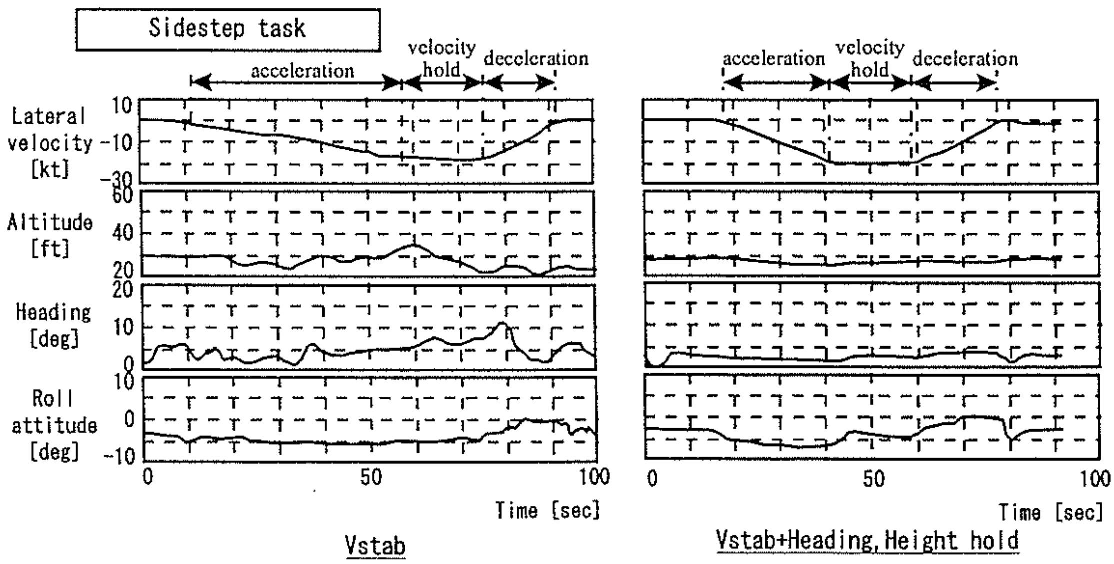

Figure.12 Time histories of the Hold Function evaluation

direction and altitude were suppressed to a low level when the hold function was engaged. Considering the evaluation results of other flight tasks, it is clear that use of the hold function will further improve the flying qualities.

6.3 Evaluation of IMC Tasks

We have evaluated how much the flight control law in this study will contribute to reduce pilot workload in IMC. The results for low speed climb and descent task in IMC are shown in Figs. 13. Comparing with the VFR results (shown in Figs. 14), pilot workload was not so high, and it was found that flying qualities level 1 was achieved by attitude mode and velocity-stabilization mode.

Figs. 15 shows the results for low speed flight task in IMC with and without hold function. It was confirmed that heading and height hold functions are very useful also for IMC tasks.

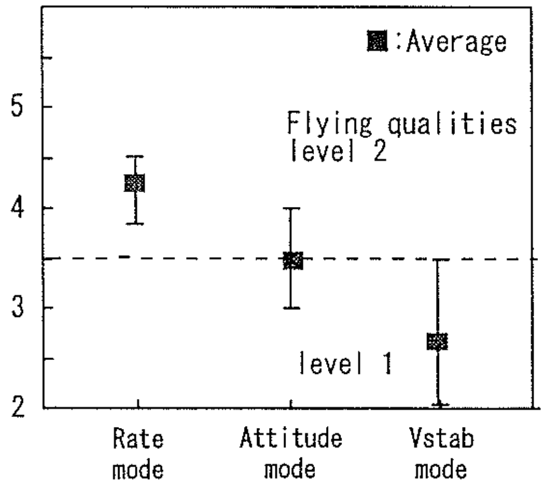

Figure.13 Pilot Rating of Low-speed climb and descent in IMC

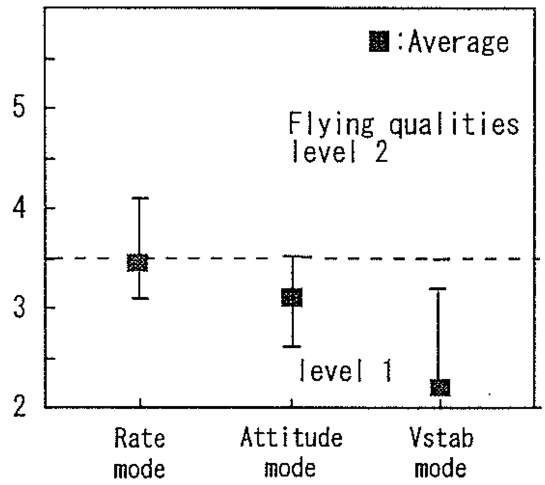

Figure.14 Pilot Rating of Low-speed climb and descent in VMC

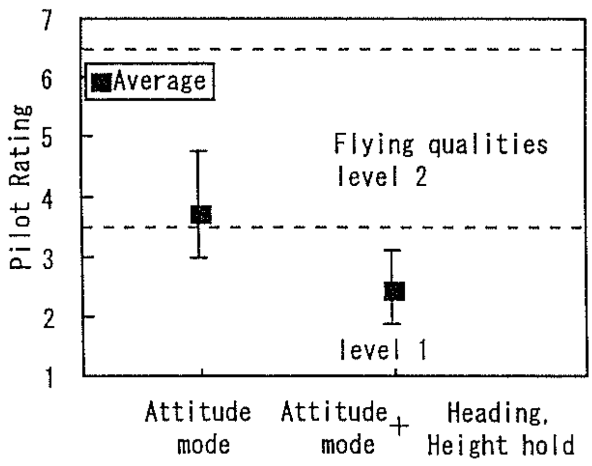

Figure.15 Pilot Rating of Law-speed flight task in IMC with and without Hold Function

7. CONCLUSIONS

In this paper, we described the flight control law for civil helicopters being developed by ATIC to reduce pilot workload. We prepared design requirements, considering the operation of civil helicopters, designed a flight control law based on those requirements, and evaluated the results of our design through piloted simulations. The following results were obtained:

1. Using the core function to improve the basic flying qualities can greatly reduce the pilot workload in piloting. The three control modes of the core function have different features and are suitable for different flight tasks.
2. Adding the hold function to the core function suppresses the direction and altitude fluctuations to a low level and thus further reduces the pilot workload.
3. Using the control law in this study, with the hold function added to the core function, greatly improves the flying qualities also for IMC tasks.

At present, we have roughly completed the flight control law design and evaluation, and are examining how much the improved flying qualities contributes to improve capabilities at a low speed/steep approach for civil helicopters, such as commuter helicopters. This control law will be subjected to ground tests and subsequent flight demonstrations from 1999 to 2000. We will report the results of these demonstrations in another opportunity.

8. REFERENCES

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