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DFVLR HELICOPTER IN-FLIGHT SIMULATOR FOR FLYING QUALITIES RESEARCH

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Abstract

New missions for civil and military helicopters lead to increasing higher demands in the field of flying qualities. The necessary research activities require extensive ground-based simulations and flight tests in particular. For flight testing operational helicopters and research helicopters with variable dynamic characteristics are used for specific tasks. In order to fulfill the research needs for future helicopter systems in-flight simulators will play an important role in flying quality research.

The intention of this paper is to discuss the need for and the tasks of an in-flight simulator for flying quality research with emphasis on DFVLR activities. The DFVLR in-flight simulator BO 105 ATTHeS will be described including the model following control system design and realization. First results of a ground-based simulation program and flight tests will be presented showing the efficiency of the concept and demonstrating the potential for future flying quality research.

1. INTRODUCTION

The increasing demands on and the complexity of future helicopter systems call for extensive simulation activities during the execution of research and development programs. In all the different tasks from phenomenon oriented investigations to helicopter certification programs various simulation methods and facilities are used having the common objective to improve and to optimize the systems. An additional goal is the reduction of development risk and costs.

In *Figure 1* the spectrum of simulation methods is quoted together with their main tasks. Due to the different tasks and objectives the application of all the simulation elements is of importance for helicopter research and developments (*Ref.1*). Because the different simulation methods serve in a complementary role the shift of specific tasks from one method to another will, in general, yield big disadvantages. In the past, many helicopter development programs, for example, tended to shift ground base and in-flight simulator tasks to prototype flight testing causing considerable disadvantages with respect to cost and duration of these flight tests. In addition, this proceeding includes the risk that the design optimum aimed at can no longer be attained at that time other than accepting considerable cost increases.

In the area of helicopter flying qualities, modern piloted ground-based simulators have become one primary tool for control and handling qualities engineers. The initial assessment of flying qualities of new designs, the preliminary design and evaluation of control system concepts including actual hardware, and the evaluation of hypotheses concerning flying qualities criteria are just a few examples of the many uses of ground-based simulators. The wide-spread potential of these facilities was highlighted in several papers (*Ref. 2-4*).

Obvious limitations of ground-based flight simulators have been the basis for extensive discussions. These limitations include restricted vertical and longitudinal motions and especially a narrow visual field-of-view. It is well-known that such deficiencies led to some faulty conclusions in the field of fixed-wing aircraft flying qualities (*Ref. 5*). This lesson was learned with aircraft having a much longer history of development and operational use than helicopters.

In view of the existing severe uncertainties of helicopter modelling and the very demanding operational environment it becomes clear that airborne research capabilities are required in many investigations concerning helicopter flying qualities. These capabilities include both operational helicopters and in-flight simulators providing variable stability and control characteristics. The use of operational helicopters for flying qualities research is highlighted in *Ref. 6*. As shown in *Figure 2* especially mission analysis, task performance evaluation, and the generation of so-called 'anchorpoints' for showing the credibility of in-flight simulator results are main tasks for operational helicopters in this respect.

For in-flight simulation a unique role complementary to other simulation methods is seen and will be demonstrated in this paper in the light of relevant DFVLR activities.

2. IN-FLIGHT SIMULATOR OBJECTIVES AND TASKS

The development and operation of in-flight simulators cause high cost in general. Therefore, it is essential to specify and to found the objectives and tasks in detail in order to establish the specific requirements for an in-flight simulator (*Ref. 7*).

In the following the main tasks of helicopter in-flight simulators in the field of flying qualities will be discussed.

2.1 In-flight validation of ground-based simulation results

The increasing application of ground-based simulators for research and development tasks requires the validation of the obtained results in consideration of realistic operational conditions as far as possible. Especially important in this respect are the pilot cues like visual, aural, and acceleration inputs as well as the realistic presentation of environmental influences like turbulence and ground effects. In addition, the effects of psychological factors on pilot behaviour have to be assessed. The relatively relaxed atmosphere in ground-based simulation tests may entail that the pilot operates with lower gain as he will do normally during flight tests. Therefore, critical flight control system problems may be not revealed during these tests. In the past, these effects were identified in several cases as main reason for large discrepancies between ground base simulator and flight test results (*Ref. 8*).

For obtaining valid results it must be guaranteed that both the in-flight and the ground-based simulator represent the almost identical dynamic behaviour. For that purpose precise mathematical models of the helicopter dynamics are required. In *Figure 3a* the development of mathematical models through system identification procedures is shown. The verification with flight test data not used for the identification (*Figure 3b*) demonstrates that all essential states showing excellent fit between flight test and computer simulation data (*Ref. 9*). The development and practical application of system identification techniques (already routinely used for fixed-wing aircraft) for helicopter research and development tasks is one main topic at DFVLR-Institute for Flight Mechanics.

2.2 Handling qualities investigations, development of new criteria

The existing handling qualities criteria, especially for military applications, are no longer suitable as a design guideline and for the evaluation of new helicopter projects. Therefore, the U.S.-Army initiated a program having the objective to develop new missionoriented handling qualities criteria (*Ref. 10*). Experience in previous efforts to revise the handling qualities criteria showed that the primary handicap to develop new requirements was the lack of systematic data from which new criteria could be developed and substantiated. In order to expand the data base and to obtain generally valid results systematic tests are required using ground-based simulators, operational helicopters, and especially variable stability helicopters. This data generation seems to be both very important and voluminous requiring the cooperation of all institutions having relevant experimental capabilities.

Key contributions to be made by in-flight simulators include:

Control system/display relationship

Several studies (*Ref. 11,12*) have shown a number of years ago that for constant pilot workload a tradeoff exists between control system complexity and cockpit display sophistication. In other words this hypothesis (*Fig. 4*) says that a very advanced pilot information system could compensate for a degraded flight control system and a very advanced flight control system would minimize the need for display sophistication. Together with the practical consideration of cost, which normally increases with sophistication, these relationship seems to be very essential for the design of future helicopter systems. There are many and good arguments for the general validity of this hypothesis but, there are only a few missionoriented flight test data available for the design engineer or for the development of generic requirements.

Control response characteristics

There is a lack of data for specification of control system response types necessary to guarantee level 1 handling qualities for specific missions in varying environmental conditions. Possible control system responses include acceleration, rate, attitude, and translational rate response (*Ref. 13*). For this control augmentation hierarchy the required response criteria parameters like bandwidth, time delay, damping ratio, controller sensitivity, and command gradient have to be defined for both center and side stick controllers.

Cross-coupling

Control and vehicle cross-coupling characteristics have fundamental influence on pilot workload and task performance. The data available from ground-based simulation programs needs to be verified using flight test data. In addition, new data generated in realistic operational environment are necessary for specification of the requirements.

Degraded handling qualities

An important aspect of the development of new criteria that was sometimes overlooked in the past is the determination of boundaries defining minimum acceptable standards for civil criteria, or to meet level 2 and 3 of military flying qualities specifications. Up to now there exists very few data to specify limitations on degraded handling qualities following failures in control systems and vision aids (*Ref. 14*). These boundaries seem to be very sensitive on the operational environment and therefore tests using in-flight simulators are required.

2.3 Support for helicopter design and development

The application of in-flight simulators to support new developments in the rotorcraft industry was up to now limited. This fact is certainly connected with the limited number of helicopter in-flight simulators which are available providing adequate equipment and with the inadequate recognition of the potential of these general-purpose flight research facilities in the past.

The increasing importance for integration of pilot, helicopter, and equipment requires thorough utilization of different simulation facilities. In particular in-flight simulators are needed at an early stage of new helicopter developments for systematic studies and improvements of both specific helicopter characteristics and pilot/helicopter interrelation.

Key contributions are expected especially in the following fields:

- Basic design parameter investigation
- Pre-production design verification
- Flight control system development
- Hardware in-flight testing

- Simulation of system failure states
- Pre-first-flight pilot training
- Support during certification procedure

The discussion of the various tasks points out that it will not be possible to produce all data needed with only one type of in-flight simulator. Instead, carefully planned investigations in the different fields using facilities with complementary capabilities are required to generate data with a high level of confidence.

3. LIMITATIONS FOR IN-FLIGHT SIMULATORS

Dependent on the characteristics of the basic helicopter, the equipment installed, and the operational conditions the capabilities of in-flight simulators are limited. The exact knowledge and the consideration of these limits are supposed to be essential pre-requisites to conduct successful flight test programs.

Basic Helicopter

The possibility to simulate the dynamic response characteristics of other helicopters in specific flight regions is restricted by the flight envelope, the control power available in each axis, and the bandwidth of the control system of the basic helicopter. *Figure 5* shows the control power of different helicopter types in pitch and roll axes. This diagram illustrates that helicopters with hingeless rotor systems like BO 105 are especially suitable for in-flight simulators with respect of the control power available. However, the inherent interaxis couplings of these rotors require a level of performance from the variable stability control system that is difficult to achieve.

Equipment

The in-flight simulator must be able to assume the dynamic characteristics of the other helicopters with adequate accuracy. Normally this will be achieved by a variable stability control system combined with a high-authority fly-by-wire system impressing the required dynamic characteristics on the basic helicopter.

In general, control of the dynamic response characteristics is accomplished using either response feedback and control feedforward techniques, or model following systems. The comparison of both techniques (*Ref. 15*) demonstrates essential advantages for the model following control system, particularly due to the capability to suppress real turbulence effects and to introduce simulated turbulence including wind-shears without manoeuver response. In addition, this method is very flexible and allows for quick and easy adaptation to helicopters with different dynamic characteristics.

Dependent on different factors like model bandwidth, sample time of the control system etc. it is not possible to realize the exact dynamic model characteristics with the in-flight simulator. Therefore, quantitative analysis is required to estimate and evaluate the actual simulation performance with regard to the specific test program (*Ref. 16*).

Particular attention must usually be paid to the in-flight simulator's instrumentation system for high accuracy motion measurements including low airspeed data. In addition, the controls and information systems or displays in the simulation pilot's cockpit have to be very flexible to allow for simulation adaptation to different test programs.

Because only four controls are normally available in a helicopter, the motion can be independently controlled only in four degrees-of-freedom. The realization of a six degree-of-freedom helicopter in-flight simulator asks for additional longitudinal and lateral force-generating capabilities, and therefore it seems to be very difficult and costly, if required in the total flight envelope (*Ref. 17*). The limitations arising from this point influence the longitudinal and lateral motion and in addition, the turbulence response characteristics of the simulator.

Flight operation

Severe restrictions in the in-flight simulator's flight envelope may be caused by flight safety aspects. In general, it will be inadmissible and has to be avoided to operate extremely close to the ground using a simplex fly-by-wire control system only. The reasons for that are of course the lacking redundancy in case of failures in the system, but in addition, the impairment of the evaluation pilot's behaviour by his knowledge of the safety critical situation. By means of thorough training programs for the safety pilot the flight safety can be improved substantially. This includes the simulation of critical system failures in safe altitudes and the subsequent taking over the controls from the evaluation pilot to the safety pilot who recovers the helicopter. In this respect, the safety features incorporated in the in-flight simulator are of decisive consequence. Very essential devices are: (1) An automatic safety trip that disengages the variable stability system if a system failure occurs or if a sensor measurement exceeds a level corresponding to a structural or flight condition limit, (2) a control monitoring system which supports the safety pilot to diagnose a failure status.

In *Figure 6* BO 105 flight test data are presented, demonstrating the runaway of one fly-by-wire actuator during an evaluation flight and the subsequent taking over and recovery by the safety pilot. The evaluation of the data produced in this program showed that only slight losses in altitude take place following a failure during manoeuver flights if the safety pilot is well trained. Nevertheless, aggressive manoeuvers extremely close to the ground (below 100 ft) are safety critical using a simplex fly-by-wire system only.

The improvement of the control system to a redundant duplex system, as proposed for fixed-wing in-flight simulators, is not really satisfying for helicopters. Dynamic manoeuvering close to the ground is not covered by the fail-passive characteristics of the duplex system. To avoid safety critical operations in the total flight envelope a triplex system is required, including the fly-by-wire system, the control system, and related sensor signals.

For successful conduction of a flight test program comprising different dynamic characteristics of an in-flight simulator, the status of training of the evaluation pilot is very essential. In view of the experimenter's ambition to involve many evaluation pilots in his program and in addition, considering the high operating costs for an in-flight simulator it is required to monitor the evaluation pilot's training status. *Figure 7* demonstrates one possible procedure used at DFVLR. This method includes the pilot's adaptation to both, the helicopter characteristics and the flight task. In this respect, the absolute value of the score factor is of lower importance while the differences between two runs seem to be essential.

4. DFVLR IN-FLIGHT SIMULATOR BO 105 ATTHES

For flying qualities evaluations under operational conditions with regard to future helicopter systems including different integrated subsystems the research helicopter BO 105-S3 is operated at DFVLR-Braunschweig. The helicopter provides a fly-by-wire control system and is just being equipped to the in-flight simulator BO 105 ATTHeS (Advanced Technology Testing Helicopter System).

Basic System

The basic helicopter BO 105 S-3 corresponds in all essential components to the serial helicopter MBB BO 105 with the exception of the control system (*Ref. 18*). The modified system requires a two-man crew for simulation flights. The safety pilot, who occupies the left hand back seat, is provided with a direct link to the primary helicopter controls through the standard mechanical/hydraulic control system.The evaluation pilot, seated in the center in front of the cockpit, has conventional rudder pedals, a control stick and power lever, however the link between these and the helicopter controls is a purely electrical one. A simplified schematic diagram of the control system is shown in *Figure 8*. The hydraulic actuators of the fly-by-wire system are full-authority and non redundant (Simplex FBW-System). When the fly-by-wire system is engaged, the actuators operate in a electrohydraulic mode with mechanical feedback to the safety pilot's controllers. The safety pilot can override the fly-by-wire system by applying a specific force to the appropriate controller. The system can be disengaged by both the simulation pilot or the safety pilot. In addition, the fly-by-wire system can be disengaged by a safety system dependent on pre-set limitations in selected sensor signals. In the disengaged mode the safety pilot has exclusive control and the system operates in response to his mechanical input identical to the conventional helicopter.

Model Following Control System (MFCS)

For realization of variable stability characteristics a model following control system was designed (*Ref. 19*). In a typical MFCS the pilot's commands are disconnected from the actual aircraft and fed into a model. This model represents the equations of motion of the aircraft to be investigated. The errors between the states of the model and those of the base system are fed into the control system, which attempts to minimize the state errors by generating control signals for the actuators. If the state errors are always zero, the controlled vehicle exhibits the dynamics of the model.

The block diagram of the designed MFCS is shown in *Figure 9*. As mentioned above, the number of states to be followed must equal the number of controls available. The outer feedback loop is used to feed back the helicopter attitudes, and the inner loop feeds back the helicopter rates. The selected inner-loop and outer-loop helicopter states are then compared with the corresponding four model states and the resulting error vector is fed into the controller matrix. The controllers used are feed-forward gains calculated using a non-realtime identification procedure which incorporates a linearized version of the simulation model. In addition, the elements of the controller matrix are adjusted with airspeed to improve the accuracy and robustness of the system.

In order to evaluate the performance and limitations of the DFVLR-designed MFCS and to qualify the system for use in helicopter flight research, a U.S./German simulation experiment was conducted on a ground-based simulator at NASA Ames Research Center. This joint research program was part of the U.S.-Army/DFVLR cooperation under the Memorandum of Understanding on Helicopter Flight Control.

To demonstrate the performance of the MFCS a linear decoupled model of the BO 105 and with that a very demanding task for the control system was chosen in course of the simulation experiment. The pilot commands pitch attitude with longitudinal cyclic, roll attitude with lateral cyclic, yaw rate with pedals,and earth-fixed downward velocity with collective. Since the decoupling effects of the MFCS are very pronounced in the dolphin task, time histories of that task are used to illustrate the results. The control strategy the pilots were instructed to follow was to use primarily collective inputs to perform the task and to minimize deviations in airspeed, heading, pitch attitude, and roll attitude with the remaining three controls.

Figure 10a illustrates the effects on pilot's control activity for the 60 kt dolphin task. For the unaugmented BO 105 the pilot used as instructed the collective as the primary control but in addition, he needed all other controls to compensate coupling effects. The identical task was flown with the BO 105 augmented with the MFCS. The time histories indicate that the pilot needed only the collective control to perform the task.

A comparison of the BO 105's states, with and without MFCS, during these same dolphin evaluation runs is shown in *Figure 10b* . In general, the criterion for acceptable model following performance is based on the error between the commanded and measured response. Maximum errors of 5 deg/sec in yaw rate, 7.2 deg in pitch attitude, and 9.6 deg in roll attitude were observed for the unaugmented BO 105. These errors reduced to 2.4 deg/sec, 1.8 deg, and 3 deg in yaw rate, pitch attitude, and roll attitude, respectively, for the augmented BO 105. In addition, the airspeed errors went from 5 knots in the uncontrolled case to nearly 0 knots in the controlled case. This result shows that without wind and turbulence the desired flight path and airspeed were held constant, even though those parameters were not commanded directly by the MFCS.

For accurate evaluation of the performance of the MFCS a quantitative measure was developed and used in the simulation experiment (*Ref. 16*).

Overall System BO 105 ATTHeS

For application in the helicopter the MFCS will be installed in a distributed onboard computer system based on LSI 11 components. The parallel processing of partial problems in three processors allows to meet the high demands with respect to computing speed. The data computer (DSR) is mainly used for communication between the processors and for data handling. The controllers are implemented in the control computer (RR), which in addition, is used for signal monitoring and limiting. The simulation model is installed and will be processed in the user computer (USR).

After integration of the computer system and the data acquisition system (*Ref. 20*) in the helicopter BO 105-S3 the in-flight simulator BO 105 ATTHeS will be completed in its main components. *Figure 11* shows a simplified block diagram of the overall system. For adaptation to specific test programs additional sensors and cockpit equipment will be installed. *Table 1* summarizes the characteristics and the hardware of the system.

System Simulation

For development, preparation, and pre-flight check of software and real hardware components used in the in-flight simulator a system simulator will be assembled. For this purpose the basic helicopter including the fly-by-wire system and the sensor system will be simulated in realtime on a multiprocessor system Applied Dynamics Inc. AD 10. The onboard computer system including the MFCS software and the signal conditioning system as used in the in-flight simulator will be integrated and linked to the simulation computer (*Ref. 21*). In *Figure 12* the overall concept of the system simulator is shown.

This ground-based simulation system will be realized using the existing simulation facilities for the DFVLR fixed-wing in-flight simulator ATTAS (Advanced Technology Testing Aircraft System) (*Ref. 22*).

5. FIRST RESULTS AND FUTURE PLANS

The in-flight simulator BO 105 ATTHeS as described in the preceding section will be operational in 1985. However, first flight test data was generated during pre-tests for MFCS realization and especially during an extensive flight test program using the fly-by-wire helicopter BO 105-S3 as a variable control vehicle.

Figure 13 shows first flight test data produced for demonstration of the model following control system performance. The measured time histories illustrate the success in decoupling the helicopter as required by the simulation model used in this tests. With the augmented BO 105 the pilot needs only the collective controller for performing the climb. As mentioned above, in the meantime the MFCS was optimized and qualified for operational application through an extensive ground base simulation program.

One of the main objectives of the flight test program using the BO 105-S3 as a variable control helicopter was the investigation of control moment effects with respect to handling qualities evaluation. *Figure 14* presents some time histories for a 60 kt NOE slalom task in 100 ft above ground which was the minimum altitude during this test program.

The data shows differences in pilot's control activity and task performance (esp. roll angle) for the original BO 105 control system compared with the control system having reduced control sensitivity in longitudinal and lateral stick. The analysis of this data together with the obtained pilot ratings and comments represent a data base for the evaluation of specific helicopter characteristics (control sensitivity) with regard to a specific task (NOE slalom).

After completion of the in-flight simulator BO 105 ATTHeS different flight test programs are planned especially in view of data generation for new missionoriented handling qualities criteria (Revision MIL-H-8501 A). This midterm planning includes flight tests for the investigation of coupling effects and different control laws during various NOE manoeuvers using both center stick and side stick controllers.

For the expansion of the in-flight simulator's flight envelope especially in view of the realization of flights extremely close to the ground it is planned to equip the helicopter with a redundant fly-by-wire system.

In addition, the realization of an operational in-flight simulator on the basis of the helicopter BK 117 is planned in cooperation with MBB for the near future (*Ref. 23*). The application of this facility is mainly intended for tasks in the areas of development, testing, and integration of new technologies with regard to development and certification of future helicopter systems.

6. CONCLUDING REMARKS

Helicopter in-flight simulators will be an increasingly useful tool for future flying qualities research and new developments in the rotorcraft industry. These facilities will serve in a complementary role to ground-based simulators. Due to inherent limitations it will not be possible to meet all the objectives with only one type of in-flight simulator.

On the basis of many years of experience with a fixed-wing in-flight simulator DFVLR is completing a helicopter in-flight simulator BO 105 ATTHeS. Ground-based simulation and first flight tests using a new designed model following control system show excellent overall performance. The new in-flight simulator will be used among others to support the development of missionoriented handling qualities criteria.

Future DFVLR plans include significant improvements and expansion of the simulation flight envelope for the in-flight simulator BO 105 ATTHeS. In addition, the realization of an operational in-flight simulator on the basis of the helicopter BK 117 is under discussion.

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Flight envelope of basic aircraft	-20 kt to 120 kt longitudinally 25 kt in lateral flight
Rotor system	Single hingeless rotor
Basic controls available	Longitudinal cyclic Lateral cyclic Main rotor collective Tail rotor collective
Control power levels	
Hover, altitude 1500m, INA	
$\ddot{x}$ due to long. stick	-0.2 m/s^2 per deg.
$\ddot{y}$ due to lat. stick	+0.26 m/s^2 per deg.
$\ddot{z}$ due to collective	-1.4 m/s^2 per deg.
$\dot{p}$ due to lat. stick	+2.4 $1/s^2$ per deg.
$\dot{q}$ due to long. stick	+0.85 $1/s^2$ per deg.
$\dot{r}$ due to tail rotor	-0.19 $1/s^2$ per deg.
Cruise (200 km/h), altitude 1500m, INA	
$\ddot{x}$ due to long. stick	-0.2 m/s^2 per deg.
$\ddot{y}$ due to lat. stick	+0.26 m/s^2 per deg.
$\ddot{z}$ due to collective	-1.4 m/s^2 per deg.
$\dot{p}$ due to lat. stick	+2.4 $1/s^2$ per deg.
$\dot{q}$ due to long. stick	+0.85 $1/s^2$ per deg.
$\dot{r}$ due to tail rotor	-0.19 $1/s^2$ per deg.
Thrust/Weight ratio in hover	1.3 for hover o.g.e. in s.l. with max. power and normal operating weight
Variable stability system actuator characteristics	Electrohydraulic actuators, 4-axes, 100% authority, bandwidth 10 Hz, Stop-to-stop travels achieved within 0.82 sec.
Control system monitoring	safety pilot monitors control rate and position
In-flight simulation method	Model-Following Control System (MFCS)
Instrumentation	
Motion sensing system	pitch, roll, yaw } gyros pitch, roll, yaw } rate gyros long. accel., lat. accel., vert. accel. } accelerometers (CG and pilot station) u, v, w low airspeed system
Guidance and navigation system	Flight Director, Doppler
Cockpit	Two-man cockpit (Simulation pilot, Safety pilot)
Computational capacity	3 PDP computer (0.7 MByte)
Data recording	Magnetic tape (on-board or ground station)

Table 1 Characteristics of the BO 105 S-3 In-Flight Simulator

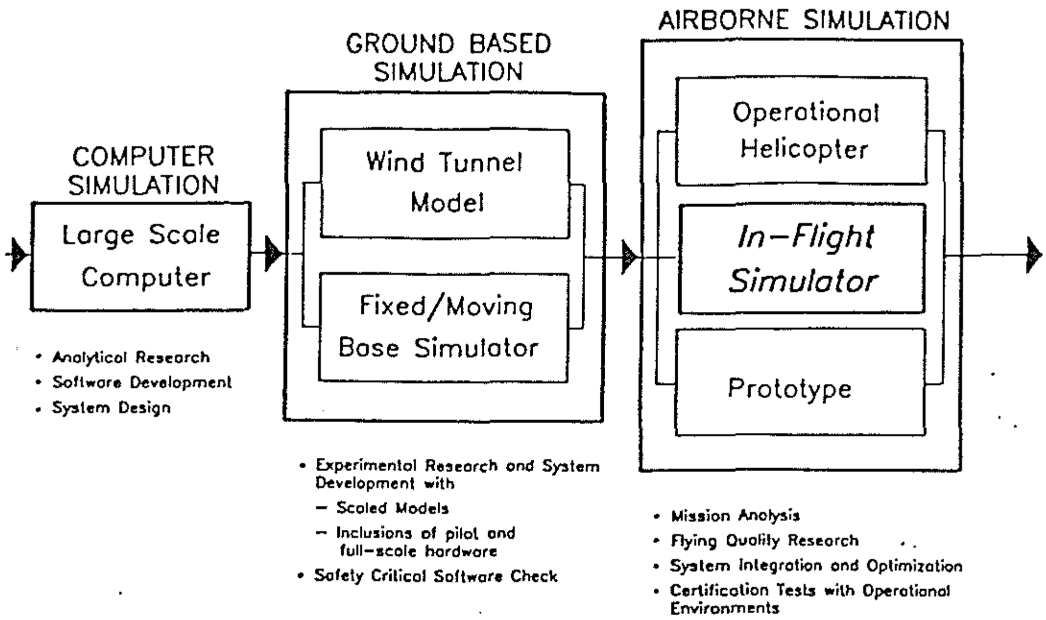

Figure 1 Simulation for Research and Development

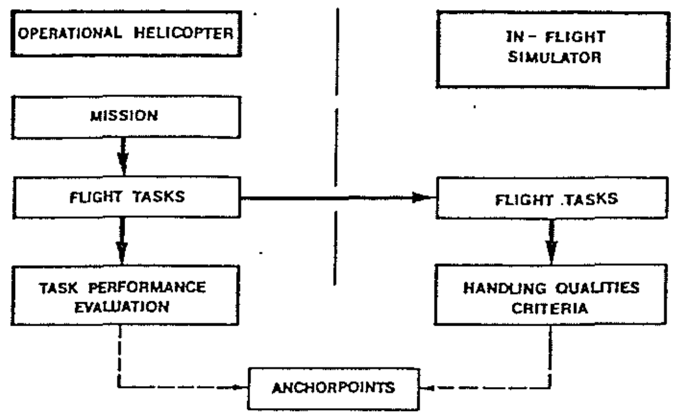

Figure 2 Generation of Flying Qualities Data Base

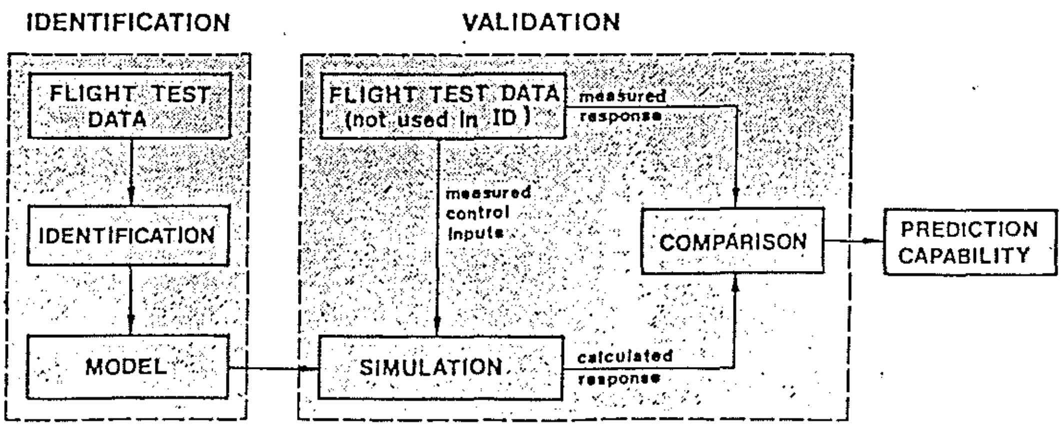

Figure 3a Development of Mathematical Models

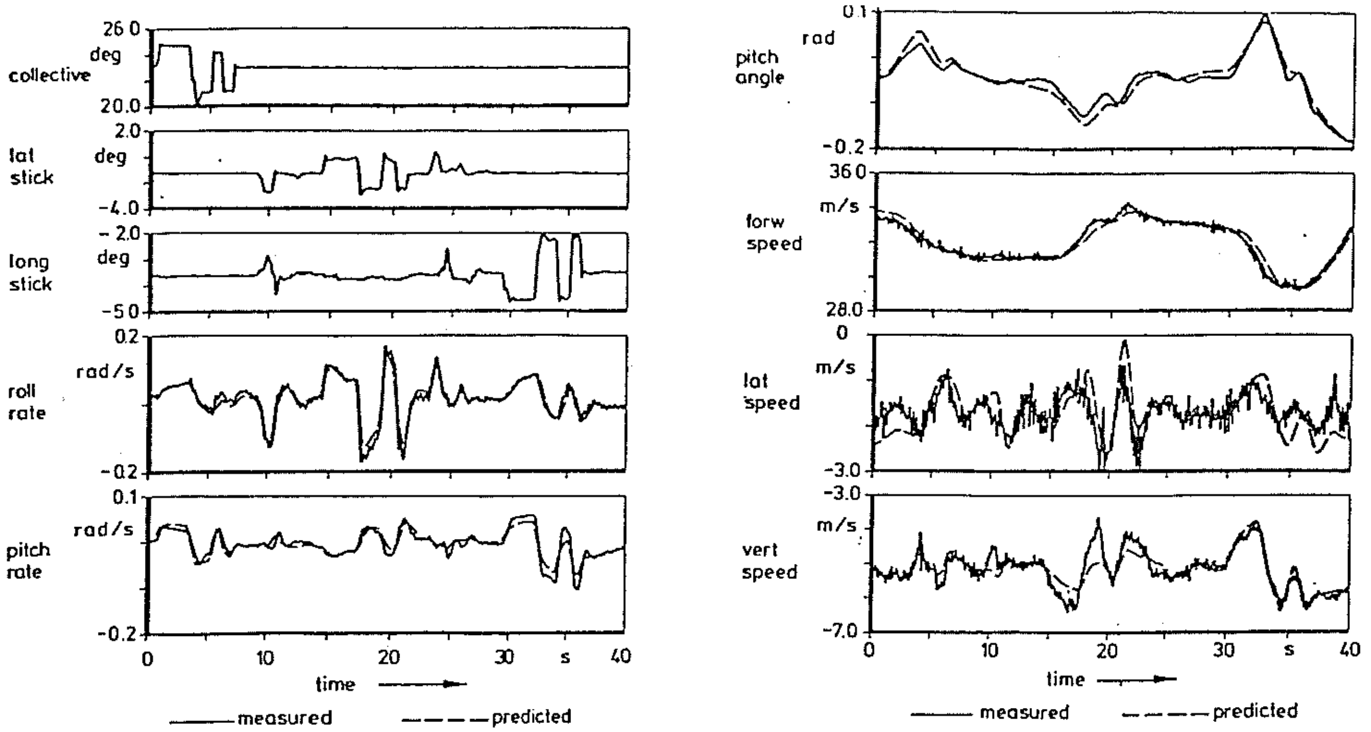

Figure 3b Verification of Identification Results (Data not used for the Identification)

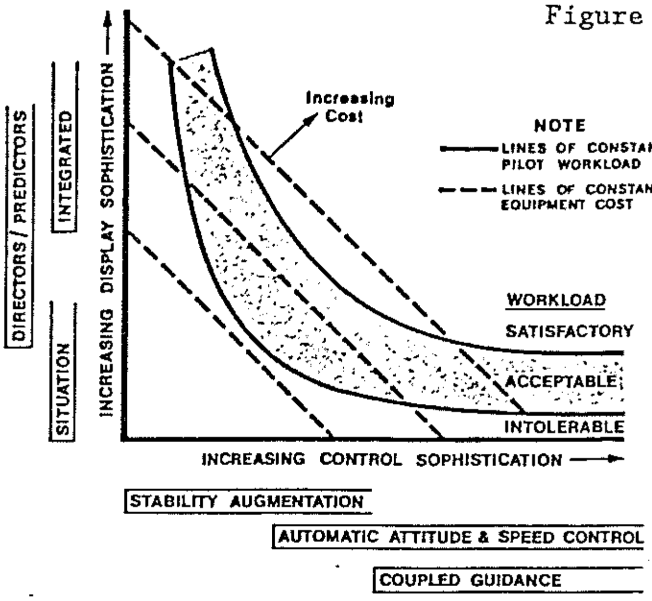

Figure 4 Hypothesis for Control System/Display Tradeoff

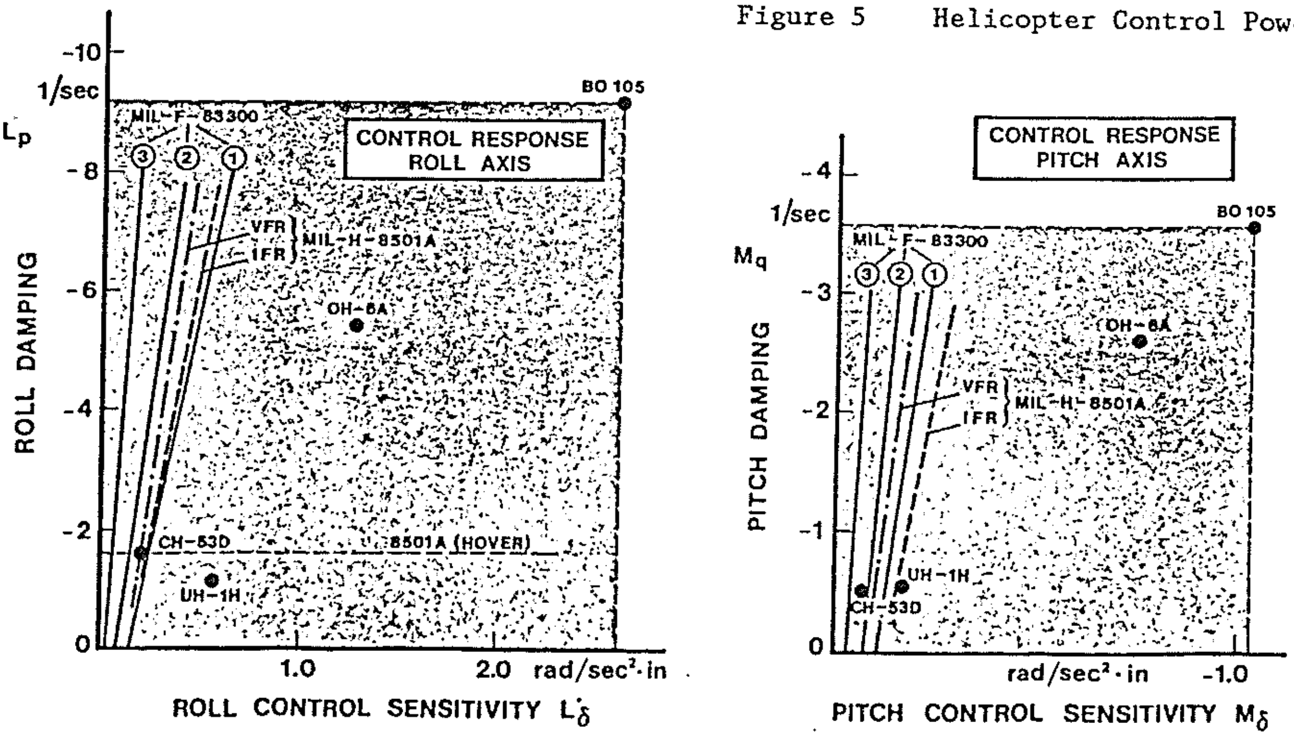

Figure 5 Helicopter Control Power

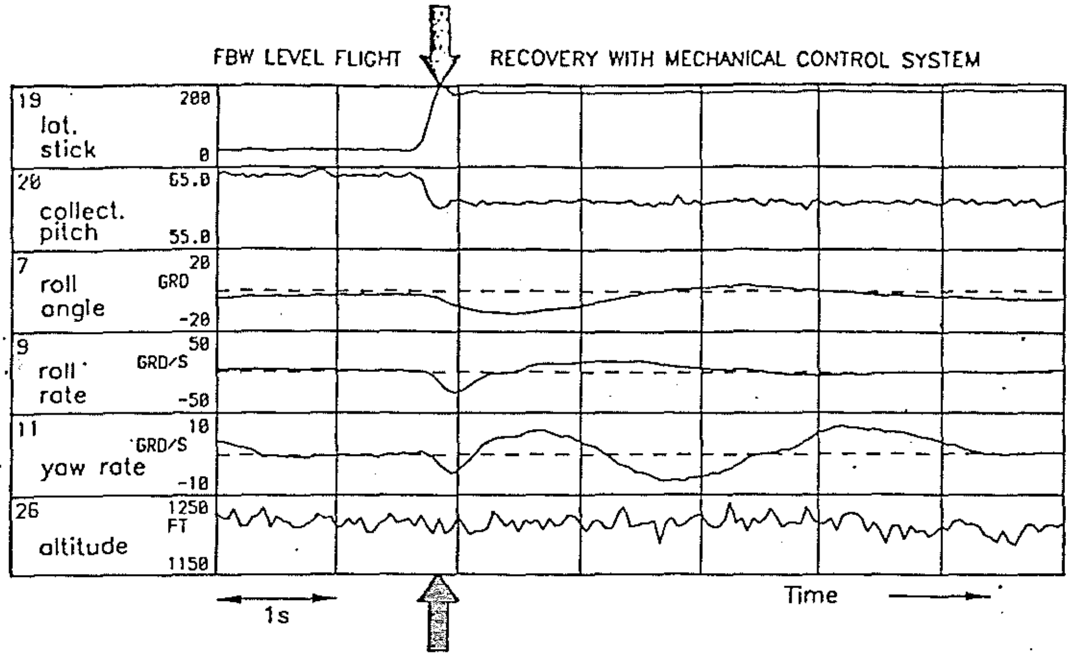

Figure 6 Fly-by-Wire Actuator Runaway

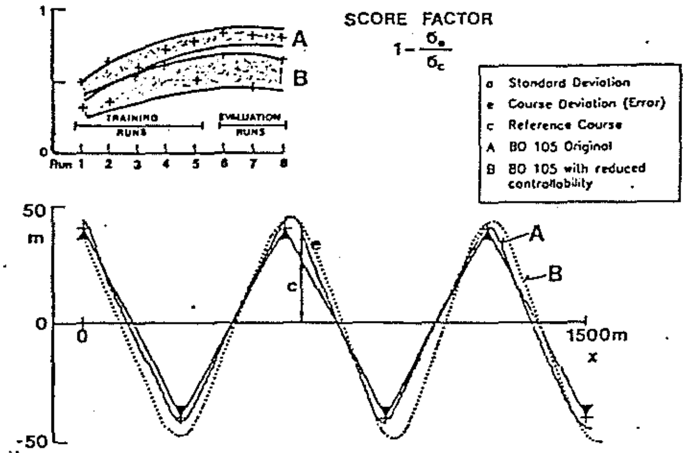

Figure 7 Check of Pilot Training Status

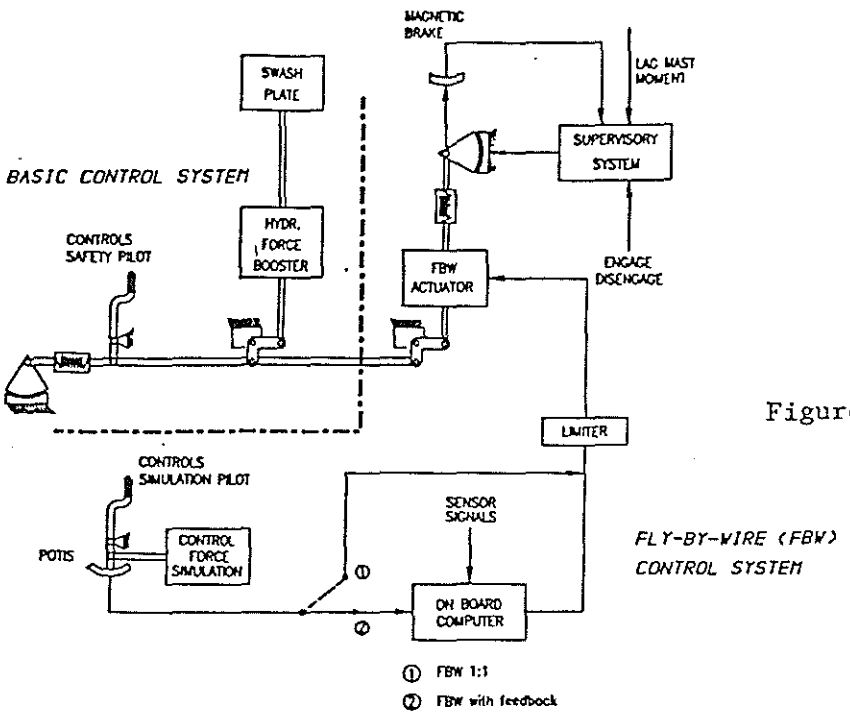

Figure 8 BO 105 S-3 Control System

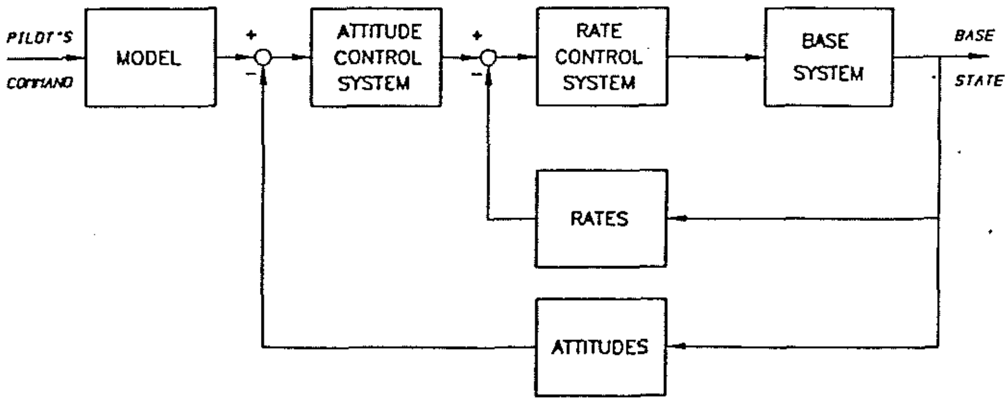

Figure 9 Model Following Control System

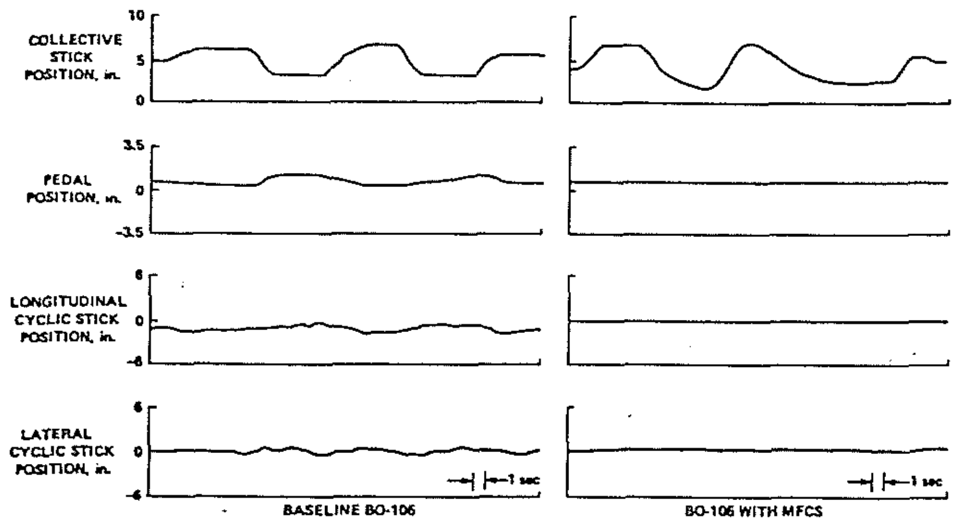

Figure 10a Comparison of Pilot's Control Activity (60 kt Dolphin)

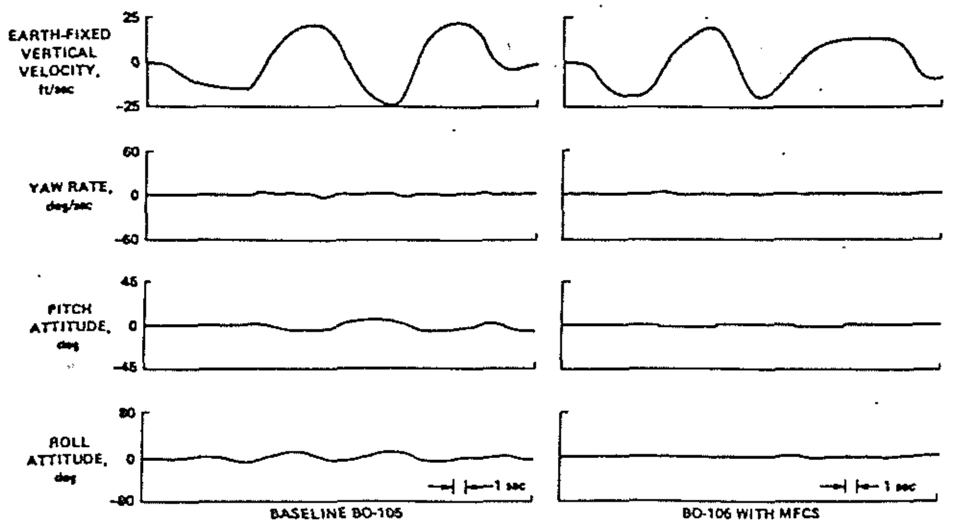

Figure 10b Comparison of States (60 kt Dolphin)

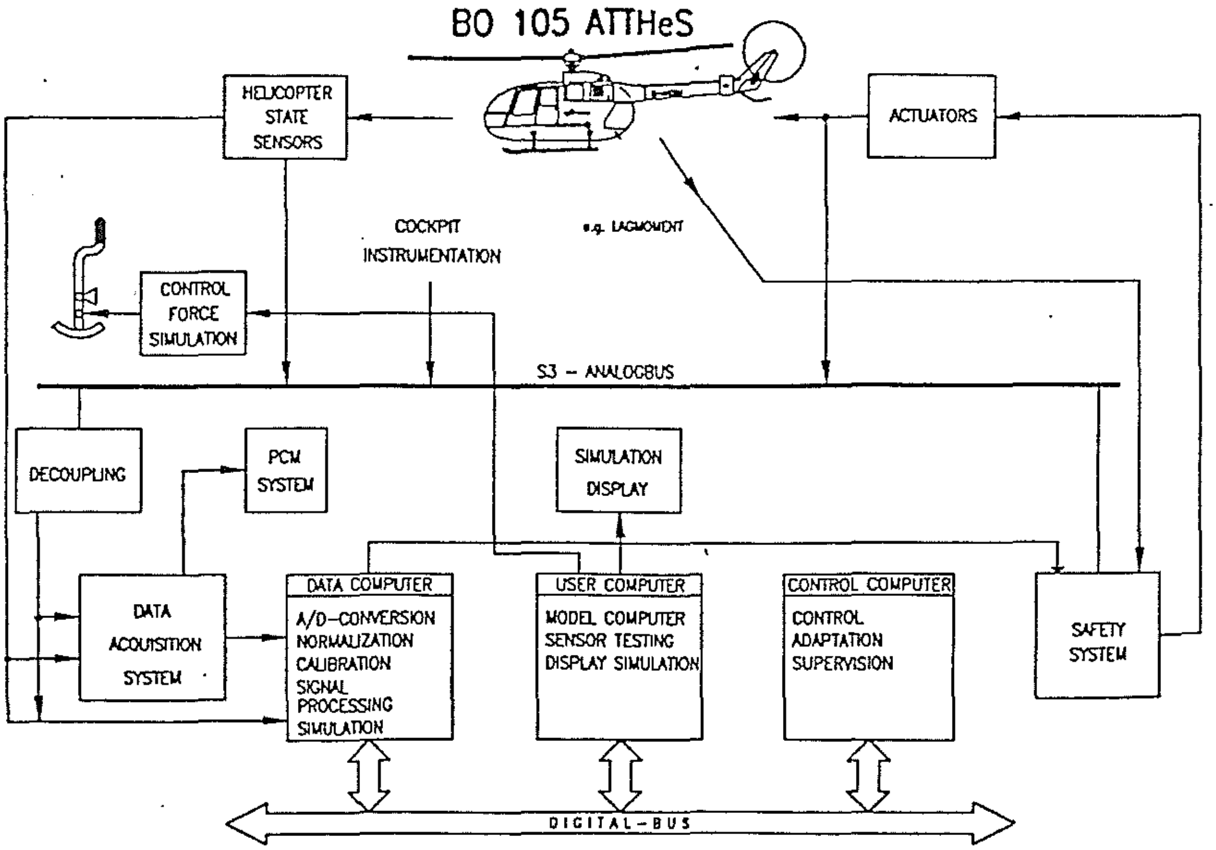

Figure 11 Overall System BO 105 ATTHeS

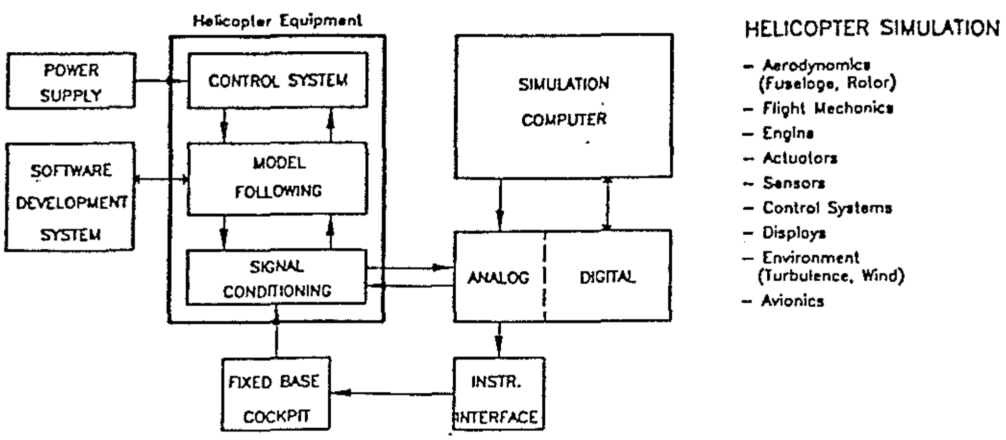

Figure 12 System Simulator for BO 105 ATTHeS

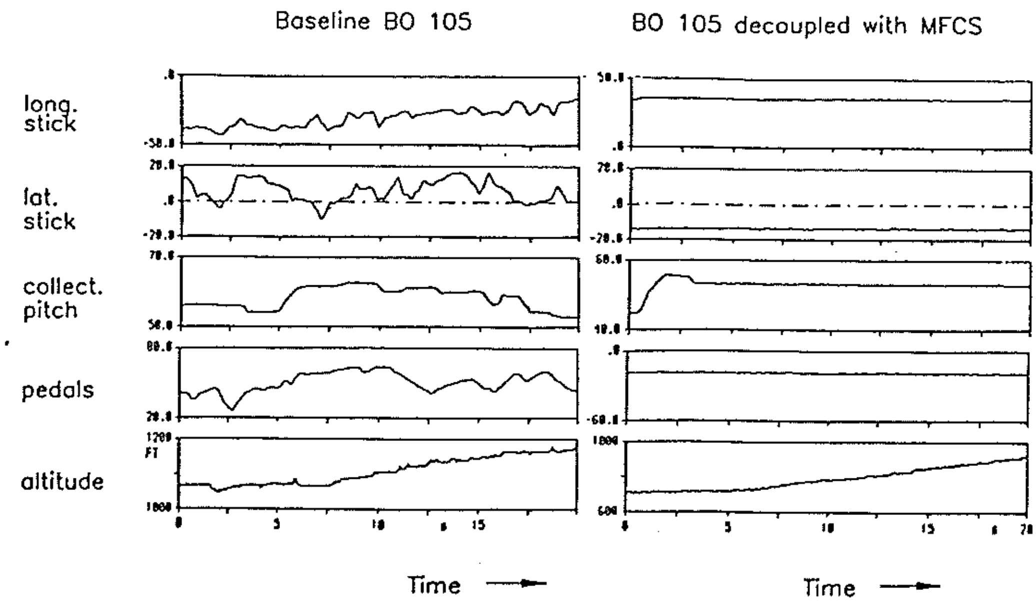

Figure 13 Comparison of Pilot's Control Activity in Climb (1000 ft/min)

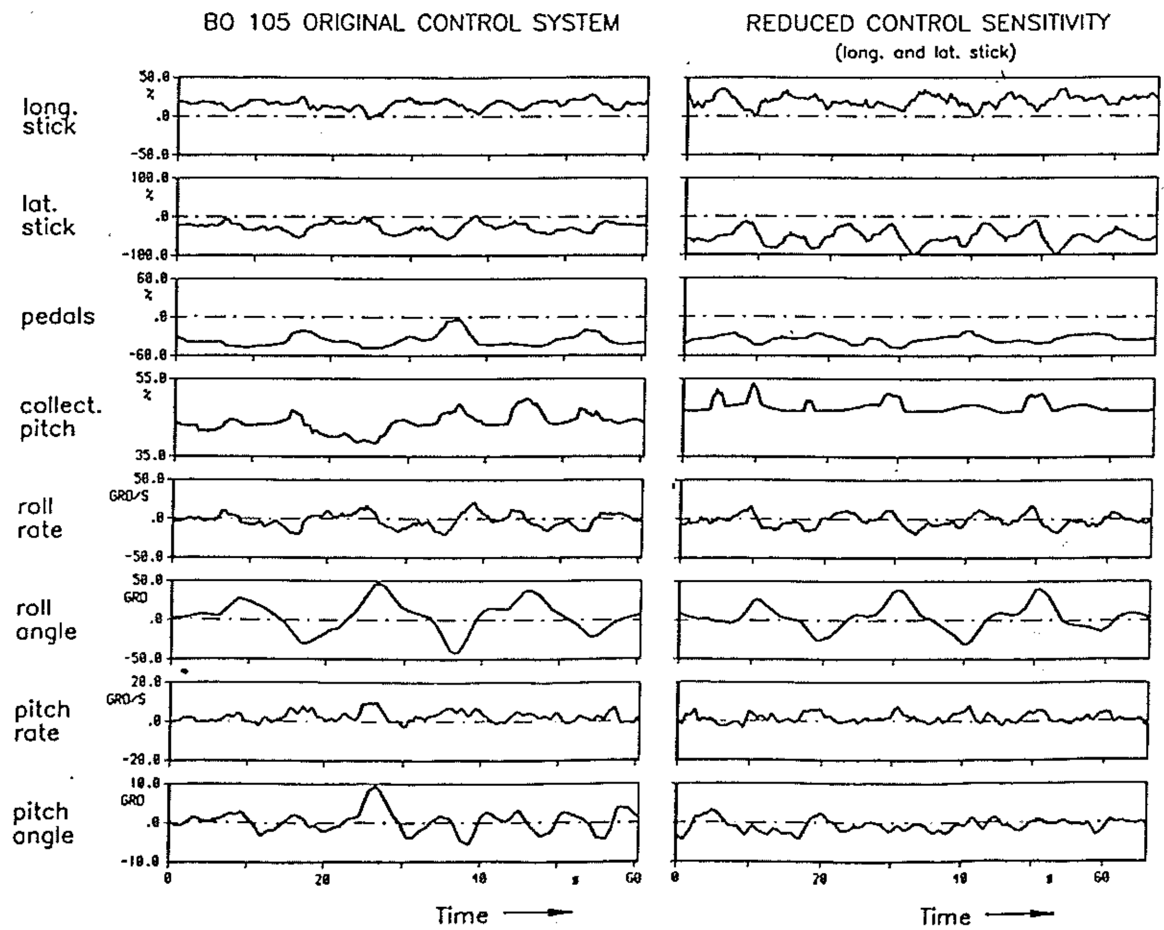

Figure 14 Effect of Control Sensitivity in NOE Slalom Task