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REALIZATION AND FLIGHT TESTING OF A MODEL FOLLOWING CONTROL SYSTEM FOR HELICOPTERS

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Abstract

The realization of a designed model following control system on a BO 105 fly-by-wire helicopter is described. A multicomputer system performs the numerous tasks of the in-flight-simulation facility. Different displays and flight test parameters can be easily selected by the simulation pilot. High system capability is achieved by supporting simulation software for different applications. The possibility of real-time ground simulation with the helicopter and the flight test crew allows effective flight test preparation. Extensive test data analysis software enables the user of the in-flight simulator to analyse his tests quickly. Flight test results demonstrate the high effectiveness of the helicopter in-flight simulation.

Nomenclature

DELTAX	longitudinal cyclic
DELTAY	lateral cylic
DELTAØ	collective
DELTAHR	pedal
ETAX	longitudinal cyclic actuator
ETAY	lateral cyclic actuator
ETAØ	collective actuator
ETAHR	pedal actuator
THETA	pitch attitude helicopter
TTACOM	pitch attitude model
TTA-DT	pitch rate helicopter
TTADTC	pitch rate model

VBAR	airspeed helicopter
U-COM	airspeed model
PHI	roll attitude helicopter
PHICOM	roll attitude model
PHI-DT	roll rate helicopter
PHIDTC	roll rate model
PSI	heading
PSI-DT	yaw rate helicopter
PSIDTC	yaw rate model
HPBEOB	observers rate of climb
HPCOM	models rate of climb
HBAR	pressure altitude
BETA	sideslip angle helicopter
BETACM	sideslip angle model

In 1983, a Model Following Control System (MFCS) for helicopters, originally designed at Deutsche Forschungs- und Versuchsanstalt für Luft- und Raumfahrt e.V. (DFVLR), was tested in first flights to demonstrate the general possibility of in-flight simulation with a BO 105 helicopter. Results of extensive ground simulations at NASA Ames Research Center, accomplished in a joint research program between the U.S. Army and the DFVLR under the Helicopter Flight Controls Memorandum of Understanding in 1983/84 are described in ref.1. The long term objective of the program is to develop and implement a MFCS in a flight research facility for use in handling qualities, parameter identification and control system experiments.

The advantage of using a MFCS on an helicopter in-flight-simulator is that the characteristics of the model to be followed can be varied quickly and easily depending on the task to be performed. The main elements of a MFCS, shown in figure 1, are the model, the base helicopter with its actuating system and the control system. In a MFCS the simulation pilot commands are fed into a mathematical model. This model contains the dynamic equations of the system to be simulated in-flight. The model's response to the pilot commands is compared with the base helicopters state and fed into a control system which tries to minimize the state error by manipulating the base helicopter controls via the actuating system. If the state error is always zero, the base helicopter behaves like the model. This is the condition of perfect model following.

Figure 2 shows the BO 105-S3 ATTHeS (Advanced Technologies Testing Helicopter System) of the DFVLR, the only fly-by-wire research helicopter in Europe, used since 1983 as a testbed for MFCS research. Because of its high main rotor moments, this helicopter is responding quickly to control inputs and is therefore well suited for control system applications. On the other hand, strong nonlinearities, high couplings and uncertainties in the system parameters make a control system design more complicate. The BO 105-S3 is equipped with a full authority, quick responding non-redundant fly-by-wire system for all main rotor and tail rotor controls. The fly-by-wire system moves the controls of the safety pilot who always can overcontrol the fly-by-wire system to prevent hardovers and dangerous flight conditions. However, the control rates of the actuators have to be limited, especially the collective control with respect to rotor rpm changes. These effects implement additional nonlinearities to the base helicopter, which have to be considered in the MFCS design, described in ref. 2.

System design

To realize a MFCS in a real helicopter, the main tasks of a MFCS (figure 1), the model to be followed and the control system, have to be completed by numerous functions. Since already the model to be followed requires extensive calculation of differential equations, the MFCS is realized with a multi-computer system, shown in figure 3, consisting of four PDP-type computers. The Data Control Computer DCC accomplishes, in addition to the main tasks, the controlling of all computers and handles all sensor inputs and controlled outputs to the fly-by-wire actuators. All sensor signals are off-line calibrated and transformed to engineering units. For signals, which cannot be measured, the main computer incorporates transformations and state observers. In addition, the DCC is connected to a mini-tape recorder for reading specific flight test data and recording system parameter changes. The sensor data are processed by a Data Aquisition System (DAS) with programable gains, offsets and cut-off frequencies of six-pole Bessel filters and then fed to the DCC as well as to a PCM data transfer for quicklook analysis in a mobile Ground station.

The communication between the simulation pilot and the onboard computer system is accomplished by the pilot communication computer (PCC). The simulation pilot can manipulate easily numerous functions, displayed with menu-technique on a screen in the cockpit, by operating a numerical keyboard.

All digital data of the DCC is transfered to the data recording computer (DRC). The DRC is connected to a Floppy-disk drive, where all helicopter and control system states are recorded during flight test runs.

The ground simulation computer (GSC) enables a real-time ground simulation by simulating the actuating system, rigid-body dynamics and the DAS of ATTHeS. Simply by plugging a contact into the front panel, the GSC is engaged and the in-flight-simulation software can be tested in a real-time simulation.

System capability

The main interest of the user of an in-flight-simulator is to program his model to be followed in the in-flight-simulation. In ATTHeS on board computer system the user has read - access to all helicopter and system states, which are stored in one common block. The commanded signals in pitch, roll and yaw rate, vertical velocity, pitch and roll attitude,altitude and sideslip angle have to be generated by the applicant of ATTHeS. It is the users responsibility to command these signals in the correct mathematical connection.

To facilitate the users task of programming his model, ATTHeS software supplies a special filter library with typical functions for handling qualities investigation, such as rate-command, rate command/attitude hold, and attitude command filters with different dynamics. In addition, an 8-degrees of freedom model for helicopter simulation is provided. The user has to supply this model with the stabibility and control derivatives and the trim conditions at the desired airspeeds to be simulated. Since the derivatives are updated with ATTHeS airspeed, a helicopter simulation is possible over the entire flight enveloppe of the BO 105. To investigate a stability augmentation system (SAS) on the helicopter to be simulated, the user has access to all parameters of a common SAS applied to his model.

Simulation Organization

The first step of an ATTHeS user is to undergo a nonreal-time simulation on the IBM 4081 computer of the DFVLR. This IBM has the complete MFCS system including ATTHeS simulation for program development. If the user is more familiar with a VAX computer, these investigations can be accomplished on the VAX, which has a network to the IBM. Since all simulation computers are programmed in FORTRAN, the program development is made very easy. The final software program is then transfered via disk to a PDP computer (fig.4).

From the PDP, the software is implemented in the MFCS and stored into bubble memories, which are inserted into the on-board computers for real-time and in-flight-simulation. The complete MFCS then is checked in the ground simulator shown in fig. 5.

The third simulation step takes place in ATTHeS. Supplied with external electrical and hydraulical power, the flight-ready ATTHeS simulates the user's model. Now both the simulation and the safety pilot 'fly' their simulation on the ground.

When this simulation is successful for both pilots, the power is disconnected, the ground simulation plug in the cockpit removed and ATTHeS is ready for in-flight simulation.

Simulation Data Management

ATTHeS ground station software provides the user of an in-flight simulation with helpful tools. The flight test engineer runs the pre-flight software to define his parameters to be investigated. If desired, he even programs the flight test task. These informations are stored on a minitape and then transfered to ATTHeS. During the in-flight-simulation every data change made by the simulation pilot is recorded. After the flight test, the tape is transfered to the ground computer and these parameter changes are documented with the post-flight software.

Simulation Analysis

Software tools for simulation analysis is provided in three stations. ATTHeS on-board computers supports the simulation pilot with a Multi-Function-Display (MFD), display of numerical values of all chanels, time histories and cross-plots. The parameters such as length of x- and y-axes in the plots can be varied easily by the simulation pilot. On-board frequency analysis is currently prepared.

The ground station provides the flight test engineer with quicklook on different personal computers and strip charts of 16 channels. Since the PCM-data is recorded and digitized, flight test analysis described in ref. 3 is possible directly after the flight. The digital tapes are transfered to the IBM and can be analysed with the program system DIVA described in ref. 4. Since these different analysis features are applied to all simulation steps described above, the user of ATTHeS works with the same procedures from the beginning on.

Flight Test Results

Results of ATTHeS in-flight simulations are shown to demonstrate flight testing of the different models described in the section 'system capabilities'. All figures are directly received from the DIVA system. All time histories a) describe the control inputs in longitudinal cyclic, lateral cyclic, collective and pedal in the dashed lines from the simulation pilot and in the solid lines the MFCS output to the corresponding actuators. The time histories b) show the models (dashed lines) and ATTHeS (solid lines) responses in pitch attitude, airspeed, roll attitude, heading, rate of climb, altitude and sideslip angle.

Figure 6a shows the MFCS response to a computer generated 3-2-1-1 signal in the lateral axes and the high control activity of the MFCS. The decoupled model (fig.6b) responses with a coordinated turn, no changes in pitch attitude, rate of climb and sideslip can be seen. The roll attitude response of ATTHeS shows a well following to the commanded signal, but with a delay of about 300 milliseconds. The theoretical delay is between 50 and 100 milliseconds, the additional delay is caused by the 6-pole-Bessel filters in the data aquisition system. The helicopter is very well decoupled, since the errors of 1.5 degrees pitch attitude, 100 feet/min rate of climb and 1 degree sideslip angle are neglectable. The high control activity and state changes at 20 sec are caused by gust.

A frequency analysis of this flight test is shown in a DIVA bode plot in figure 7. The transfer function from the lateral stick to the roll attitude is described. The amplitude and phase characteristics represent a second order attitude command system with time constants of 0.2 sec, 1.0 sec, a gain of 0.8 degree/% and a dead zone of 5%.

The result of an autopilot flight test is shown in figure 8. In figure 8a no pilot control inputs, but high MFCS control activity in all axes can be seen. The autopilot task was to hold airspeed, altitude and heading in a gusty environment. Again, the small errors of 4 kts airspeed, 3 degrees heading, around 10 feet altitude and 1 degree sideslip document the high accuracy of the MFCS.

To investigate the effects of pitch-due-to-roll coupling on helicopter handling qualities, slalom flight tests with different models were accomplished in 1985. The upper x-y diagram in figure 9 shows the slalom course, described in detail in ref. 5. In the lower diagrams the lateral control inputs of the pilot and the corresponding roll attitudes are shown for three different models. The left pair shows the slalom flown with the basic BO 105, the diagrams in the middle represent the flight with a rate-command-attitude-hold (rc-ah) system and the right diagrams the slalom with an attitude command system. The main difference between the basic helicopter and the rc-ah system can be seen in the level flight conditions, where control activities are much higher in the basic helicopter. The attitude command system has the lowest control frequency in the pilot's lateral stick.

An application of a helicopter simulation with ATTHeS is shown in figure 10. Figure 10a demonstrates, that the simulation pilot held his controls constant, but the MFCS fed control inputs to ATTHeS. An unstable oszillation in pitch attitude and rate of climb of the model as well as of the base helicopter can be seen in figure 10b. The model to be simulated was a model of the BO 105, where the phygoid oszillation was exited just by gust influences. ATTHeS had to simulate itself. The control activity of the MFCS indicates, that the model's dynamics was slightly different from ATTHeS dynamics, but again, the good convergence between commanded state and real helicopter state demonstrates the high capability of ATTHeS.

Conclusions

The MFCS, realized on a multi-computer system, has a high in-flight-simulation capability. The numerous features of the system are easy to handle for the simulation pilot. Easy flight test preparation is supported by the fully ground simulation capability and extensive analysis software. Different application results demonstrate the capabilities and effectiveness of the system.
Future application of ATTHeS will be in the fields of handling qualities investigation, helicopter model verification, autopilot research and new sensors for specific helicopter tasks.

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5	Pausder, H.J.	A Study of Roll Response Required in a Low Altitude Slalom Task. Paper No. 79, 11th European Rotorcraft Forum, The City University, London, September 10-13, 1985.

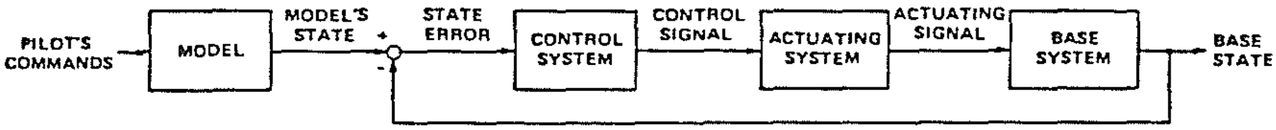


Figure 1: Basic Model Following Control System

Figure 2: BO 105-S3 ATTHeS

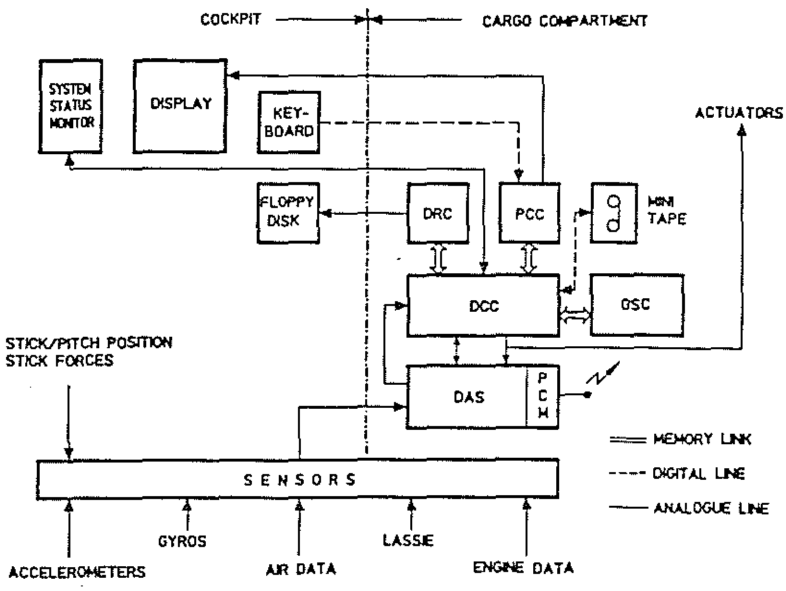


Figure 3: Realized MFCS System Structure

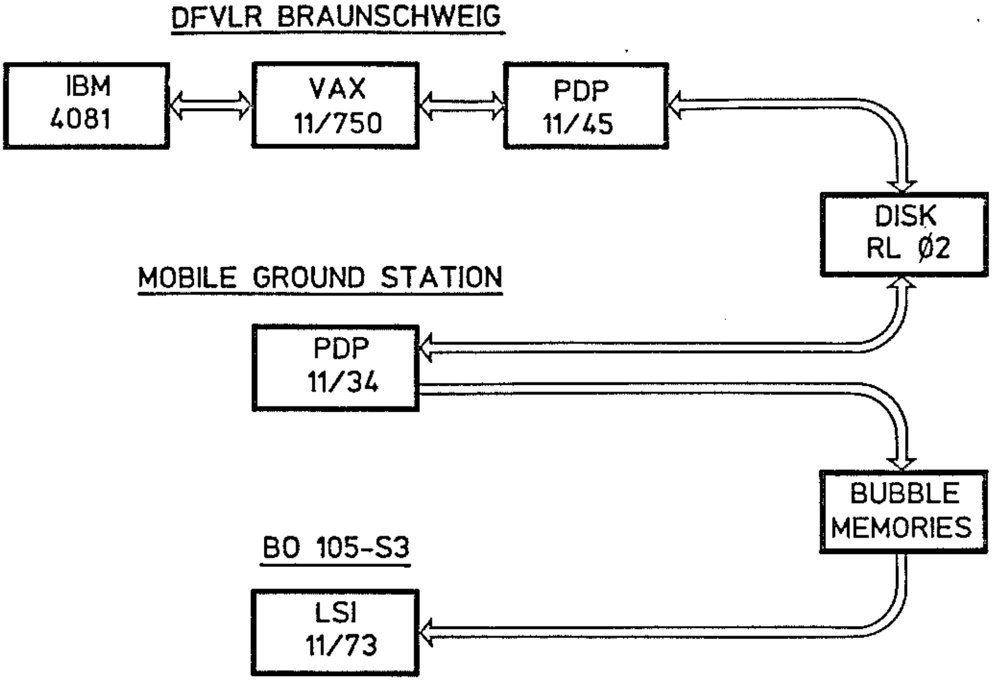


Figure 4: Simulation Software Data Flow

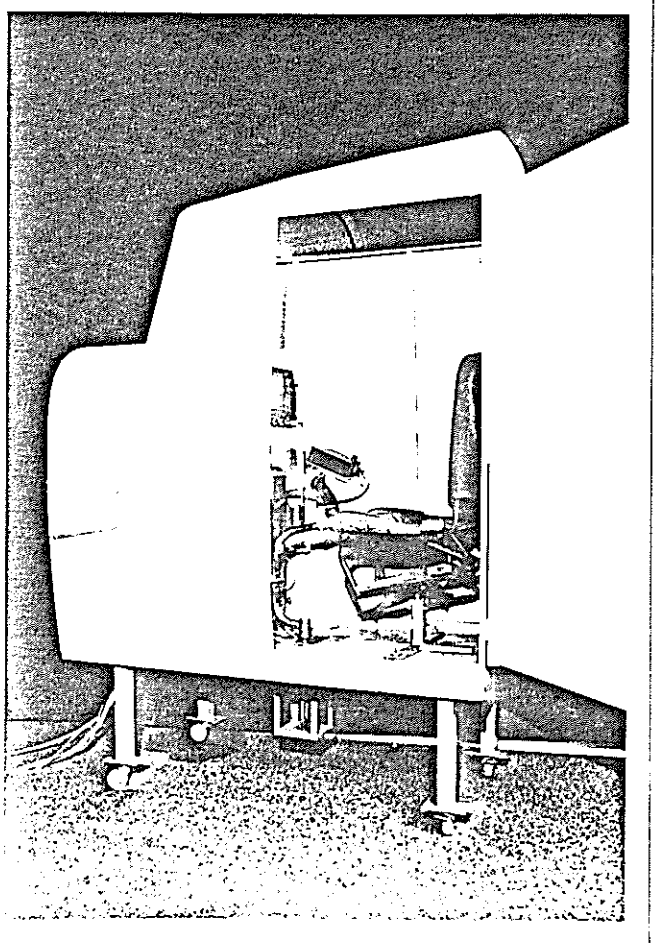
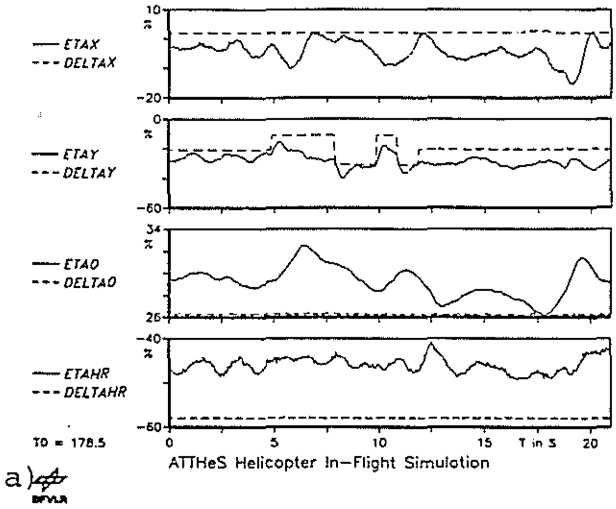


Figure 5: ATTHeS Ground Simulator



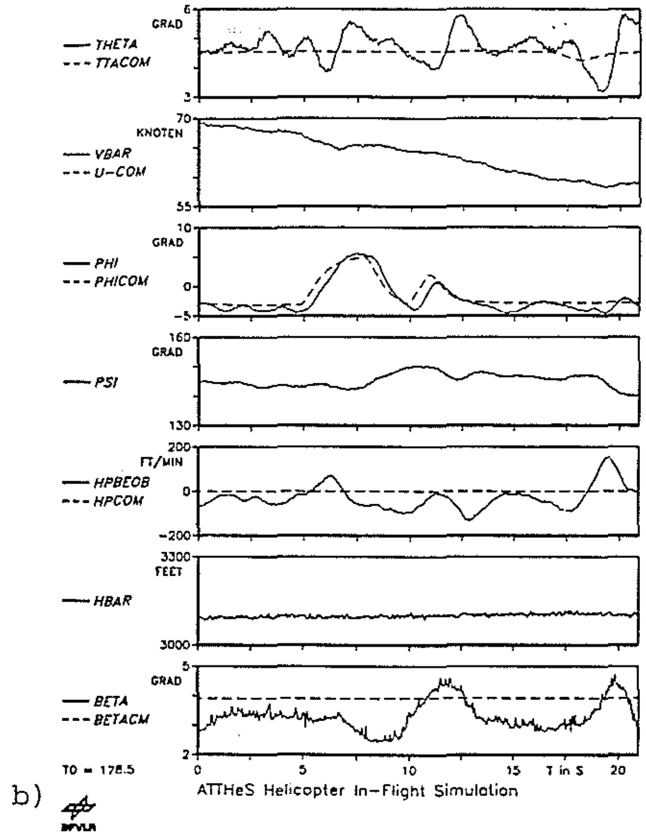


Figure 6: ATTHeS Response to a 3211 Lateral Stick Input

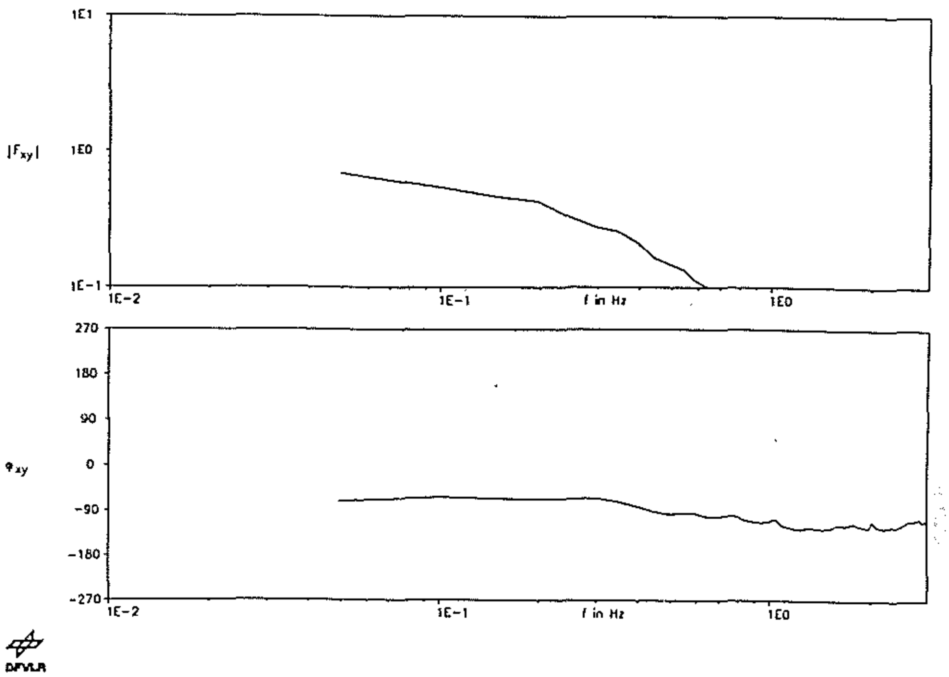


Figure 7: Bode Plot of a Simulation Model (PHICOM/DELTAY)

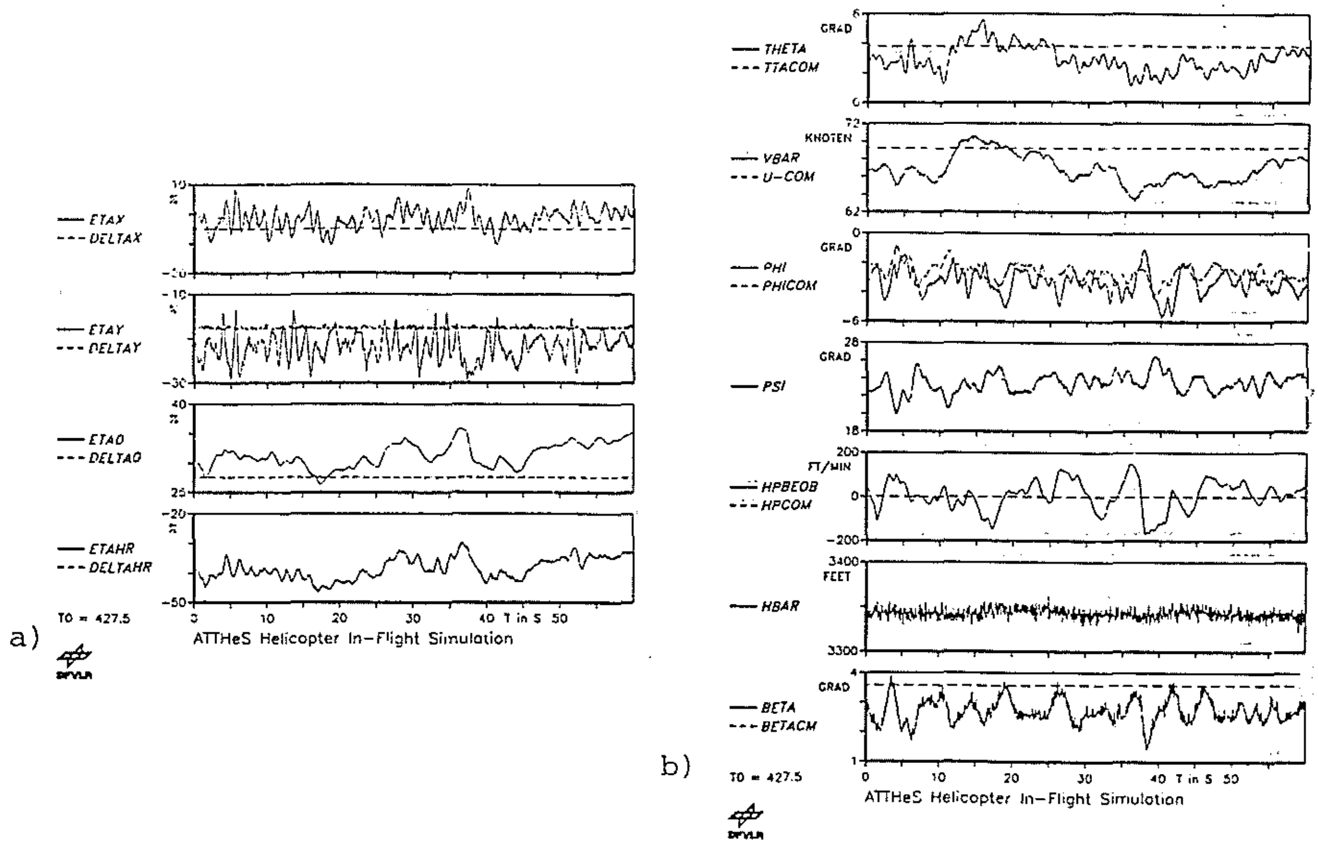


Figure 8: ATTHeS Gust Response in an Autopilot Mode

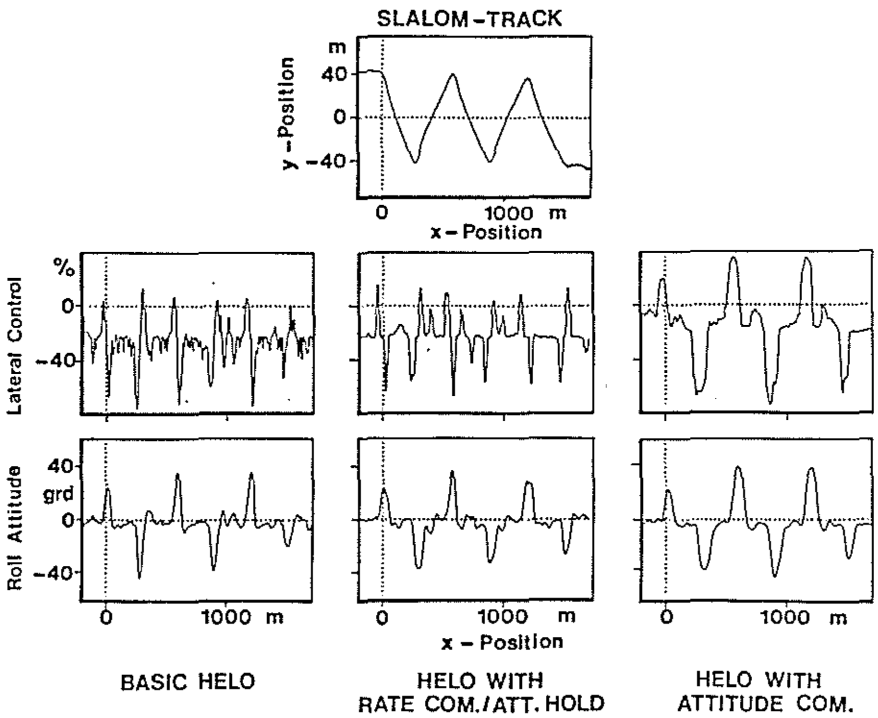


Figure 9: Time Response of Different Models
in the Slalom Task