FHS, the New Research Helicopter: Ready for Service

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Abstract

The DLR **F**lying **H**elicopter **S**imulator (FHS) has been taken into service by the end of 2002. A standard EC135 helicopter was significantly modified. In particular, the mechanical control system was replaced by a full authority fly-by-light control system. A specific system architecture was defined consisting of a multiple redundant core system, meeting the highest safety level, and a simplex experimental system giving the flexibility for easy adaptations. These characteristics together with an extensive instrumentation make the FHS a suitable tool for various applications. The helicopter was developed and financed in a co-operative effort by the DLR, Eurocopter Germany, Liebherr Aerospace, and the German Ministry of Defence. It was designed to support national and international research and technology programs. It is operated by the DLR in Braunschweig, where also the FHS related ground stations are located: a ground based system simulator and transportable telemetry- and data evaluation stations.

The paper first concentrates on the presentation of the FHS system philosophy and design. It explains the FHS operational modes and presents the ground facilities. Then, it gives an overview on the present user programs and finally presents an outlook on future extensions of the FHS.

Introduction

In November 2002 the Deutsches Zentrum für Luft- und Raumfahrt (DLR) received its new in-flight simulator, the **F**lying **H**elicopter **S**imulator (FHS). It was planned and developed in a joint effort of the DLR, Eurocopter Deutschland (ECD), and Liebherr Aerospace Lindenberg (LLI). Funding was provided by these organisations and by the German Ministry of Defence (BMVg). The development of the FHS was started in 1996. As basic aircraft, the Eurocopter EC135 was selected. However, the conversion of the original EC135 helicopter into the FHS research platform required significant modifications. The general guideline was to design a vehicle with a high application oriented flexibility, i.e. to cover a wide range of user requirements in order to support the various national and international research and technology programs.

There are two major areas in the spectrum of user needs:

- **Airborne simulation:** Airborne simulation gives the possibility to modify the dynamic characteristics of the basic helicopter in the way, that the pilot has the impression to fly a different vehicle. Such modifications range from the variation of a single parameter, like increase of a time delay between pilot input and actuator response - used to demonstrate PIO tendencies - up to the simulation of a different helicopter that may not even exist in reality but can still be in a design phase. In comparison to ground based simulators, the pilot is in a true airborne environment with real sight and motion cues. The airborne simulation is not only an excellent tool for basic and applied research in handling qualities, controls, displays and human factors. It will assist in the design and development of new helicopters and it allows detailed evaluation of their future characteristics before the actual vehicles exist. This avoids later expensive modifications in the development process of a real helicopter. For fast changes required in the research environment, a high degree of flexibility must be provided for the airborne simulation role.
- **Technology demonstration:** The second key area for the FHS is the development, integration and qualification of new technologies, like active control components, new flight control laws, and new cockpit systems. These applications also need a high flexibility in system changes to implement both hard- and software modifications. Technology demonstration encompasses evaluating and proving the functionality and operational benefit of new technologies up to the point of certification.

To meet the future requirements a completely new control system and system architecture were developed. The original mechanical control system was removed and replaced by a full authority digital fly-by-light system. Major emphasis in the design was placed on two essential factors: high safety standard, according to the stringent civil certification requirements and at the same time, maximum flexibility for configuration changes due to user needs.

The FHS had its first flight with the fly-by-light control system in January 2002. After extensive ground and flight testing under the responsibility of ECD (Ref.1) the helicopter was delivered to the DLR in November 2002. It is operated by the DLR research center in Braunschweig, where also ground support elements are located, which complete the FHS system: a ground based system simulator and two ground facilities, a telemetry station and a data evaluation station. As these stations are installed in two transportable containers the FHS can be used in other locations without major external support.

The paper will at first concentrate on the FHS helicopter itself. Emphasis is placed on the design philosophy, safety considerations, and handling of the control system by the pilots. Then the main features of the ground simulator and the ground stations are addressed. Finally, an overview of the present use of the FHS is given and the potential for future user programs is outlined.

The Flying Helicopter Simulator (FHS)

Selection of the basic helicopter

The basic aircraft for the FHS is a Eurocopter EC135 helicopter (Figure 1). It is a modern, twin-engine, light helicopter with a bearingless main rotor and fan-in-fin tail rotor. The helicopter was selected for the FHS development for mainly two reasons:

- It is evident that an in-flight simulator cannot represent an aircraft with faster dynamic responses than those of the basic aircraft. Therefore, a fundamental requirement for airborne simulation is a high dynamic response capability of the basic vehicle. The EC135 is a rotorcraft with very high agility particularly due to its main rotor system with an equivalent hinge offset of 8.7%. That allows a roll bandwidth of about 3.7 rad/s and a pitch bandwidth of approximately 1.8 rad/s (Ref. 2). It has the potential for the simulation of the existing and future helicopters and also for the lower speed regime of tilt-rotor vehicles.

Figure 1: The Flying Helicopter Simulator EC135 (FHS)

- It is planed to use the FHS over the next 20 years. The DLR as the operator of the helicopter has to consider the operational costs. Furthermore, it is important that the FHS can be offered at an acceptable operational price. With decreasing budgets nowadays, cost to benefit considerations are playing an increasing role for the decision of using the FHS. The EC135 is a newly designed modern small helicopter with moderate operational costs. It has sufficient space and load potential to allow for the various user needs.

EC135 becomes FHS

This chapter will concentrate on the modifications that were necessary to convert the basic EC135 into the FHS (Ref. 3).

Design of the system architecture: The basic EC135 is equipped with a conventional mechanical control system with hydraulic boosters. The FHS user requirements clearly indicated that the mechanical system had to be replaced by a full authority digital flight control system using fly-by-light technology. A hierarchical system architecture was defined to meet two major requirements:

- Safety: The objective was, that the standard operation of the helicopter for all flight conditions is the fly-by-light mode. This configuration had to comply with civil certification requirements. An additional mechanical feedback system should only serve in case of emergency.
- Flexibility: For the conduction of user programs and in particular for the simulation task it is absolutely mandatory to easily change control laws or models or connecting new hardware without extensive system modifications, qualification, and test.

The FHS on-board system consists of two associated units as illustrated in Figure 2: The "core system", which provides the safety and the "experimental system", which gives the flexibility for modifications. The core system meets civil certification requirements with a probability of catastrophic failures less than 10^{-9} per flight hour. It was achieved by quadruplex redundancy of all components together with dissimilarity of both hardware and software (Ref. 4) The "heart" of the core system is the core system computer. It is the central interface that receives the control signals from both pilots and flight state signals from the basic sensors. It communicates with the experimental system, which can modify the evaluation pilot control commands. The final control commands are fed to the hydraulic smart actuators. Some additional functions of the core computer are addressed below. As the core system is quadruplex, with dissimilar level A software in the core system computer and the actuator electronics it is obvious that any later changes of the core system will require a significant effort, in particular with respect to testing and qualification. It is therefore intended to not modify the core system for the next years.

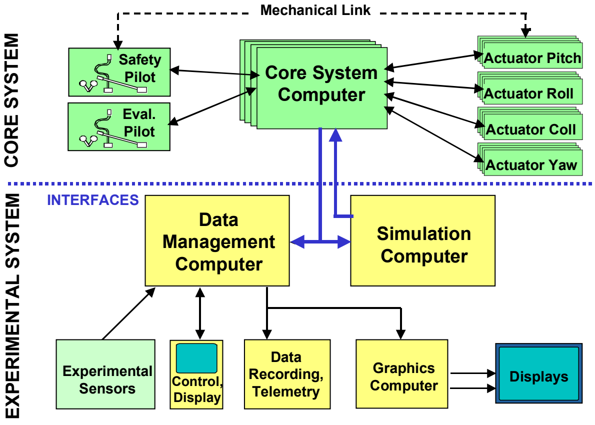


Figure 2: FHS system architecture

The main elements of the experimental system (Ref. 5,6) are the experimental computer and the data management computer. The first one communicates with the core system computer. It receives the evaluation pilot command signals, modifies them according to the programmed control laws and transfers them back to the core system. The data management computer collects all data provided by basic sensors and sensors in the experimental system, and transfers them to the telemetry, the on-board data recording, and to the graphics computer that controls the displays. In contrast to the core system, the experimental system is only simplex to allow relatively easy and fast modifications. The criticality level is "minor", which implies that the system may fail and produce errors. Therefore, several safety features are implemented in the core system computer to avoid critical helicopter responses.

Figure 3 illustrates the technical realisation of the architecture and some of the major helicopter modifications. The EC135 cabin accommodates a three men crew with a safety pilot on the left pilot

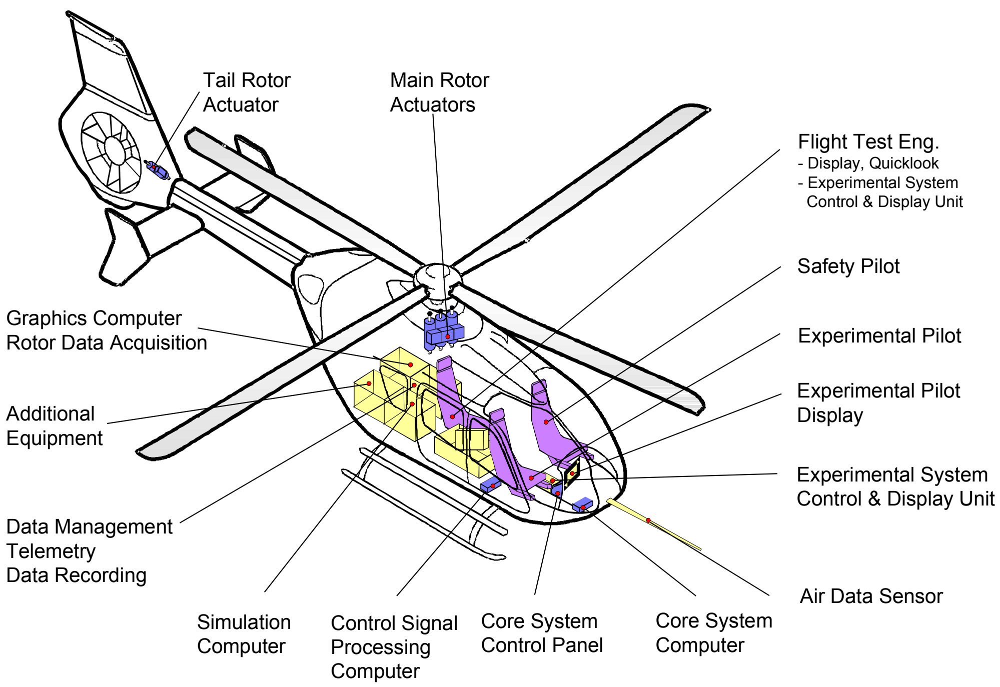


Figure 3: FHS modifications and additional equipment

seat and an evaluation pilot on the right pilot seat. A flight test engineer station is located behind the two pilots. Both pilots have conventional controls (stick, collective, pedals). The control positions are measured by linear voltage differential transducers (LVDTs). The original mechanical control system was replaced by flexball cables, which connect the safety pilot controls with the hydraulic actuators as a mechanical back-up. Due to their flexibility the cables for the main rotor actuators are routed within the windscreen centre frame. So the centre post was removed.

The safety pilot panel is equipped with an *Avionique Nouvelle* glass cockpit with standard instrumentation which allows a wide outside field-of-view. In the centre console between the two pilots is a control unit for the core system. Both the evaluation pilot and the flight test engineer have a freely programmable multifunction 10” experimental display and a control panel for the display. The units are identical but independent from each other: e.g. the pilot may select navigation instruments on his display while the flight test engineer can choose a quick-look from recent flight measurements. The flight test engineer has additional access to the experimental system e.g. for changing configurations and parameters. The seat of the flight test engineer is located in the centre of the cabin so that he also has a view to the cockpit. His panel is on his right hand side.

The four core system computers are located in two housings under the floor. Each housing contains two computers, which are dissimilar in hard- and software. The original hydraulic actuators have been replaced by FHS specific smart actuators underneath the main rotor and close to the tail rotor. The actuator electronics receive the control commands from the core system computers by optical fibers. Most components of the experimental system are installed in the cargo compartment behind the flight test engineer. They are mounted on three pallets, which can easily be removed from the helicopter and reinstalled. It allows fast modifications and testing in the laboratory or on the system simulator. A fourth pallet is free for user specific equipment. As a research helicopter, the FHS is fully instrumented with a number of redundant sensors and measuring equipment. The instrumentation system mainly includes two air data units, two AHRS (attitude and heading reference systems), a radar altimeter, FADEC data, individual linear accelerometers, INS, nose boom air data (static and dynamic pressure, angle of attack and sideslip, temperature), differential GPS, and control input signals at various positions.

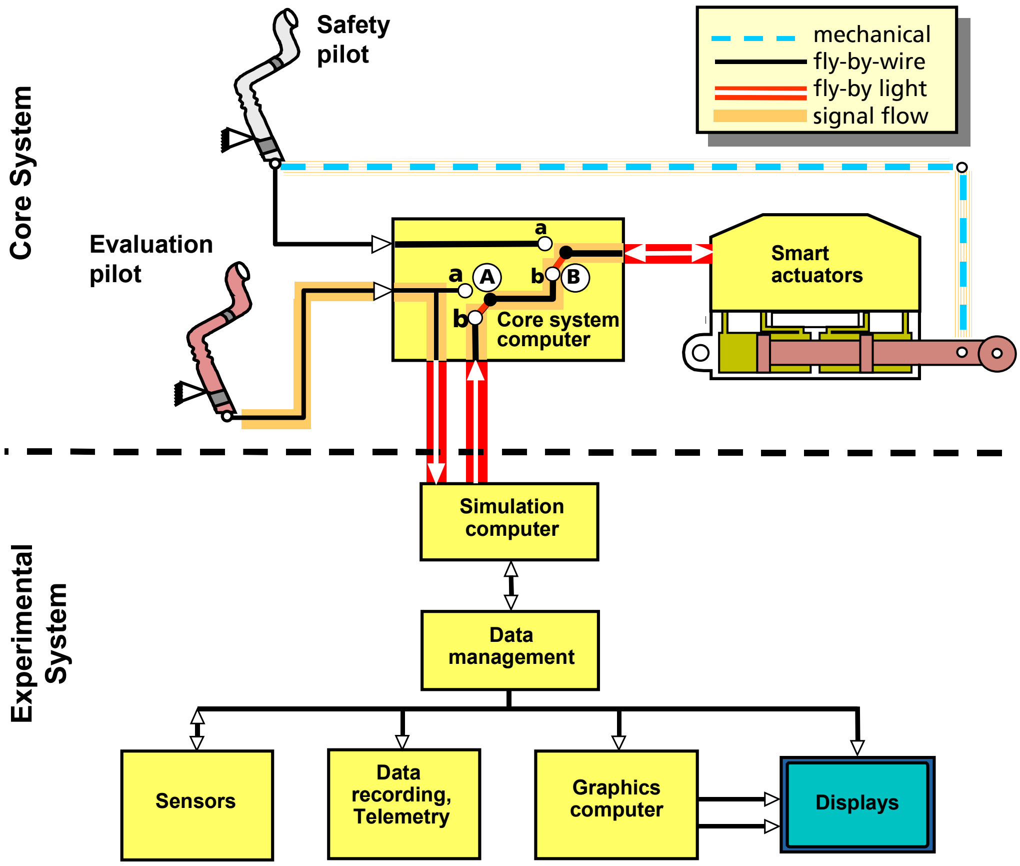
<u>FHS operational modes:</u> Depending on the signal flow and the pilot-in-command, the FHS has three standard control modes: (1) safety pilot mode, (2) evaluation pilot direct mode, and (3) experimental mode. In a fourth mode the mechanical backup can be used. The mechanical link is not intended to be a standard control mode, but it plays an important role in the evaluation pilot mode, as described below.

In Figure 4 the individual modes are illustrated. The mode switching is controlled within the core system computer. The principle is shown in the figure by the two switches A and B. For simplification only one pilot control element (stick) and one data channel is presented. However it has to be kept in mind that all four pilot controls are considered and that all core system components, from the sensors, measuring the pilot inputs, down to the actuator electronics are quadruplex redundant.

- Safety pilot mode: With switch B the pilot-in-command is selected. In position “a” it is the safety pilot. The control positions, measured by LVDTs, are transmitted by electrical wires to the core system computer and demodulated. As the computer is located close to the sensors, only short wires are needed. The core system computers send the inputs via optical fibers to the actuator electronics which control the hydraulic valves and consequently the actuator motion. The distance from the core system computers to the actuators is relative long (in particular for the fan-in-wing tail rotor actuator) so that full advantage is taken from the fiber optics technique. The pilot also moves the mechanical control system. However due to a clutch system in the actuators it is decoupled and has no influence.

- Evaluation pilot direct mode: Change of switch B to “b” transfers the command from the safety pilot to the evaluation pilot. Switch A is in position “a”. Now, the evaluation pilot control positions, measured by LVDTs, are transmitted to the core system computer and sent by the optical fibers to the actuators. As there is no mechanical link to the evaluation pilot controls, the pilot flies the helicopter in a pure fly-by-light mode. In contrast to the safety pilot mode, the hydraulic clutch in the actuator is closed and the actual actuator position is backdriven to the safety pilot controls.

- Experimental mode: Like in the previous mode, switch B is still in position “b” and switch A is changed to “a”, as shown in Fig-



Switch B in a: Safety pilot (basic EC 135)	Switch B in b and Switch A in a: Evaluation pilot direct mode (basic EC135)
Both switches in b (as shown above): Evaluation pilot in experimental mode	

Figure 4: Principle of FHS control modes

ure 4. Now, the evaluation pilot is in command for the experimental mode. His control inputs are received by the core system computer and transferred to the experimental computer. Here, the control inputs are modified according to the implemented user's software and sent back to the core system computer and from there to the actuators. The actuator motion and consequently the FHS dynamic response is now due to the modified inputs and no longer directly related to the pilot inputs: The evaluation pilot flies the helicopter with modified flight characteristics in a pure fly-by-light mode. The actual position of the hydraulic actuators is back-driven to the safety pilot controls. Therefore, his control position always corresponds to the basic EC135 position and is different from the one of the evaluation pilot. So, when he has to take over the command immediately, his controls are in the correct position.

The appropriate modes are selected by using the core system control unit and switches on the safety pilot and evaluation pilot controls. For the transition to "higher modes" (e.g. from safety pilot mode to evaluation pilot mode) the new mode is first pre-selected and the evaluation pilot controls are synchronised with the current actuator position or the position obtained from the actual model in the experimental computer. The evaluation pilot controls are driven by the trim motors. During this process lights flash on the core system control unit for pilot information. A continuous light confirms successful synchronisation. The actual mode change can be activated by the pilot-in-command by pressing a button on his collective stick. Due to the synchronisation and an additional fading function transition errors during mode change are avoided.

Switching into "lower" modes (e.g. from experimental mode to safety pilot mode) does not require synchronisation as the controls are already in the right position. The desired mode is immediately active. This fact is essential as it allows the safety pilot to take over control of the helicopter without delay by either pressing a button or by overriding the control forces.

The mechanical control system is primarily needed during the experimental mode for the above described feedback of the actuator motion to the safety pilot. But it is also a full control system for the safety pilot in case of failures or loss of function (e.g. due to power loss) of the fly-by-light system. This control mode is considered as a backup and an additional safety feature. From its design, the FHS is qualified to operate in the fly-by-light mode within the full flight envelope.

FHS operation

FHS safety aspects

The FHS is the first helicopter with a full authority fly-by-light system as primary flight control system. To obtain the required safety level and to avoid critical situations, the core system is not only quadruplex redundant but additional data checks, error detection and suppression features have been implemented mainly in the core system computer and the electronics of the hydraulic actuators (Ref. 7).

For each of the four pilot controls the core system computer has four functionally identical lanes. All lanes run asynchronously with a cycle time of 4 ms. Each individual lane continuously performs its own data handling routines and tests and finally sends the control commands to the actuator electronics. Depending on the selected operational mode the core system computers perform the following safety functions:

Before the final control commands are sent to the actuators they are passed through a phase shifting filter to prevent pilot induced oscillations in the roll axis. A limiter constraints the commanded rates to 190%/s to not exceed the capacity of the hydraulic system. In addition, the core system computer continuously monitors all outputs and can detect failures in a single lane. This lane will immediately go into a fail safe mode and is no longer used. However, the lane can be reset in flight, provided the failure has disappeared . A final check of the data is made to detect a stalemate situation.

In the experimental mode, the pilot control inputs are passed through the experimental computer. As this computer is simplex and its software is often changed according to user requirements, there is a higher probability of both hard- and software errors. Whenever the control inputs are received from the experimental computer by the core system computer, they are first monitored with respect to validity, parity, update and range. But it is still not possible, to decide if, for example,

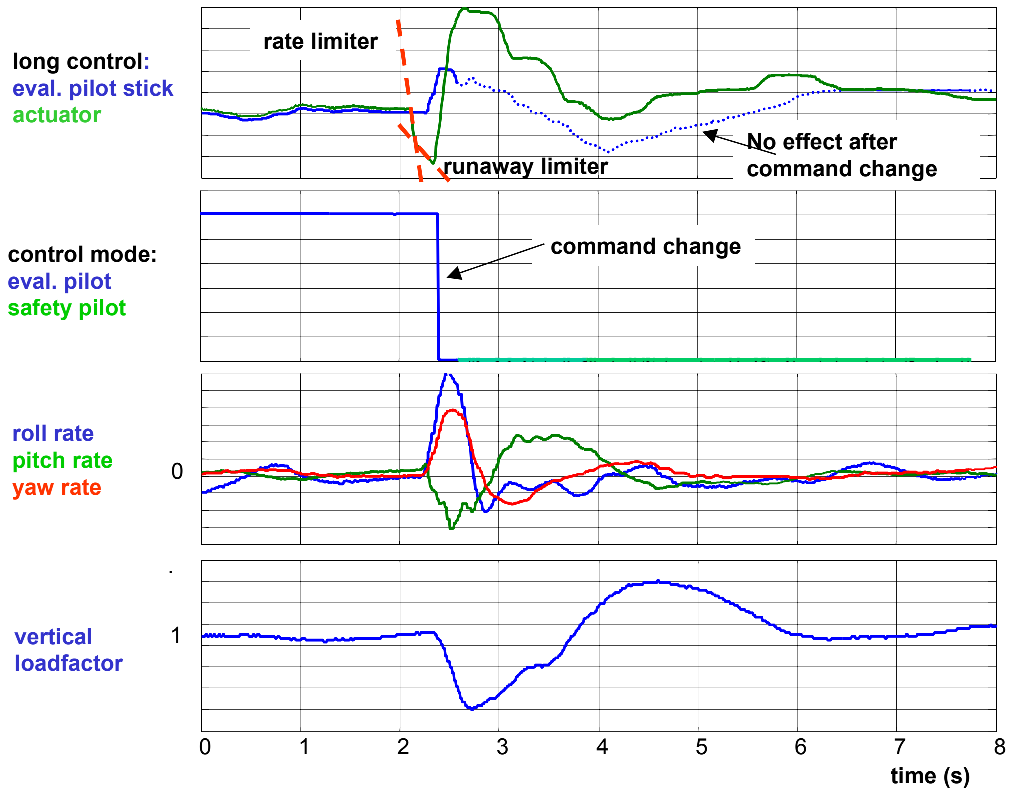


Figure 5: Runaway Test: Demonstration of limiter efficiency, mode change and helicopter response

a high amplitude signal is a valid command from the experimental system or if it is caused by a failure. To avoid structural damage of the helicopter, the signals from the experimental computer are passed through runaway limiters. In the core system computer, four different sets of limiters can be included. Presently two sets have been defined with the design objectives to (1) allow all manoeuvres within the EC135 capability and (2) restrict control inputs that are beyond the EC135 capability and consequently can cause a helicopter damage.

The four limiter sets for experimental mode operations are:

1. A minimally restrictive limiter for true airspeed up to 120 kts
2. A more restrictive limiter for true airspeed higher than 120 knots
3. A rather restrictive limiter for low speed flights close to the ground and, if possible, take-off and landing. This limiter has been defined and first theoretical calculations for the flight envelope definition were conducted. It has been implemented in the simulation computer and is presently in the flight test phase.
4. A limiter with no restrictions at all, which can be used with a safe and redundant experimental computer that includes either its own limiters or any other means to avoid unrealistic control inputs

The current limiter values are determined from simulation, using the assumption that a 400 ms intervention time is needed for the safety pilot to resume control after a runaway. The final limiter values will be fixed after flight testing.

During the final test phase of the FHS and its first operation at DLR, different runaways were generated by the simulation computer to test the limiter efficiency. Figure 5 presents a result for the “worst case” situation, a runaway in all four control axes. As an example, the longitudinal actuator motion is shown together with the mode switching between the evaluation pilot and the safety pilot, the helicopter rate and vertical acceleration responses. When the runaway occurred, the actuator motion was first limited by the rate limiter and then by the more restrictive runaway limiter. The safety pilot immediately gained the command by overriding the evaluation pilot inputs and stabilised the helicopter without any difficulty within a short time.

Role of the FHS crew

Although the core is able to detect, eliminate or alleviate the effect of certain failures it cannot replace human judgement. Therefore the FHS crew and in particular the safety pilot is an essential part in the FHS safety concept.

Flight test engineer: The flight test engineer keeps track of the planned flight test program. Before starting a new test he informs the pilots about details of the test and the required flight condition. As he has direct access to the experimental computer he can also select any pre-programmed configuration or change parameters. After a test the flight test engineer can document comments and conduct a short evaluation of the test. Communication with the engineers in the ground station is possible.

Evaluation pilot: The evaluation pilot conducts the individual flight experiments. He is in close contact with the flight test engineer, and gives comments.

Safety pilot: Although each individual test scenario is tested and evaluated on the ground simulator, critical situations can arise in the experimental mode e.g. due to hardware failures or non-realistic software commands. Therefore the safety pilot permanently observes the motion of his controls, the helicopter response, and the flight condition. During the experimental mode the safety pilot is flying “hands-on” to be able to immediately take over the command by pressing a button or by overriding the control forces. Due to the mechanical control system feedback the control positions of the safety pilot always correspond to the actuator positions. To evaluate and prove, that the safety pilot is able to react fast enough to critical situations, a major part of the FHS flight test program was used to generate both single axis and multiple axis runaways in the experimental computer. It was demonstrated that (1) the limiters in the core system computer are able to decelerate the control inputs, (2) the safety pilot is able to immediately obtain control and (3) the safety pilot is able to stabilise the helicopter without difficulty and without significantly loosing altitude.

The safety pilot is responsible for the total flight including the intervals where the evaluation pilot is in command. Due to this responsibility and the specific safety task for the FHS the pilot must have a test pilot qualification and FHS experience. Therefore, the safety pilot will generally be provided by the DLR, independent from the individual user of the helicopter.

Ground facilities

The FHS system also includes a ground based system simulator and a mobile data/telemetry ground station to support the flight tests.

Figure 6: Transportable FHS ground support: Telemetry station and data evaluation station

Data ground station

The ground station consists of two modules, a telemetry and a data evaluation station (Figure 6). They are housed in two containers that can be transported to the actual flight testing site to allow FHS operation including ground support at user sites or at more remote air fields than Braunschweig. The telemetry station provides an automatic aircraft tracking antenna with video camera and communication equipment. PCM data, sent by the FHS, are received, recorded and transferred to the data evaluation station via Ethernet.

The data evaluation station offers working places for three engineers. Each place is equipped with PC based data stations to allow real time data monitoring by quick-look or appropriate software tools during the flight tests. Communication with the helicopter flight test engineer and/or evaluation pilot is conducted by the responsible test engineer on the ground. Based on the first data check he will decide if a test was successful or has to be modified and repeated. The on-line data can be recorded in the station. However, for a more detailed evaluation data recorded on board of the helicopter will usually be preferred. After landing, the data storage disk is taken from the FHS experimental system and replaced by an empty one. Data are then stored on a computer in the container to allow the full range of project oriented off-line evaluation. In addition, the PCs can be used to develop and modify the evaluation software. So two major objectives in the FHS flight test data concept are met: (1) during the flight testing the FHS user is provided with the required real-time information to control the tests and (2) at the end of the flight he has access to both his own and DLR developed software tools to conduct detailed data analysis and evaluation.

Figure 7: FHS fixed based system simulator

Fixed base system simulator

The system simulator is primarily designed as a hard- and software in-the-loop test facility for the FHS (Figure 7). The main objectives are:

- Development, test, and preparation environment for engineers,
- Tests and verification of new hard- and software components before implementation in the helicopter and before flight,
- Pre-flight training and briefing of the crew, in particular when new pilots are involved.

The simulator replicates the airborne environment of the FHS with a real cockpit obtained from a BO105 and a large field-of-view visual system. Figure 8 compares the basic structures of the FHS and the simulator. On the ground, the EC135 itself, the core system computer, and some sensors are simulated. Here, the emphasis was placed on a realistic EC135 mathematical model (Ref. 8). However, pilot controls, the core system control unit, and the complete experimental system are the same as in the aircraft. It offers a perfect test facility for new equipment as all functions and connectors are identical. Pilots find a very similar cockpit as in the FHS. It not only includes side-by-side seating for the safety pilot and the evaluation pilot, but also the same displays, control units, and control grips. The same operation of the core system and representation of the FHS modes (transfer of command between the pilots), a true replication of cockpit instruments and a realistic force feel system with a simulation of the mechanical control backdrive also contribute to a useful pilot training station.

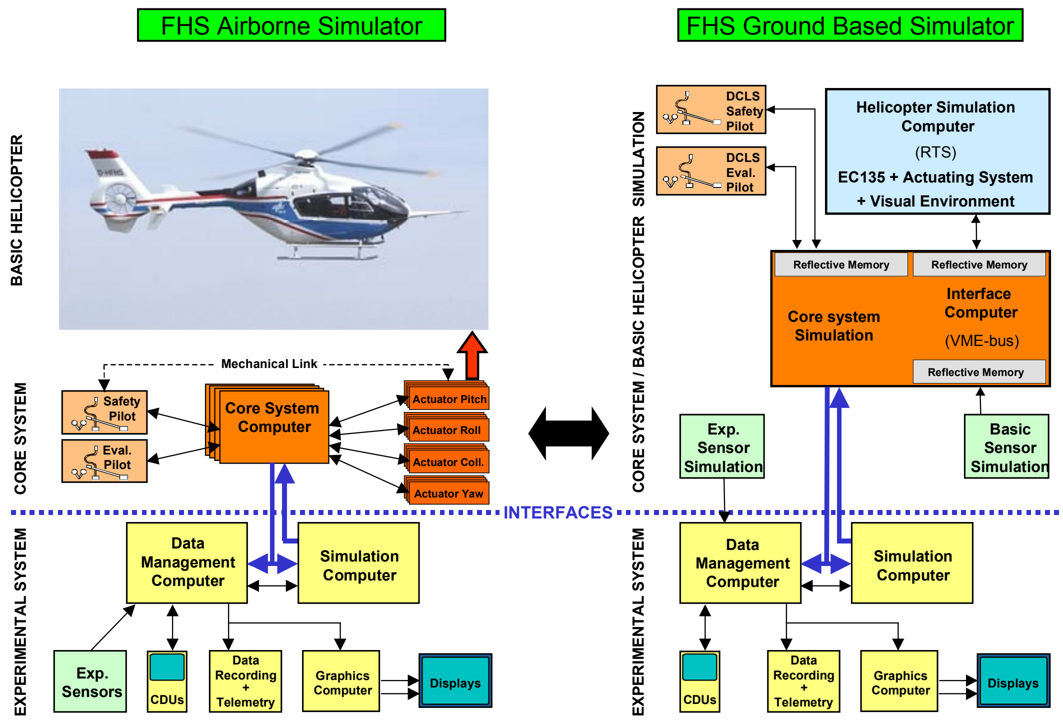


Figure 8: Comparison of the system architectures of the FHS and the FHS ground simulator

User programs

A selection of present user programs is presented below.

Control system design for airborne simulation

A major DLR objective for the FHS use is the design and optimisation of the Model Following Control System (MFCS) for the airborne simulation (Ref. 9). It gives the FHS the potential to change its basic EC135 dynamic flight characteristics and to pretend to the pilot he is flying a different vehicle. The principle approach for the control system is given in the lower part of Figure 9. Here, the key elements are the “model of FHS dynamics” representing a mathematical model

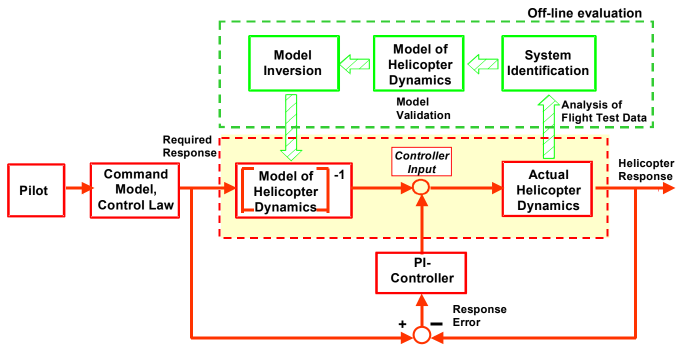


Figure 9: Principle of Model Following Control System (MFCS)

and “actual FHS dynamics”, which is the true helicopter. Under the assumption that the mathematical model exactly describes the helicopter behaviour the inverted model neutralises the original EC135 dynamics. From a control point of view this part of the forward path becomes unity in the equation and the pilot flies the model implemented in the “simulated helicopter model”. However, there are two error sources: the accuracy of the mathematical model and external disturbances. Due to the high complexity of helicopter dynamics, the model will always have deficiencies. Therefore, emphasis is placed on developing the best possible model. Here, system identification methods have proven to be ideally suited as they allow extracting appropriate models directly from flight test measurements. To compensate for remaining errors and for external disturbances (e.g. gusts) a feedback controller is used. Usually, only low gains are needed to avoid instabilities. There is a major advantage of this “implicit” control system design: It is independent from the system to be simulated, so that the command model can easily be modified without requiring a redesign of the control system. The development of the control system is a key element for the use of the FHS. Application areas are: (1) Support the design of new helicopters, (2) Development and optimisation of control laws, (3) Evaluation of handling qualities and new criteria, and (4) Demonstration of modified flight characteristics, e.g. for test pilot schools.

Control law development

An important area for future helicopters is the development and testing of more powerful (adaptive) control laws to facilitate the pure piloting task for the benefit of the pilot mission performance. It includes advanced auto-pilot modes as well as mission oriented control laws. First approaches and tests have been made for the development of model following control laws. Here, the control laws are adapted to the actual flight configuration to improve the helicopter efficiency in operational missions and to optimise the handling qualities within the full flight envelope. As a further step, the pilot tasks can be supported by associating the control laws to the functions of an active sidestick for developing a carefree handling system. A new control system with specific emphasis on flight conditions with degraded vision has been designed and tested on a ground based simulator by Eurocopter (EC). The FHS will be used to finally demonstrate the feasibility, effectiveness, and benefit of the new control system in real flight environment.

Integration and test of new sensors

Because of the extensive instrumentation and data recording equipment the FHS is an ideal platform for the integration and test of new sensors. In this respect, recently tests with radar and laser altimeters were conducted

During flight tests on the previous DLR in-flight-simulator BO105 ATTHeS, a video camera signal was used to demonstrate optical tracking for both, automatic position hold and an automatic following of a moving target. This investigation will be continued by improving the control system and the evaluation of optical sensor data (Ref. 10). It can also be extended towards obstacle warning and obstacle avoidance techniques.

Pilot assistance systems

As mission complexity increases, along with the sophistication and performance of future helicopters, support for the pilot will become more and more important. Present automation is task-centred, resulting in multiple separate task-dedicated systems, which, because they are independently structured, can place excessive workload on the pilot. Although all kinds of information are principally available to the pilot it consists of a number of individual signals and indicators and it is not presented in a format that a pilot can easily use for making fast and right decisions. This is particularly true under high stress conditions, for example in high traffic, during take-off and landing, or in flight situations where pilot augmentation is required to compensate for degraded visual information. What is needed is a pilot assistant that uses common knowledge and information resources, is self co-ordinating and operates on the human 'recognise and act' basis. An interface with the human should be highly intuitive, relying on a graphical presentation and, ultimately, voice input and output. The pilot assistant fuses signals from various sources into a few „pictures“, which offer pilots real-time decision support and relieve them from information overload.

DLR and ONERA are developing a pilot assistant with concentration on the approach/landing and take-off/departure flight phases in the framework of the project PAVE (Pilot Assistant in the Vicinity of Helipads). It also includes the optimisation of the flight trajectory based on selectable attributes, e.g. quiet or efficient (Ref. 11). The assistance system simultaneously considers various additional information sources on environment, terrain, air traffic, airport infrastructure, helicopter configuration and performance, and others. Results are presented to the helicopter crew in different automated or selectable maps on a multi-purpose display. Figure 10 presents a map design showing a suggested flight path, where restricted as well as noise sensitive areas area avoided. The pilot assistance system will first be tested in a ground based simulator and then in the FHS to assess the functionality and the benefits in real flight environment.

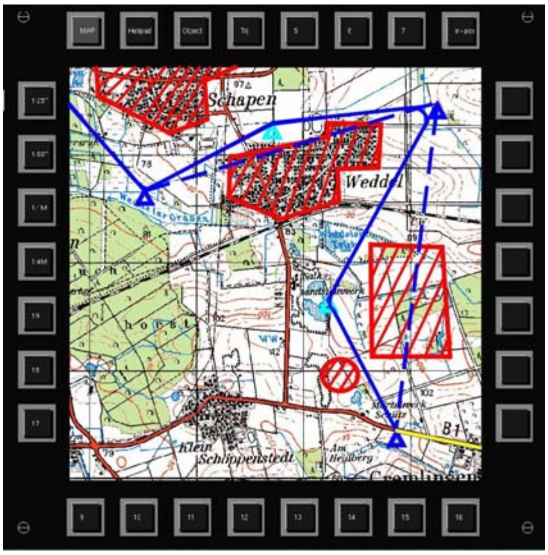


Figure 10: Map design for flight path presentation

The FHS is an excellent testbed for pilot assistant research. It provides space to add additional computer power, a free programmable display, a programmable augmentation control system, an interface to all sensor signals and a safety concept to enable evaluation of future automation concepts without extensive certification.

Future FHS development

The FHS is only in operation for a few months. Nevertheless, there are some quite detailed plans for its extension to keep the helicopter attractive for future use. Here, two areas are addressed, the implementation of an active sidestick and the development of a simulation computer with higher safety.

Active controller

Almost all helicopters currently have conventional helicopter controls, a centered cyclic stick, collective and pedals. This arrangement of the controls introduces several problems. The most obvious one is that both hands are occupied with controlling the aircraft, leaving the pilot with no hand for minding other cockpit duties (adjusting the engines, operating radios, etc.). Therefore, all possible buttons are placed on the collective and cyclic grips: The FHS has seven buttons on the cyclic and eight on the collective, a lot less than some military helicopters have. Another less obvious problem is the seating position needed to operate the controls, one reason for back aches of a high percentage of helicopter pilots. Further disadvantages are weight and space. Active controller technology is being assessed as an alternative. Although sidesticks are standard on new fixed-wing aircraft (AIRBUS, military planes), the helicopter manufacturers are reluctant towards introducing new control concepts. To obtain a better understanding of their benefits, an active sidestick

Figure 11: Grip of the FHS sidestick

is being integrated in the FHS ground based simulator and a second one is planned to be used in the actual helicopter (Figure 11). The key application areas are:

- Handling qualities

So far little systematic work has been done to establish a direct relationship between handling qualities requirements and the use of sidestick controllers. Ideally, criteria should be formulated to define which handling qualities characteristics are required if sidesticks are used. Such parameters should be established for axes likely to be controlled with sidesticks: pitch, roll, yaw, and heave axis.

- Tactile control law support

The use of advanced and full authority flight control computers opens up a whole new array of possibilities for the flight control system designer. Many functions can be integrated to automate routine or critical piloting tasks and to reduce the pilot's workload during high stress flight phases. The introduction of many different flight control system modes and functions, however, also has a major disadvantage: the pilot can no longer be instinctively aware of what he is supposed to do and what the control system is doing for him. A further danger of automation is that the pilot may no longer be aware of where the aircraft is with respect to its (control) limits.

Tactile control law support could provide the pilot with a much more instinctive feel for what his task is and what the flight control computer's task is. Additionally, tactile cues can provide the pilot with direct information about mode changes.
A research program aiming at the demonstration of tactile control system support could show that:

- Advanced forms of trim follow-up can be used to enable the pilot to distinguish between modes, for instance between rate command and velocity command.
- Non-linearities in the force gradients can be used to indicate mode blending, e.g. from attitude command at small amplitudes to rate command at large amplitudes.
- Changes in breakout force and force gradient can be used to indicate that certain control modes are active, e.g. a very 'stiff' lateral cyclic stick while speed hold is activated.
- Tactile cues can be used to warn the pilot of approaching control limits, e.g. directional 'vibrations' to indicate that a control is approaching the limit although it is a centered position.

- Ergonomics

- Ergonomics are a very important aspect of the operational use of sidesticks and a research program aiming at the operational evaluation should focus on the following questions:
- How should sidesticks be installed for maximum comfort?
- Which degrees of freedom are practicable?
- What control forces are optimal?
- What is the best concept for dual pilot authority?

Other areas for the implementation of the side stick on the FHS are related to installation, certification, and safety aspects.

Simulation computer with higher safety

The present experimental system is based on a simplex simulation computer with no specific safety requirements. This design provides a high flexibility for any modifications, but it also causes flight envelope restriction in the simulation mode for low level flight, take-off and landing. For a future use of the FHS within the full EC135 flight envelope, concepts are developed for a safer simulation computer that still keeps the present flexibility for changes. It is tried to stay with a simplex experimental computer with the individual user specific software and to generate the required safety by a redundant system, which is independent from the actual user program or task. Here, approaches with more intelligent limiters or observers or with tools that are able to predict the helicopter near future response are possible candidates.

Concluding Remark

The EC135 Flying Helicopter Simulator has been developed in a joint effort by the German industry (ECD, LLI), research organisation (DLR) with a strong support from the German Ministry of Defence (BWB, WTD61). It was designed to support research and development projects for the benefit of present and future helicopters, to assist in pilot training and to contribute to an improved man/machine relationship. The FHS is now available and ready for service.

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