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ACT/FHS FOR THE NEXT GENERATION TECHNOLOGIES EVALUATION AND DEMONSTRATION

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ACT/FHS for the Next Generation Technologies Evaluation and Demonstration

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Abstract

An advanced flight research helicopter, the Active Control Technology Demonstrator and Flying Helicopter Simulator (ACT / FHS) is being developed by DLR (Deutsches Zentrum für Luft- und Raumfahrt) and industry (Eurocopter Deutschland and Liebherr Aerospace). The development program is commonly funded by the German Ministry of Defense, the DLR and the industry partners. Using an EC 135 helicopter as a baseline vehicle, the ACT/FHS is designed as a flying laboratory capable to be used as a flying simulator and to support the research and development requirements of major programs of DLR, industry, and test centers. These programs will focus on the technology concepts for extended operational flight envelopes of the future helicopters, the man vehicle interface and cockpit technologies, and the safety concepts for digital control system design. The ACT/FHS system architecture reflects the envisaged broad application range. The hierarchically structured system includes a reliable quadruplex 1:1 fly-by-light control system with smart actuators and a modular experimental system which will be realized as a simplex system but can be extended into a redundant system. The test bed will be flown by a safety pilot from the left hand seat and an evaluation pilot from the right hand seat. The modular experimental system provides the evaluation pilot with the capabilities needed for in-flight simulation and for demonstration of digital control, sensor, display, and cockpit technologies. The development of the ACT / FHS was started in 1995. The first flight is scheduled for 2000 and first application programs are planned in 2001 after achieving the test certification. The development approach, the status, and selected features of the scheduled application programs are described.

1. Introduction

Over the last decades, piloted simulators and demonstrators have emerged as recognized and widely accepted tools to support the research and development approach for future control and cockpit technologies. In the preamble to the proceedings of an international symposium on "In-Flight Simulation for the 90's" (Ref. 1) the following evaluation of flying simulation and its incorporation into the overall design process has been expressed:

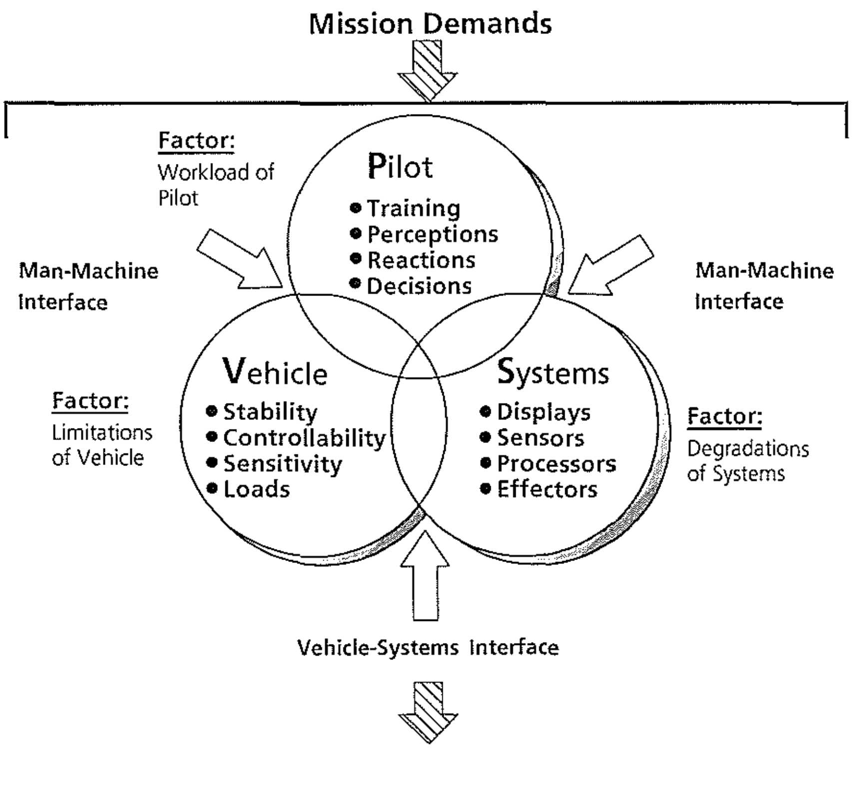
> "Within the aerospace community flight simulation has become virtually synonymous with the reproduction of the cockpit flight environment in a ground-based flight simulation facility. As this discipline has matured and assimilated the advanced in digital processor and electronic imaging technologies, ground-based flight simulation has found its legitimate domain of pilot-in-the-loop investigations both as research and development and as a training aid. Nevertheless ground-based flight simulation does have limitations related to incomplete – and sometimes conflicting – nature of visual and motion cues which are presented to the evaluation pilot.
>
> In-Flight Simulators and Variable Stability Aircraft have played an unique role in aerospace research, development and for test training by providing the proper environment and immersing the pilot in a real flight situation."

In the fixed wing aircraft industry and research, the value of piloted flight demonstration and flying simulation has been exploited more extensively compared to the rotorcraft community. For helicopters, flying test beds become increasingly important as fly-by-wire/light control systems are considered within the overall design and as autonomous systems are integrated to support the pilot and the crew and to reduce the extensive workload within delicate and critical flight phases. Indeed, the crew station design undergoes fundamental changes with the availability of advanced cockpit technologies.

In (Ref. 2), Huber and Hamel overviewed the status and the future directions for helicopter flight control design including the ground based and airborne simulation facilities. Extensive experience with the development and the operation of flying helicopter simulators and demonstrators have particularly been made in the United States, in Canada, in Germany, and also in France.

The major forces impacting on the a/c overall system design can be classified as external or internal factors to the design process. Primary external factors are the mission and mission environment. The next generation of helicopters, both civil and military, will have to meet extended operational requirements including operation close to the ground with high agility and high precision maneuvers, in extremely bad visual environment at night and in adverse weather, and over unknown terrain and obstacles. In addition, the flight safety must be guaranteed and the operational and development costs have to be reduced.

The operational demands dictate the functional requirements which can be allocated to the human element (pilot) capabilities, the vehicle (baseline helicopter) characteristics, and the integrated system elements. Figure 1 sketches these internal elements and the areas of interfaces. The design of a well balanced integrated system has to consider the limitations of the baseline helicopter, the probability of degradation due to failures of integrated systems, and the workload of the pilots. Indeed, it is necessary to use the full capabilities offered by the technologies for active control, digital cockpit equipment, and intelligent sensors which support the pilot to improve the performance in current missions and to accomplish new complex missions. To meet the operational demands for future rotorcraft, advanced guidance systems, high authority and high bandwidth control systems, active controllers, and sensor systems combined with enhanced visual information for the pilot's tasks have to be integrated. Much of the work is needed to develop practical pilot-vehicle systems that allow to make full use of the adaptive human pilot without exceeding his capabilities. With modern technologies it will be possible to partly or fully transfer pilot tasks to automatic intelligent systems such as guidance and control of the aircraft, navigation, system monitoring, and mission planning. With the digital systems taking major steps forward, helicopters become highly complex and there may be concerns that development time, technological risks, and costs will be increased.



For the effective realization of the envisaged benefits from these technologies, the use of flying simulators / demonstrators is required. Recognizing the demands for a flying test bed, the program for the development of the Active Control Technology Demonstrator / Flying Helicopter Simulator (ACT / FHS) was launched (Ref. 3).

Figure 1:
Integrated System Aspects

2. Background and Project Objective

DLR's Institute of Flight Mechanics has gained international reputation in the field of in-flight simulation, covering the methodology and the simulator flight vehicle development and operation (Ref. 4). The fixed wing test bed ATTAS, based on the VFW 614 aircraft, has been used successfully as a flying simulator since 1986. Until 1995, DLR has operated the in-flight simulator ATTHeS (Advanced Technology Testing Helicopter Simulator) which was based on a BO 105 helicopter (Ref. 5). ATTHeS was equipped with a full authority, but non-redundant digital flight control system. Applications of the airborne test facility covered a wide variety of pilot-vehicle topics like handling qualities research, test pilot training, helicopter simulation in flight, control system design, and active controller evaluation. ATTHeS was used in research and industry programs, many of them performed within international cooperations. A summary of the application programs is given in the statistics of Figure 2.

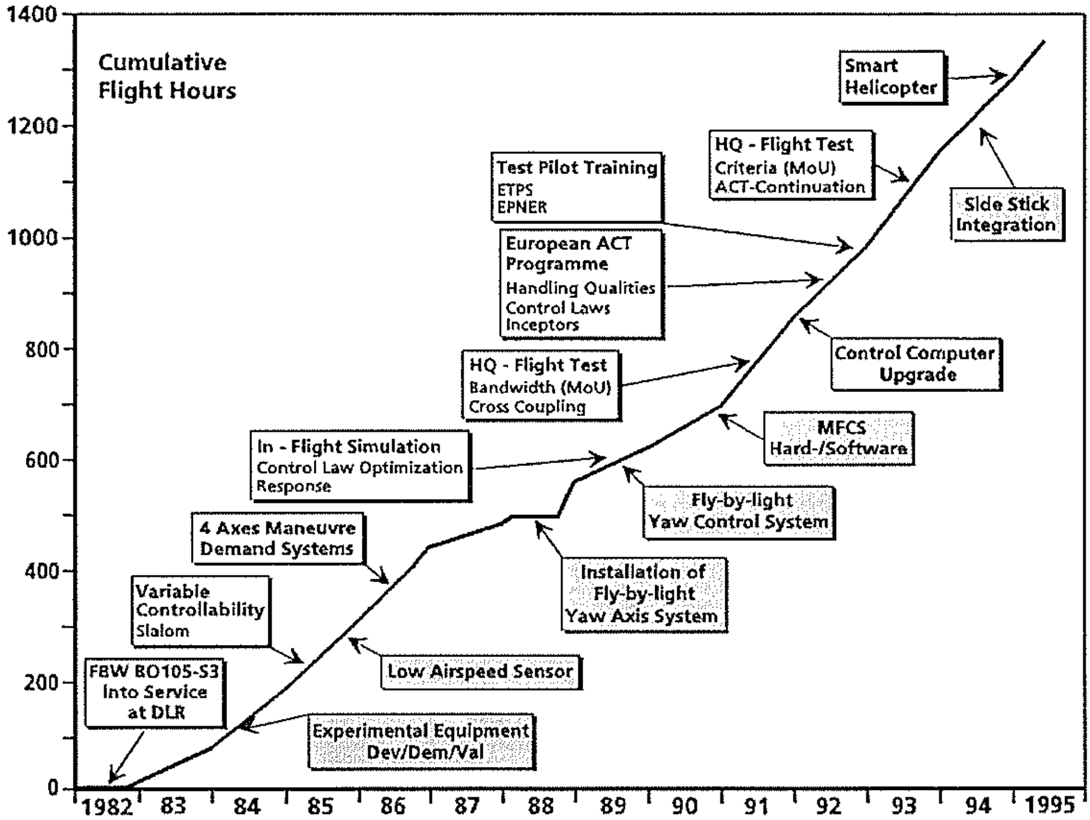


Figure 2: ATTHeS Flight Test Statistics

In 1995, the German Ministry of Defense, German helicopter industry and DLR has launched the program for the development of an advanced flying simulator called Active Control Technology Demonstrator / Flying Helicopter Simulator (ACT / FHS).

The overall objective of the ACT / FHS project is the development of an airborne test bed which will meet the various application requirements from industry, DLR, and official test centers. The use of the ACT / FHS will concentrate on the investigation and assessment of the technical feasibility and operational benefit of key technologies for future helicopter systems and the establishment of the design criteria for the integrated systems. The major applications, as specified by the main users, are:

- In-flight simulation;
- System development and integration;
- Technology demonstration.

The ACT/FHS in-flight simulation capability will be used to support the development of advanced systems and to adapt them to the pilot and the baseline helicopter. A primary objective of an ACT/FHS simulator will be the simulation of the dynamics of future helicopters with high fidelity and the evaluation of the performance and flying qualities of future helicopter designs to establish a basis for the specification and certification of tomorrows technologies.

The field of system development and integration requests specific capabilities and provisions for the integration of new active control and intelligent crew station functions. New concepts, including high authority control systems, active controllers, advanced display systems and modes, vision enhancement concepts, and mission packages have to be validated in flight as integrated part of the complete system and with specific emphasis on an improved mission effectiveness and on an optimized interface to the human pilot.

The third area of application of the ACT/FHS will be the demonstration of the functionality with respect to the operational benefits of new technologies. The technology demonstration shall be possible up to the certification tests for the new technology systems.

The specified different areas of use require the ability to integrate in ACT/FHS and evaluate hardware and software systems with various safety standards depending on whether experimental or operational equipment shall be tested. In-flight simulation and system development need an adequate flexibility to allow configuration changes, hardware and software modifications, and system upgrades. Systems and software have to be tested, which did not go through a safety examination in any detail. A slight reduction of the flight envelope can be accepted for these tests. The flight demonstration of technologies has to be performed in the full envelope. For the evaluation of the operational benefits and a pre-certification assessment, an operational standard with a proof of the failure probability of the integrated hardware and software must be provided.

An additionally indispensable fact for the accomplishment of the two-edged demands on safety and flexibility for modifications is that the test helicopter will be flown by a two-man crew. A safety pilot on the left hand seat is the pilot in command. The right hand seat is equipped for the evaluation pilot. Both pilots have access to the basic flight control in the ACT/FHS. When the evaluation pilot is flying, the experiment configuration mode can be switched on. However, access priority to control the helicopter is assigned to the safety pilot who can take over the control from the evaluation pilot at any time.

Application	Standards	Criticality Level	Safety Requirements	Failure Characteristics
In-Flight Simulation, System Development	Experimental Standard	Non Essential	Safety Pilot Reduced Flight Envelope	Fail-Safe
In-Flight Simulation, System Development, Technology Demonstration	Development Standard	Essential	Safety Pilot Full Envelope	Fail-Operate Fail-Safe
Technology Demonstration	Operational Standard	Critical	No Back-Up Full Envelope	(Fail-Operate)* Fail-Safe

Figure 3: Required System Standards

With these concept features, it will be possible to test non-redundant, non-qualified experimental equipment with non-validated software (experimental standard), partly redundant equipment (development standard), or fully redundant, highly reliable equipment (operational standard) (Figure 3).

3. Baseline Helicopter

As a result of an assessment using technical evaluations and the operational costs the EC 135 helicopter was selected to be the appropriate vehicle as a baseline for the in-flight simulation facility (Figure 4). For the selection of the aircraft, a representative test configuration was defined:

- 250 to 500 kg of payload
- 3 men crew (2 pilots, 1 flight test engineer)
- Fuel for 2 flight hours with maximum continuous power

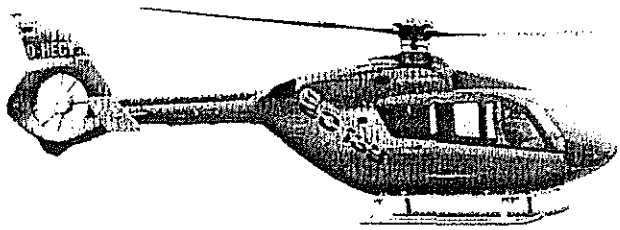


Figure 4: EC 135 Helicopter

The EC 135 is a light twin-engined multi-purpose helicopter with space for two pilots and five passengers. The EC 135 was selected in particular because it shows a very homogeneous, well balanced assessment result without significant weaknesses. Its bearingless main rotor and digital engine control represents modern helicopter technology. Furthermore, the EC 135 has low operating costs.

4. System Architecture

A hierarchical system architecture of the control system provides the pilots to fly the ACT/FHS in four different modes. The system is designed in a modular structure and with standardized interfaces and consists of the two interwoven technology units (see Figure. 5)

- a core system and
- an experimental system.

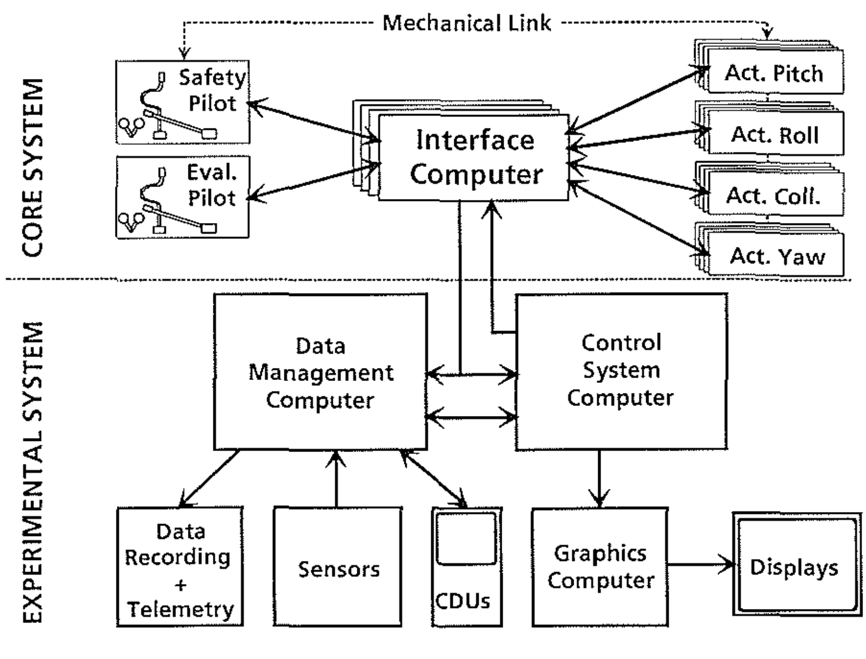


Figure 5: System Architecture

The mechanical control is used as a backup system.

Core System: The core system is the direct link (1:1) fly-by-light control system (more details in Ref. 6). It is the primary flight control system of ACT/FHS for the safety pilot and the evaluation pilot. The core system is designed in a rigid architecture according to the high safety standards for civil certification. In this 1:1 mode the pilot commands are directly processed through an interface computer to the actuators. The system consists of the inceptors with position transducers and trim actuators, the interface unit, optical data links to the actuators, and the smart actuation system with integrated actuator control electronics. It is a digital system with four-times redundancy and dissimilar hardware and software. The mechanical part of the actuators is designed as a duplex system. Built-in test functions provide continuous monitoring as well as pre-flight check and diagnostic tests for maintenance. The architecture of the core system is presented in Figure 6.

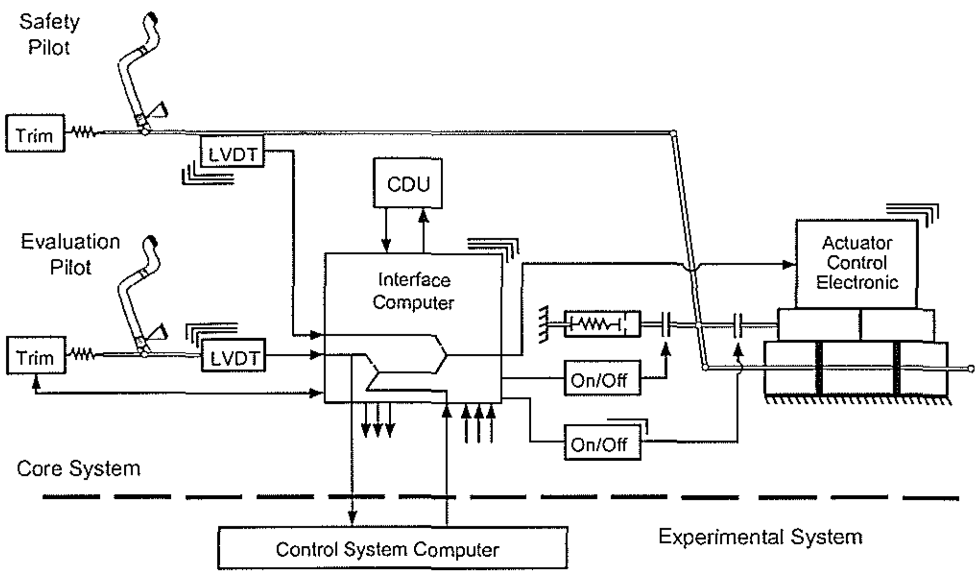


Figure 6: Core System

<u>Experimental System:</u> The evaluation pilot can switch to an experimental system with a flight control system computer which is interfaced into the direct link control path of the core system via the interface computer. The experimental system is designed with an open architecture and provides the level of flexibility to modify, to add, and to upgrade the test-software/ hardware which is needed to achieve the capability for in-flight simulation and in-flight technology demonstration. The experimental system is a simplex system but provision are provided for an upgrade to a duplex or a duo-duplex system. Well spread standards for the elements and standard interfaces are used to be prepared for system modifications and upgrades. The experimental system contsists of the following elements:

- The control system computer with a hardware/software architecture necessary for the computational requirements of the different application programs. It is connected to the interface computer in the core system by a bidirectional highspeed optical link and a standard ARINC system.
- A sensor package and a data acquisition system suitable for the acquisition of the experimental data. This includes sensors for fixed body, flight state, rotor state, and positioning.
- A data management computer which distributes data to the on-board telemetry, the data recording and the display system. With the data management computer it is possible to operate parts of the experimental system (e.g. display system) without the installed control system computer.
- A programmable cockpit display system for the evaluation pilot with an extensive computational capability for real-time data processing. The display system can be used as a multi-function-display and for the presentation of guidance information, digital maps, and test specific information.
- A test engineer's keyboard and display system for monitoring and managing the experiments.
- The control system computer is equipped with additional standard interfaces which allow to integrate additional experimental equipment (e.g. mission equipment or active controllers).

<u>Mechanical Control System:</u> During the operation in the evaluation pilot's modes, where the evaluation pilot has the full authority of the controls, the safety pilot's controllers are back-driven by the actuators which enables the safety pilot to monitor the actuators motions. If malfunction of the core control system should cause the loss of fly-by-light control the safety pilot can activate the mechanical back-up through an emergency cut off switch on the cyclic stick. The fly-by-light control can only be activated or reactivated on the ground. The principle of the transitions between the different modes are presented in Figure 7. More details about the signal processing within the core system are given in Ref. 7.

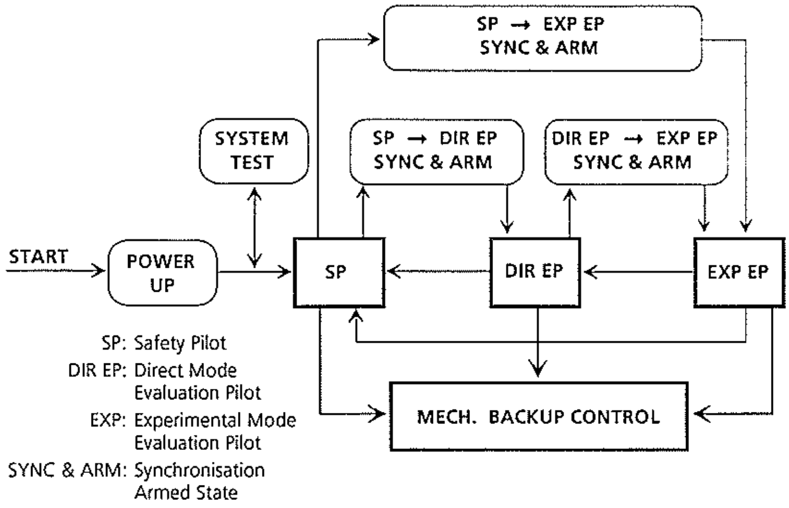


Figure 7: Modes and Transitions

Ground Stations: As an integrated part of the overall ACT/FHS facility, DLR's telemetry and engineer's ground station is adapted to the specific ACT/FHS utilization requirements. In addition, a ground based system simulator will be used for the training of the pilots and their familiarization with the ACT/FHS and for the pre-flight and compatibility testing of hardware and software modifications. Consequently, the simulator cockpit layout for the two pilots is equivalent to the cockpit environment of the flying test bed. An extended nonlinear model of the EC 135 and the coresystem is implemented. Hardware components of the experimental system are integrated which are identical to the onboard equipment.

5. Safety Concept

Functionality and reliability requirements for the two system units, the core system and the experimental system, are quite different. The core system, which is the backbone of the flight control system, has to fulfil civil certification safety requirements. For the experimental system, which shall provide a maximum of flexibility, reliability is not an explicit requirement.

Fault Tolerant Design: The complete functional chain of the core system from the position transducers to the direct drive control valves is designed as a quadruplex redundant system. In-lane monitoring within each of the four individual control channels is performed to detect and isolate component failures and deactivate faulty channels. The pure fly-by-light link of the core system has been designed in view of a catastrophic failure probability with less than 10^{-9} per flight hour.

Electrical power supply for the core system is provided by duplex essential bus bars. Transient power interrupts, which might occur due to short circuits or power switch-overs, are backed off by two buffer batteries. Hydraulic power is supplied by a duplex hydraulic system.

Dissimilar hardware for the active electronic components combined with dissimilar software is used to avoid that a generic design error would cause the the break-down of the complete system. The fail safe architecture of the control electronic is supplied by software monitoring as well as by hardware based watchdog circuits. The actuator command signals are consolidated in the actuator control electronics. The consolidation is designed in such a way that a generic failure, which is supposed to affect only one channel, would be compensated by the remaining healthy control channels.

Safety Functions: Beside the inherent integrity and reliability, the core system has to protect the aircraft against imported failures. Actuator commands, generated by the experimental system, are processed through the interface computer. Although these signals are monitored with respect to validity, parity, and update, the experimental system is able to produce runaways which must be stopped from being passed to the actuators to avoid that the aircraft is endangered. For this reason the incoming signals are processed through a runaway limiter, which can be distinguish between runaways and aggressive maneuvers. The limiter cuts off actuator commands exceeding certain combinations of signal rate and time of duration (Figure 8). Pilot control commands are processed through a phase compensation filter to avoid pilot induced oscillations, which might occur due to actuator rate saturation. Resistance against electromagnetic interference is achieved with shielded electronic equipment and optical signal transmission. Figure 9 shows a schematic signal flow within the interface computer unit, including the runaway limiter and the phase compensation filter.

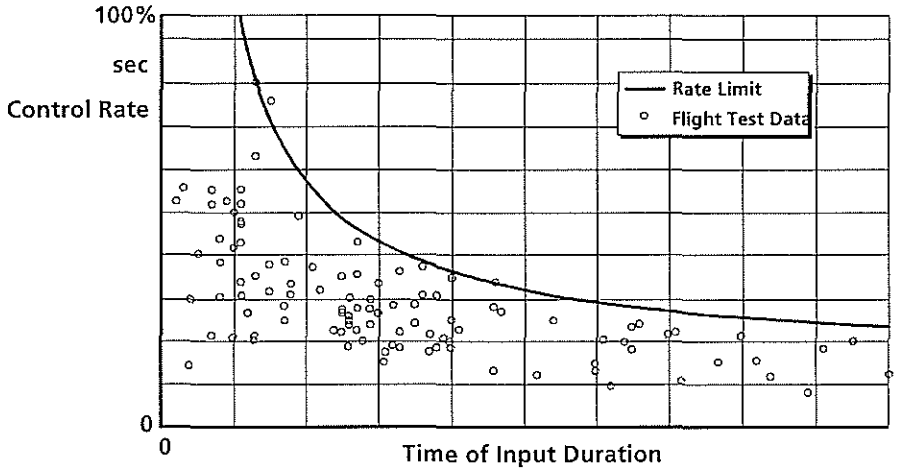


Figure 8: Rate Limitation

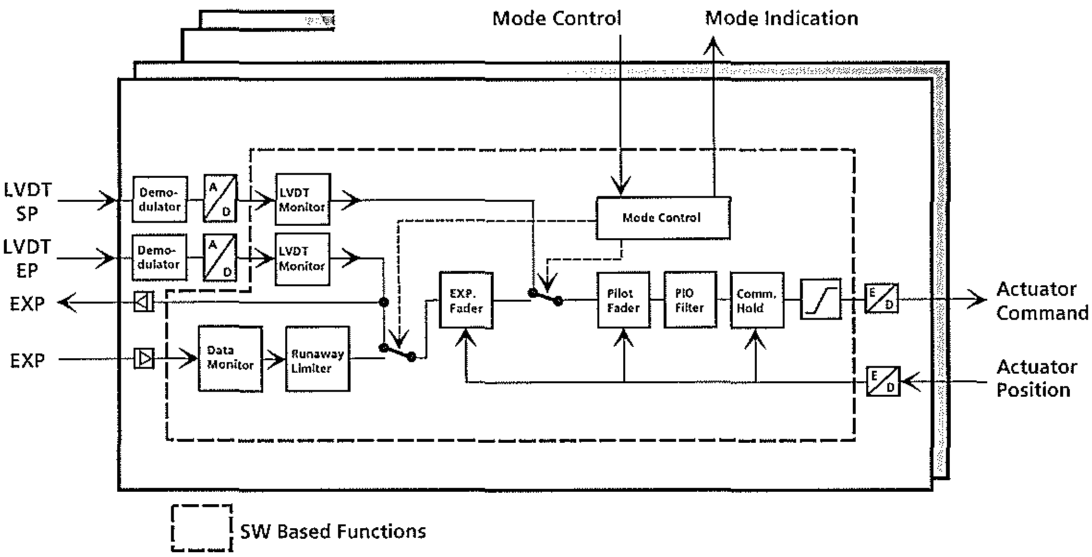


Figure 9: Interface Computer Signal Flow

Backup System: In addition to the electronic flight control system, a mechanical backup provides aircraft control in case of a total failure of the electronic system.

Safety Pilot: According to the safety philosophy adopted for the ACT/FHS, the safety pilot is the pilot in command and he has the responsibility for mode switching under normal operating conditions and a system reversion in case of failures. Switches for passing the control authority from the safety pilot to the evaluation pilot and back to the safety pilot are installed on the safety pilot's collective grip. The switches for the evaluation pilot for changing between the direct and the experimental modes are placed at the same positions at his collective grip. Switches for emergency cut-off of the experimental system as well as emergency cut-off of the complete electronic system and reversion to the mechanical backup are installed on the safety pilot's stick (Figure 10).

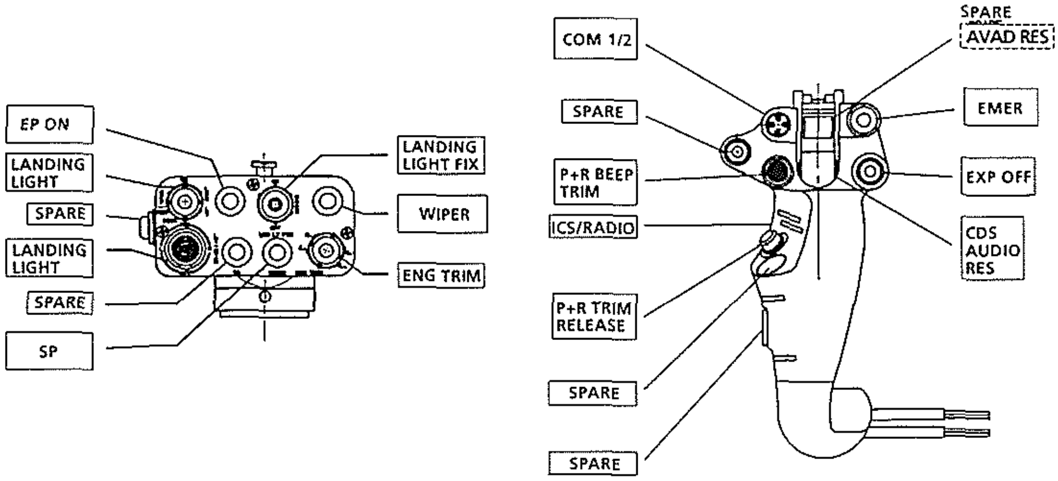


Figure 10: Safety Pilot's Controllers

In the evaluation pilot's modes, the motions of the actuators in all four axes are backdriven to the safety pilot's controllers which allows the safety pilot to monitor the activity of the actuators and enables him to quickly react in case of a failure. The safety pilot gets immediately control by applying a specified control force in any of the control axes.

In the case of any failure within the flight control system the safety pilot is alerted by a master caution indicator. Detailed failure information is displayed on the pilot's control panel. Reset switches on the panel allow the pilot to reconfigure the system after a transient failure. In the case of a severe system failure, e.g. three channels lost, a red warning light combined with an audio tone appears.

In summary, the safety philosophy for the ACT/FHS is based on a three level concept:

- The aircraft is automatically protected against system failures by a variety of safety features implemented in the system.
- The safety pilot is permanently aware of the operational situation and can take control at any time
- A mechanical backup control is available in case of emergency.

6. Schedule and Development Status

The development project was started mid 1995. The baseline helicopter was modified to provide structure, electric, cooling, hydraulic, and data link provisions for the integration of the ACT/FHS specific components. The mechanical control links have been replaced by a flexball link system. Prototypes of the core system elements are manufactured and tested. The integration of the core system has been started. Figure 11 overviews the system integration. As examples the main rotor actuator triple with the electronic control units is shown in Figure 12 and the cockpit interface unit for two lanes is shown in Figure 13. The first flight with the core system installed is scheduled for the second quarter of year 2000.

Extended component and overall system testing on the ground are performed. The flight tests needed for certification and performance evaluation in the mechanical mode and in the direct link mode for both pilots including the mode transfer procedures will be conducted following the first flight. The integration of the experimental system and the flight tests for the overall system are scheduled for the second half of 2000. The flight tests also include the final adaptation of the parameters implemented in the filters, limiters, mode transfer functions, and override forces and the pilots' evaluation of the transient behavior and the degradation characteristics after system failures. These tests will be performed with the similar software type for the core system. The development of the dissimilar software can be started after the final definition of the parameters.

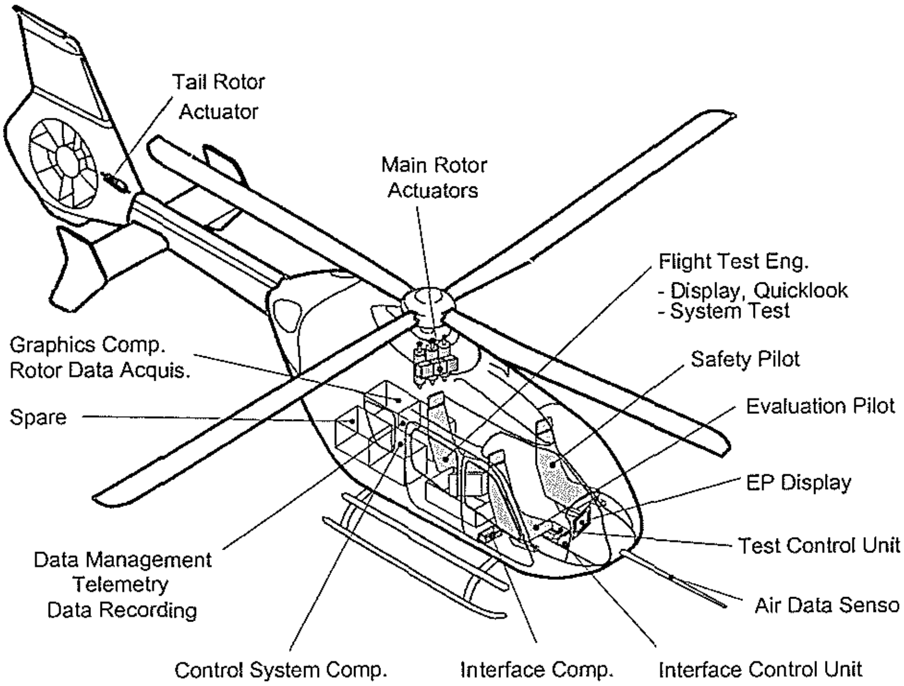


Figure 11: System Integration

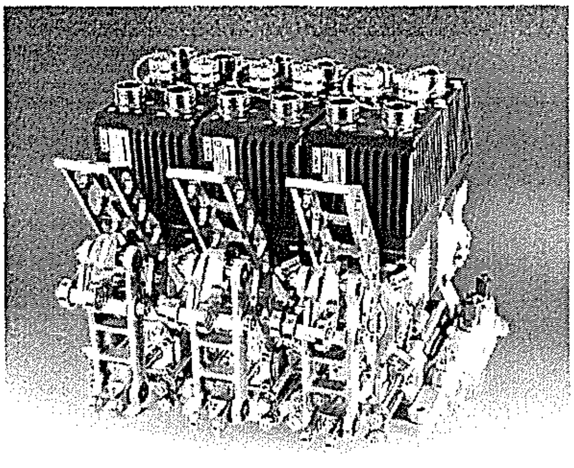


Figure 12: Main Rotor Actuator Triple

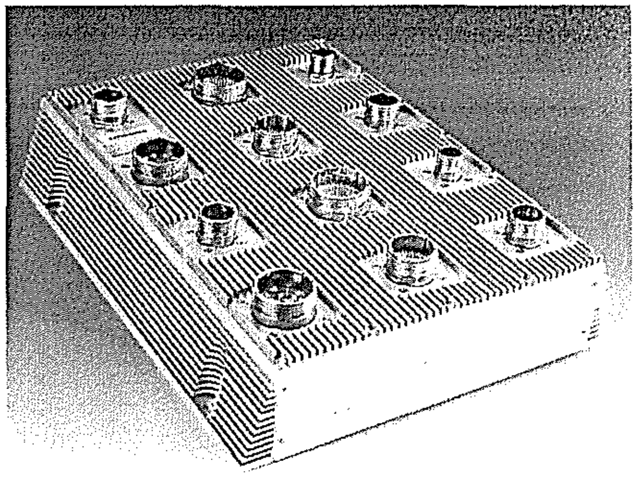
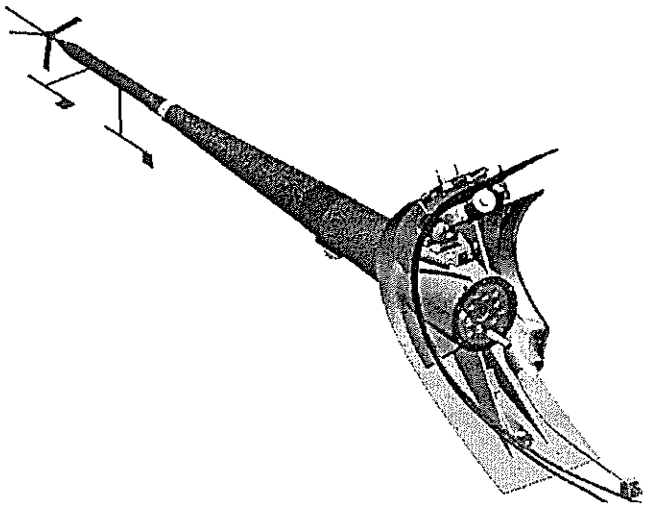


Figure 13: Interface Computer (2 Lanes)

Having considered the demands on the experimental system it was decided to use a VME bus architecture for the processing hardware. Future modifications and upgrades ask for a well established processor family with an availability of all standard interfaces. The graphics processor is an O2 machine from Silicon Graphics. Other components like the 10in flat panel displays and the control display units are off the shelf components for airborne use. The data recording is based on a silicon disk with SCSI interface. The sensor package includes the basic helicopter sensors and is completed by an attitude and heading reference system, DGPS, rotor data acquisition system, accelerometers at the pilot's seat, and an air data sensor. The swivel head air data sensor is mounted on a noseboom, specifically designed for the EC 135 (see Figure 14). All the experimental systems are ruggedized versions or have been ruggedized for the airborne environment. Most of the systems will be installed in equipment racks located in the baggage compartment, the flight engineer's panel and the evaluation pilot's panel. At present, the experimental system components are preintegrated in a mock up and are ground-tested in the ACT/FHS ground simulator.



The certification for the expe-rimental aircraft with the fully developed dissimilar software type will be applied for mid 2001 which marks the end of the development program and the beginning of the user phase of ACT/FHS. During the first half of 2001 the ACT/FHS will be used with the similar software which slightly restricts the flight envelope.

Figure 14: Noseboom with Swivel Head Air Data Sensor

7. Research Use Strategy

At first, the flying simulation capability has to be realized for the ACT/FHS. Therefor, the first research efforts will be the flight validation of linear and nonlinear mathematical models of the EC 135 helicopter. They are needed for an adequate simulation fidelity of the ACT/FHS ground based system simulator. In addition, they are the fundamental prerequisites for the design of high bandwidth control systems. To achieve the required simulation fidelity in flight, an explicit model following control system (MFCS) has to be implemented. The MFCS forces the basic helicopter to respond to the pilot's inputs as an explicitly calculated command model which is useful when a high flexibility is required to vary the commanded model without any changes of the control system. DLR has a long expertise in the field of flying simulation based on the MFCS performance with the formerly operated ATTHeS simulator. The principle of the model following control design and the achieved simulation fidelity is described in Ref. 8. DLR started the MFCS design for the ACT/FHS in a simulation environment with the aim to have the full in-flight simulation capability available when the ACT/FHS will be delivered for full operation use in mid 2001.

After the completion of the development program DLR will be the owner and the main operator of the airborne test bed. Special priorities of use are assigned to the partners which have shared the work in the development phase and the financial budget for development.

The strategy of ACT/FHS utilization considers the following common long term goals with the key aspects which should contribute to improve the overall helicopter efficiency:

- development of 24h all weather helicopter capability,
- development of autonomous helicopter capability,
- qualification and certification of new technologies related to the active control of the helicopter,
- improvement of weapon efficiency and mission equipment, and
- overall optimization of the helicopter platform with advanced control and pilot assistant systems related to performance and cost trade offs.

In order to meet these objectives the partners have agreed upon an integrated approach which will be followed within the research and development activities of research centers, test centers, and industry. The evaluation of key technologies will include the interactions between flight control laws, man machine interface aspects, navigation systems, actuators, processors, sensors and has to consider the respective environmental conditions.

Studies are performed for preparing the first research user program addressing the generation of handling qualities data bases to fill identified gaps in the existing specification documents. Here emphasis is placed on the specific relation to transport type helicopter, the integration of active sticks, the investigation of advanced controller features, and pilot assistant functions. In the first phase, industry will concentrate on carefree handling features, advanced and mission oriented control laws, and the demonstration of full fly-by-light technology. The main interests of test centers are the evaluation of performance and compatibility of mission equipment.

8. Concluding Remarks

The ACT/FHS development program has been launched in 1995. The certification for the experimental aircraft will be applied for in 2001, which marks the end of the development program and the begin of the ACT/FHS use in the full test bed envelope

The ACT/FHS is designed as a multi purpose test bed for research, industry, and test centers for

- In-flight simulation,
- System development and integration, and
- Technology demonstration.

A hierarchical system architecture will allow to integrate and evaluate hardware and software components in an airborne environment. The standard of these components can range from experimental to operational. The ACT/FHS system is based upon the technology units:

- A core system, which is the primary flight control system for both pilots (safety and evaluation pilot) designed in a rigid, quadruplex structure in accordance to operational safety standards.
- An experimental system for the evaluation pilot, designed with an open structure, providing the required level of flexibility for test modifications.
- An engineer's and telemetry ground station and a system simulator for hardware and software in-the-loop testing and crew training.

The realized safety concept is primarily based on the two pilots crew and a hierarchical architecture.

The ACT/FHS will be used in an integrated approach of research, industry, and test centers considering the improvement of the overall helicopter efficiency. The objectives are to contribute to

- the development of future 24h all weather capability,
- the development of future autonomous flight capability,
- the optimization of the overall helicopter system related to the operational requirements.

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