ACT Demonstrator / Flying Helicopter Simulator
- An Airborne Testbed Development Project -

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Abstract

This paper describes the status and the design features of a new helicopter airborne testbed which is under development. The Active Control Technology Demonstrator/ Flying Helicopter Simulator (ACT / FHS) is based on an EC 135 helicopter that is being modified by Deutsche Forschungsanstalt für Luft- und Raumfahrt (DLR), Eurocopter Deutschland (ECD), and Liebherr Aerotechnik as a subcontractor of ECD. The program is commonly funded by the German Ministry of Defence, the DLR, and ECD. The ACT / FHS shall serve as an airborne testbed for in-flight simulation and flight demonstration of modern digital technology to support research, industry development, and the technology certification process. The helicopter modifications are forced by the integration of a hierarchically structured fly-by-light / wire control system. A highly reliable quadruplex 1:1 fly-by-light control system including smart actuator technology is the core system of the testbed and will be realized for the evaluation pilot in the right seat. The mechanical back-up control system backdriven by the actuating system is installed for the safety pilot in the left seat. The testbed is completed by a flexible and modular experimental system which provides the capabilities needed for in-flight simulation and for demonstration of digital control, sensor, and cockpit technologies. The development of the ACT / FHS was started in 1995. The first flight is scheduled for 1998 and first application programs are planned in 1999 after achieving the test certification.

Introduction

The next generation of helicopters, both civil and military, will have to meet extended operational requirements including operation

- at minimum heights above ground with high agility and high precision maneuvers,
- in extremely bad visual environment at night and in adverse weather conditions, and
- over unknown terrain and obstacles.

In addition to an enhanced mission effectiveness in extended operational flight envelopes, there exists the strong need to improve the flight safety and to reduce the operational and development costs for the future helicopters.

To meet these requirements, it is necessary to use the full capabilities offered by technologies for active control, cockpit equipment, and sensors which support the pilot to not only improve performance and effectiveness in current missions but to accomplish new complex missions. These include the integration of intelligent guidance and high authority, high bandwidth control systems, combined with intelligent displayed information for piloting tasks and for aiding pilot´s decisions, active pilot controllers, and sensor systems.

The pilot has to be involved in the development approach in an appropriate way to avoid any technological misleadings and an overloading of the pilot in critical phases of the complex missions. Much of the work is needed to develop practical pilot-vehicle systems making full use of the capability of the adaptive human pilot but not 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, mission planning, and decision aiding.

With digital systems taking major steps forward, helicopters become highly complex and concerns exist 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 testbed the program for the development of the Active Control Technology Demonstrator / Flying Helicopter Simulator (ACT / FHS) was launched (Ref. 1). The development of ACT / FHS was started in 1995. The first flight is scheduled for 1998. After certifying the testbed, the application phase will be started in 1999. The development of ACT/FHS is commonly funded by the German Ministry of Defence, the DLR, and the German industry involved in the development program.

Role of In-Flight Simulation and Demonstration

A brief overview of existing airborne simulators and development programs is given in reference 2 by Huber and Hamel. DLR has operated over many years the in-flight simulator ATTHeS (Advanced Technology Testing Helicopter Simulator) which was based on a BO 105 helicopter (Ref. 3). 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 (1) handling qualities research, (2) test pilot training, (3) helicopter simulation in flight, and (4) control law and active controller evaluation. ATTHeS was used in research oriented and industry programs, many of them performed within international cooperations. DLR lost the testbed in May 1995. The crash happened in a standard tranfer flight within the mechanical control mode.

Also in Germany, the cockpit technology demonstrator AVT, based on a BK 117 helicopter, is applied in the approach to develop and test modern cockpit technologies. A digital control system is not available in the testbed for investigating a balanced design between control modes and pilot displayed informations. At ECF (Eurocopter France), the testbed Dauphin 6001 is involved in the development and evaluation of integrated digital control systems and active pilot controllers. In the US, NASA and the US Army have launched the development project Rotorcraft Aircrew Systems Concepts Airborne Laboratory (RASCAL). After the phase 1 development, RASCAL shall be available for research application in 1998. The objective of RASCAL is to support the development of integrated control, sensor, and display technology. In Canada National Research Council (NRC) operates the variable stability helicopter Bell 205. In addition, the NRC has started the development of a new in-flight simulator with an improved potential for future technology development. The host vehicle will be a Bell 412 helicopter. Some more flying testbeds are operated by industry companies which are mainly incorporated in specific helicopter development projects.

One statement that arises out of this brief summary of airborne testbed programs is the well accepted need for rotary-wing in-flight simulators. These enable and support the needed development and risk reduction to make the significant steps in progress toward the improvements in rotorcraft safety and mission efficiency with well balanced integrated technologies. These improvements will extend the operational capabilities of the helicopter. Simulation can play a critical role in the proving of a new concept, in the development of new requirements for sub-system and total system capabilities, and in the simulation of new helicopter projects. Depending on the status of a project or a concept, the demanded level of realization is increasing. Methods and facilities are available with rising system complexity and reality of the simulated environment (Figure 1). In particular, in-flight simulation plays a key role in the final proving and evaluation of promising new concepts. The value of in-flight simulation is well illustrated in the context of a development project process. At the beginning of a project the greatest design freedom correlates with the lowest knowledge where at the end of a project the knowledge expands but the options for corrections of a design are reduced to a minimum or the induced corrections will produce high additional costs. Following the first prototype flights, the knowledge about system behavior is increased significantly while the design is nearly fixed and allows only small corrections.

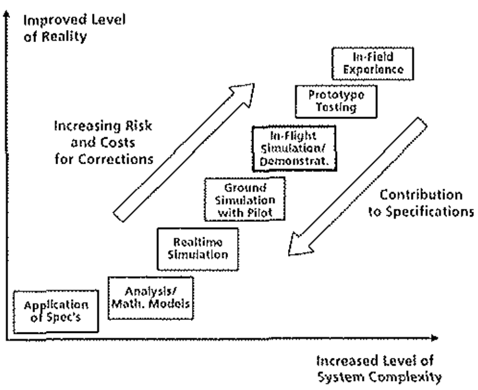

Figure 1 Development Methods and Tools

In-flight simulation lies in between ground-based simulation and flight test with prototype aircraft. The advantage of in-flight simulation compared to ground simulation is the ability to develop and test new technologies under real environmental conditions and perform tests with the pilot in the loop. The advantage of flying simulators against prototype aircraft is the fact that simulators are to a large extent independent of a particular type of aircraft and can be used for the development of various helicopters and before a prototype is available. Another advantage is a high degree of flexibility with respect to system modification and parameter variation which allows proof of new concepts in a broad variation and to generate handling qualities data effectively, both in a complementary application of pilot-in-the-loop ground-based simulators.

The experience with flying simulators and airborne demonstrators underlines that improved guidance and control systems have to be combined with improved pilot information systems and controllers to achieve a well balanced integrated design, with overall acceptable workload for the pilot, and with reasonable costs. Consequently, an airborne simulator/demonstrator in which to examine and validate integrated system designs is a growing importance and is essential in successful exploitation of new technologies in a cost effective manner.

Project Objectives and User Requirements

The objective of the ACT/FHS development project is to design and develop an airborne testbed which will be capable to cover the various demands of use at research establishments, industry, 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 ACT/FHS has to cover a wide range of applications, so that it can be used in all phases of technology development. These application demands formulate the basic frame for the overall system design.

The project was started with a project definition phase which was finished in 1995 and included the specification of the requirements of application. Based on this specification of the main users, the user spectrum will cover three principle areas (Figure 2):

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

	Industry	Research	Test Centers
In-Flight Simulation - Helicopter Simulation - Flying Qualities - Pilot Training	○	●	●
System Development - System Architecture - Control Systems - Cockpit Systems - ACT Functions - Mission Packages	●	●	○
Technology Demonstration - Functional Aspects - Operational Benefits - Certification Aspects	●	○	●

● Main Effort ○ Second Priority

Figure 2 User Spectrum

These areas of application represent all phases of technology development up to and including technology demonstration of a certifiable system. The development of new technologies requires the complementary cooperation of research establishments, industry, test centers, and certification agencies, in order to reduce development cost.

With in-flight simulation the ACT / FHS is used as a tool for development and adaptation of new technologies. Further, the ACT / FHS will be used to simulate the dynamics of future helicopters, to analyze the performance and flying qualities as a basis for the specification, development, and certification of new technologies. Therefore, the ACT / FHS must have a high degree of flexibility and simulation fidelity. Another case of application of the ACT / FHS as a flying simulator is the training of test pilots and flight test engineers for familiarization with new technologies.

Another important field of application of the ACT / FHS is the development of new active control technologies. This includes the development of the system architecture of the ACT / FHS itself, as well as the design of new flight control systems and control laws. This also includes the development of new cockpit systems and functions to evaluate the operation of new control systems for the crew and thereby improve mission effectiveness. For this task, the man-machine interface needs particular consideration. As part of system development, mission packages such as obstacle warning systems or night vision systems have to be investigated with respect to their performance within the complete system.

A third area of application of the ACT / FHS is the demonstration of the functionality and operational benefit of new technologies. Technology demonstration can be performed up to the point of certification of a new subsystem and represents the final step in using the ACT / FHS during the development of new key technologies.

In summary of the various user requirements, the ability is required to consider and integrate technologies with various safety standards depending on whether experimental equipment or operational equipment is tested. The safety concept is based on the fact that the aircraft will be flown by an evaluation pilot and a safety pilot, with the safety pilot having the authority to take control of the aircraft at any time. With this, 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).

System Standard	Characteristics	Application
Experimental Standard	safety pilot with back-up system required, reduced flight envelope	Control Law Dev. & Simulation; System Development
Development Standard	safety pilot with back-up system required, full flight envelope	Control Law Dev. & Simulation; System Development; Technology Demonstration
Operational Standard	no back-up system required, full flight envelope	System Development; Technology Demonstration

Figure 3 ACT / FHS System Standards

Baseline Helicopter

An assessment using technical evaluations and the operational costs showed the EC 135 helicopter to be the most 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 which is shown in Figure 5 for the EC 135 helicopter:

- 250 to 500 kg of payload
- 3 men crew (2 pilots, 1 flight test engineer)

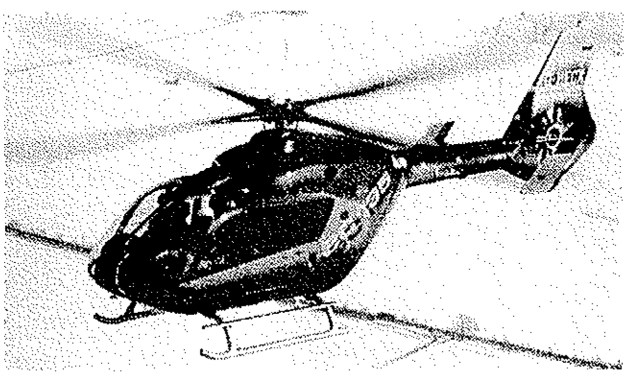

Figure 4 Baseline Helicopter EC 135

- Fuel for 2 flight hours with maximum continuous power

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. Another argument in favor of this aircraft is the fact, that this helicopter with its bearingless main rotor and digital engine control represents modern helicopter technology. Apart from that, the low operating cost makes it very attractive.

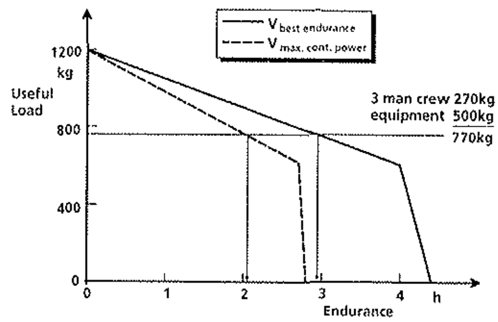

Figure 5 Test Configuration Load Diagram

System Concept

To meet the large variety of user requirements, the digital control system needs to have sufficient flexibility to allow for configuration changes, hardware and software modifications, and system upgrades. This shall be achieved by a hierarchical system architecture with a modular structure and standardized interfaces. The system shall contain technologically innovative components. Therefore, the aircraft will be equipped with optical data transmission for the 1:1 flight control (fly-by-light) and smart actuators for main rotor and tail rotor control. On the evaluation pilot seat, multi-function displays shall be integrated with the potential to be upgraded. For the evaluation tests, the need exists to have a data acquisition system and an onboard telemetry installed. A flight test engineer seat shall be available with an equipment which allows a flight test engineer to monitor the test flight and to make pre-selected configuration changes during a test. Provisions will be made for integrating smart sticks / side arm controllers and additional test specific equipment (e.g. mission equipment). Further, it is required that the system has the potential for integrating active engine control, higher harmonic rotor control, and controllable surfaces. Considering these requirements, a modular system architecture with three system levels has been selected consisting of (see Figure 6):

- a safety system,
- a core system, and
- an experimental system.

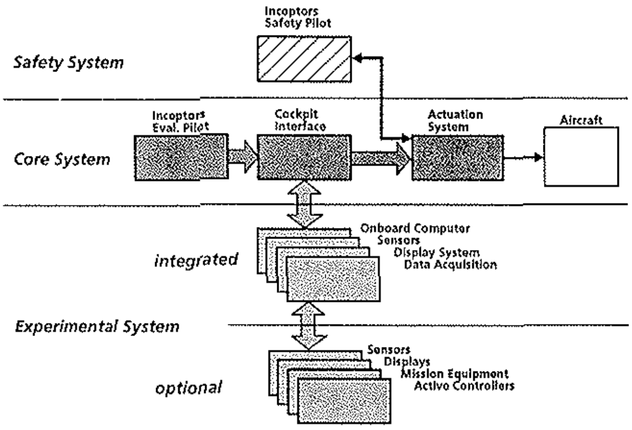

Figure 6 System Architecture

In Figure 7, the cockpit concept is described. The safety pilot´s seat is on the left hand side. The right hand seat is equipped for the evaluation pilot. The flight test engineer will be placed on a mid back seat which gives him an excellent monitoring of the pilots activity and an outside view. Most of the experimental equipment will be integrated on four experimental racks in the baggage compartment which can be removed. During the application phase, additional test-specific experimental equipment can be added on racks on both sides of the flight test engineer´s seat. In addition, the engineers seat can be used as a seat for a second pilot. This option shall enable investigations of dual pilot control modes. Also this seat is planned to be used as a pilot seat for future display technology integration research and development.

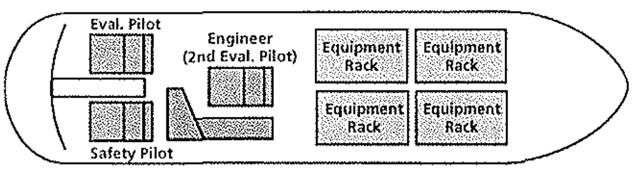

Figure 7 Crew Configuration Concept

The safety system (first level), is a mechanical flight control system, which is operated by the safety pilot. The controls of the safety pilot are mechanically linked to a clutch in the actuator control valves. The mechanical flight control system serves as a back-up system. During operation in the evaluation pilot´s mode, where the evaluation pilot has the full authority of the controls, the safety pilot's controls are back-driven by the actuators, which enables the safety pilot monitoring the actuator motion. For switching back to the mechanical controls or in case of emergency, the safety pilot can either press a cut-off switch or override by applying stick force, which gives him immediate control over the aircraft. The safety pilot´s cockpit is a conventional EC 135 configuration with added features to enhance safety and to provide simulation flexibility. The cockpit instrumentation has been configured to support Night Vision Goggles (NVG) operations.

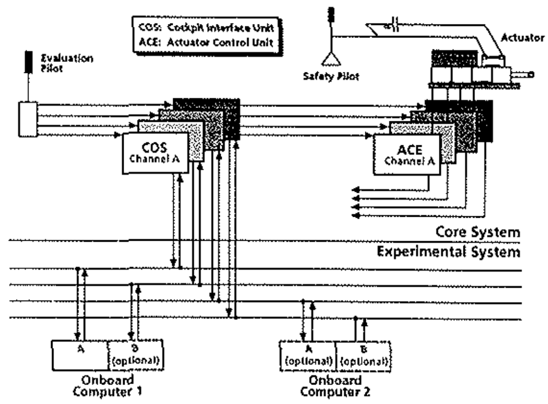

Figure 8 Structure of Redundant Core System (one control axis)

The core system (second level), is a direct link (1:1) flight control system, operated by the evaluation pilot (Figure 8). The system consists of the inceptors with position transducers and trim actuators, a cockpit interface unit, optical data links to the actuators, and the actuation system with integrated actuator control electronics. It is a digital system with quadruplex 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 core system is the backbone of the flight control system. It is designed to fulfil civil certification requirements and will be able to maintain the essential steering functions after a total failure of the flight control computers in the experimental system. The data communication between core system and experimental system is realized with the cockpit interface. In addition, the monitoring, voting, and fading functions for the redundant data system is implemented in the cockpit interface.

The experimental system is the third level (Figure 9). The experimental system is designed to provide 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 demonstra-

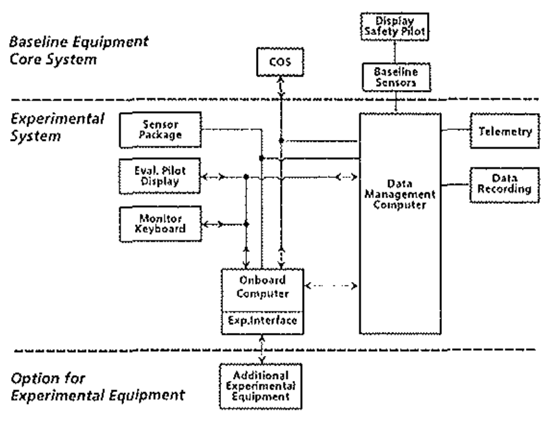

Figure 9 Structure of Experimental System

tion. After the first development phase, the experimental system will be a simplex system but with the provision for an upgrade to a duplex and duo-duplex system in the essential components. It contains of the following subsystems:

- A flight control on-board computer with a hardware / software architecture necessary for the computational requirements of the different application programs. It is connected to the cockpit interface with a bidirectional high speed optical link and a standard ARINC bus system.
- A data acquisition system suitable for the acquisition of experimental data and for implementation in flight control application. This includes sensors for fixed body, flight state, rotor state, and positioning.
- A data management computer which distributes the 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 an installed onboard control computer.
- A programmable cockpit display system for the evaluation pilot with an extensive computational capability for real-time processing. The display system can be used as MFD and for presentation of guidance information, of digital maps, and of test specific information.
- A test engineer's keyboard and display system for monitoring the experiment and inducing configuration changes to allow effective flight testing.
- The On-board computer will be equipped with additional standard interfaces (experimental interface) which allow to integrate additional experimental equipment like mission equipment or active controllers.

The system provides a variety of possible configurations and operational modes. In the direct link mode the steering commands are directly (1:1) processed through the cockpit interface unit to the actuators. In the experimental mode the steering commands are processed through the cockpit interface unit to the on-board flight control computer. The actuator commands, generated by the computers, are processed back through the cockpit interface unit and further on to the actuation system. In a ground test configuration, the actuator position signals are fed into a test computer to simulate the helicopter dynamics. This configuration enables the aircraft to be used as a ground test rig to perform hardware/software in the loop tests.

Development Schedule

The ACT / FHS is being developed by DLR and ECD with LIEBHERR-AERO-TECHNIK as a sub-contractor. The programme is commonly funded by the German Ministry of Defence, the DLR, and ECD. After completion of a one year's project definition study, the development of the ACT / FHS has started end of 1995. The baseline vehicle will be procured in 1997. First flight with the fly-by-light direct link is planned for end of 1998. A certification for experimental aircraft will be applied for in 1999, which marks the end of the development program and the beginning of the user phase of the ACT / FHS. A brief schedule is given in Figure 10.

Concluding Remarks

In-flight simulators and demonstrators are essential and integral part of the research and development of helicopter technology. The Active Control Technology Demonstrator / Flying Helicopter Simulator (ACT / FHS) shall serve

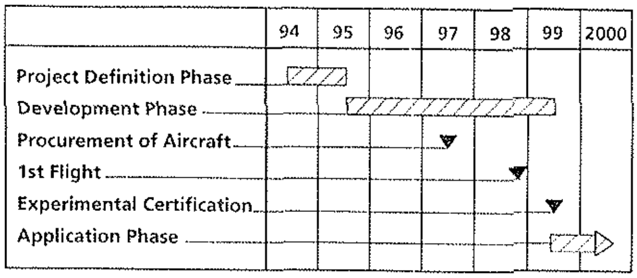

Figure 10 Program Schedule

as a testbed for in-flight simulation and flight demonstration of modern digital technology which will be one of the key technologies for future helicopter extended operation. The objective of the ACT/FHS design is to achieve an airborne testbed with the capability to be incorporated in the evaluation and development process of:

- active control systems with full authority and high bandwidth,
- active controllers,
- intelligent information systems, and
- new mission equipment packages.

The ACT / FHS design considers the various application of:

- research,
- industry, and
- government agencies.

The capabilities of the ACT / FHS will be based on a modular system with a hierarchical architecture composed of:

- a safety system,
- a fully redundant 1:1 core system, and
- an experimental system

to meet the requirements of in-flight simulation and in-flight demonstration. This system, installed in an EC 135 helicopter, will provide the performance and flexibility to meet a wide spectrum of user requirements to investigate the operational benefits of future digital control and cockpit systems and inheres the potential of growth for an utilization in the next two decades.

References

[1] Pausder H.-J., Butter U., and Gollnick V., "ACT-Demonstrator/Flying Helicopter Simulator - A New Demonstrator Test Bed for Flight Control and Cockpit Technologies", 52nd Annual Forum of the American Helicopter Society, Washington D.C., USA, June 1996.

[2] Huber H., Hamel P., "Helicopter Flight Control State of the Art and Future Directions", 19th European Rotorcraft Forum, Cernobbio (Como), Italy, September 1993.

[3] Pausder H.-J. et al, "Helicopter In-Flight Simulator ATTHeS - A Multipurpose Testbed and its Utilization", AIAA/AHS Flight Simulation Technologies Conference, Hilton Head Island, SC, USA, Aug. 1992.