

A Flight Test Experimental System For Multi Use¹

by

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Abstract

A new helicopter in-flight simulator is under development in Germany. The development project will be finished with delivery of the testbed to the German Aerospace Center (DLR) in Braunschweig in 2001. The Flying Helicopter Simulator (FHS) will serve as a testbed for technology design and evaluation especially related to the critical man-machine interface. The FHS is based on an EC 135 helicopter, which is modified with a hierarchical fly-by-light control system for a safety pilot and an evaluation pilot. The development project was started in 1996 and the first fly-by-light flight is scheduled for this year.

The FHS consists of two main technology units which correspond to the flight test operational modes: A safety critical part, which is used by the safety pilot and is certified for the full flight envelope. This part is realized with a fly-by-light system.

The second part - the experimental system - is designed as a modular multi-purpose system which is designed as non safety critical in the current development step but can be upgraded to a higher redundancy level. The experimental system is used by the evaluation pilot in order to conduct the defined experiments in the experimental mode. Depending on the implemented redundancy level this mode requires to fly the testbed in a slightly reduced flight envelope which is mainly defined by the height over ground for safety reasons.

The architecture of the experimental system has to match three major requirements:

- functionality,
- flexibility and
- expandability.

The open architecture based on VME-Bus and the hierarchical design led to an experimental system which can be used for very different types of experiments while leaving most of the system unchanged.

The overall FHS and the experimental system especially are designed with a multi use func-

tionality. These are in-flight simulation, control system configurations, side stick integration, integration of a redundant experimental control system computer and head down/head up display modes.

Introduction

DLR's Institute of Flight Research has gained international recognized expertise in the field of in-flight simulation. High level experience is achieved in the in-flight simulation methodology, the simulator flight vehicle development and the operation of the testbeds. The fixed wing testbed ATTAS (**A**dvanced **T**echnology **T**esting **A**ircraft **S**ystem), based on the VFW 614 aircraft, has been successfully used as a flying simulator since 1986 [1]. Until 1995, DLR operated the helicopter in-flight simulator ATTheS (**A**dvanced **T**echnology **T**esting **H**elicopter **S**imulator) which was based on a Bo105 helicopter. The Bo105 helicopter was equipped with a full authority but non-redundant fly-by-wire/light control system for the evaluation pilot [2].

The program to develop an advanced Flying Helicopter Simulator (FHS) was launched in 1996 [3]. The research helicopter is being developed in a common effort of the German Aerospace Center (DLR), Eurocopter Deutschland (ECD) and Liebherr Aerospace Lindenberg. The development program is funded by the German Ministry of Defense, the DLR and the industry partners. The FHS, as a successor to the DLR's Bo105 ATTheS airborne simulator has been designed as a flying simulator to support the development, demonstration and evaluation of new flight control and cockpit technologies for users from research, industry and flight test centers.

Overall System Structure

The baseline vehicle of the FHS is an EC135 helicopter ([Figure 1](#)). To transform a basic EC135 helicopter into the Flying Simulator platform requires significant modifications. The

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Fig. 1: The EC135 Helicopter

mechanical control system is removed and replaced by a full authority fly-by-light system. A mechanical backup control system is integrated for maintaining control of the aircraft in case of a total failure of the electronic system. The FHS will be operated by a three man crew consisting of a safety pilot, an evaluation pilot and a flight test engineer. The overall system is designed in a hierarchical architecture related to the role of the evaluation and safety pilot. A fault tolerant equipment design combined with a number of safety functions keeps the system protected against internal failures and disturbances imparted from outside [4], [5].

A helicopter ground simulation facility at DLR is designed as a hardware and software-in-the-loop facility for the FHS. Objectives are

- to allow software and hardware to be veri-

fied before flight in a real-time pilot-in-the-loop environment,

- to provide pre-flight training of pilots and
- to provide test preparation for the technical specialists.

To achieve this, a fixed base simulator was built with a set of original FHS inceptors, an evaluation pilot's display, a control and display unit (CDU) and a core system control unit. An active force feel system was installed to replicate the control forces in FHS. The simulator is driven by a high fidelity real-time EC135 model, with a comprehensive simulation of the 1:1 flight control system. The experimental system hardware and software is virtually identical with that of the airborne system.

To allow real-time monitoring of flight tests with ACT/FHS, a mobile flight test observation unit is being built. This unit provides facilities for real-time monitoring and off-line data analysis. It consists of two modules: a real-time monitoring station and a telemetry station.

The first flight of FHS in the mechanical backup mode was successfully performed in August 2000. After the extensive ground tests of the electronic control system equipment, the first fly-by-light flight is scheduled for fall 2001 followed by the performance flight tests needed for certification. After finishing the development phase the FHS will come into service of DLR in 2002 and will be provided for the broad spectrum of application.

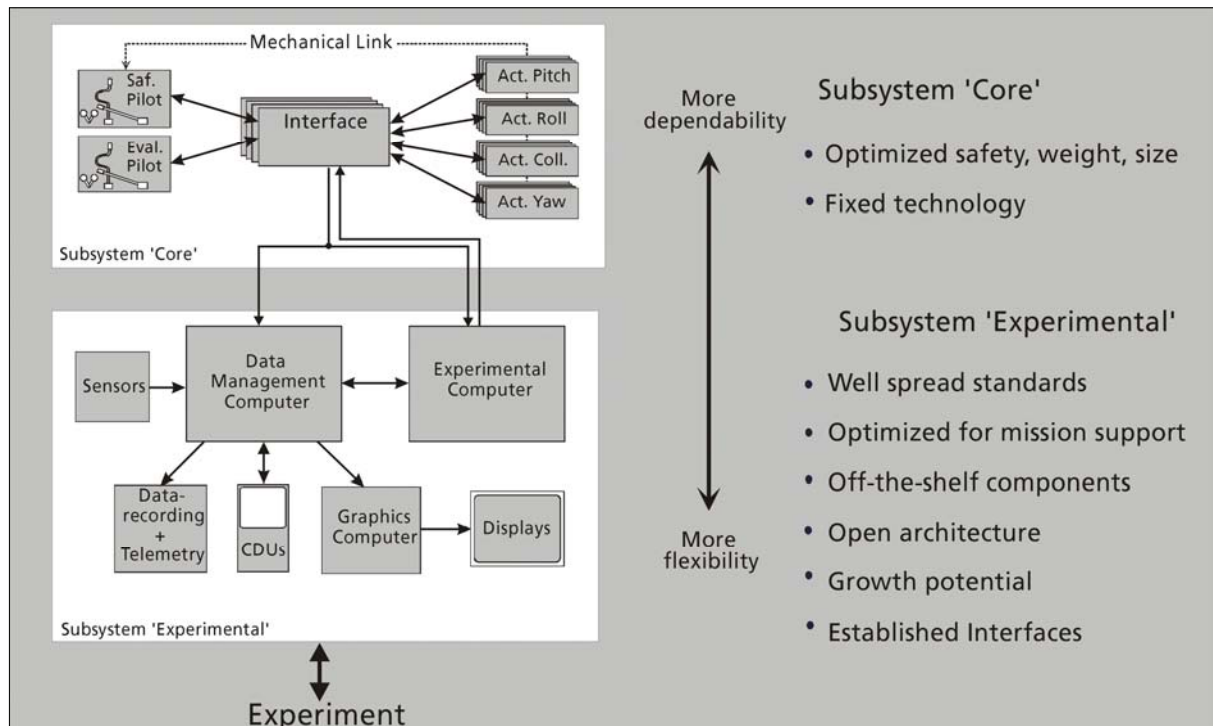


Fig. 2: Overall System Architecture

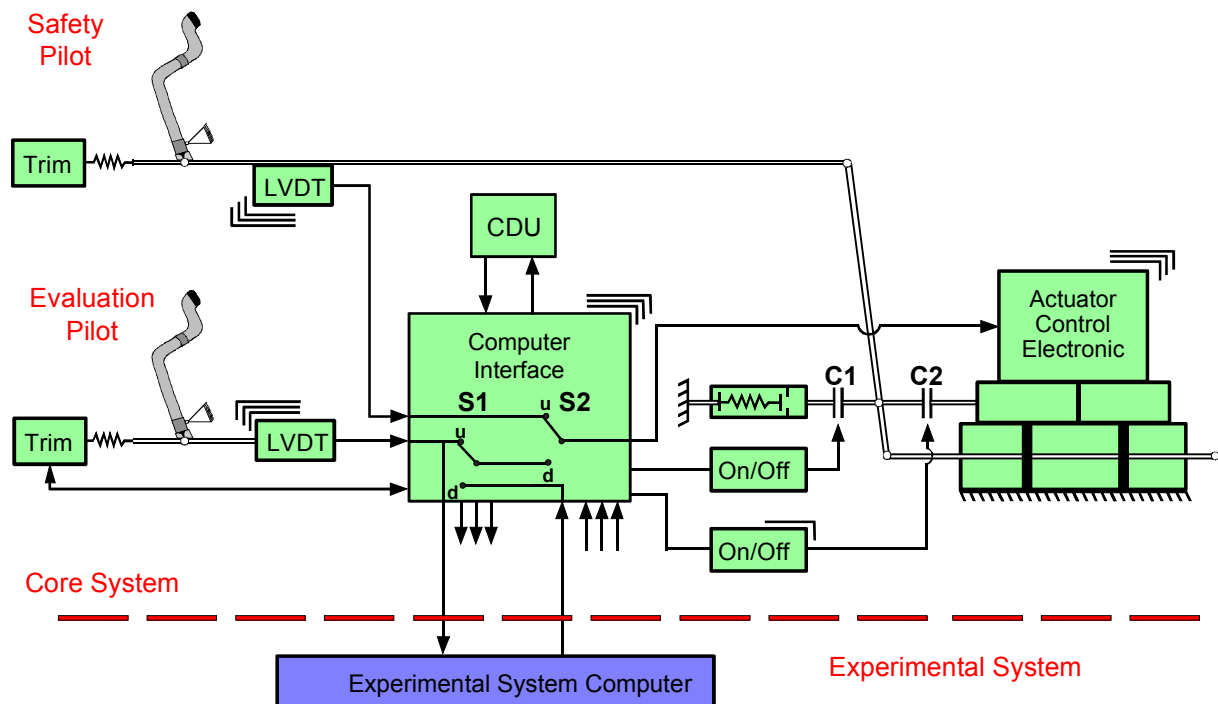


Fig.3: Control Flow

The ACT/FHS Onboard System Architecture

The system architecture must fulfill the user requirements for flight experiments (full flexibility, rapid configuration changes of flight experimental software and experimental hardware) and at the same time has to provide the full level of safety which is required for normal flight purposes or the use of the helicopter as a technology demonstrator, with no experimental HW/SW in the control loop. This twofold role of the helicopter results in a hierarchical structure which distinguishes between the categories: safety critical and non safety critical. This corresponds to two layers of the structure (Figure 2).

The upper layer called the „core system“ is the safety critical part and is used for normal flight purposes by the safety pilot. This system has to meet the civil aircraft certification requirements i. e. a catastrophic failure may not happen before 10^9 flight hours. By using this control system, which has quadruplex redundancy, the helicopter has the same behaviour compared to the unmodified series helicopter.

The second layer is called the experimental system and is allowed to be non safety critical. Therefore it is currently developed as a simplex system. Nevertheless the connection between the core system and the experimental system has been designed for later use of a safety critical experimental system with higher redundancy.

Flight Modes

Four main flight control modes are specified. The different control modes are selected by switching two clutches (C1,C2 in figure 3) near the actuators and two switches (S1,S2 in figure 3) in the cockpit interface computer „COS“. Figure 3 shows the architecture of the onboard system

I. Safety pilot 1:1

($S1=don't\ care, S2=u, C1=off, C2=off$)

In the safety pilot mode the flight envelope of the FHS is virtually the same as for the operational EC135. The safety pilot has direct control using the fly-by-light link. The mechanical link in this mode is moved, but not used for control. Of course starting and landing is possible using this fly-by-light system.

II. Evaluation pilot 1:1, experiment off.

($S1=u, S2=d, C1=on, C2=off$)

This is identical as I. The mechanical link is fed back to the safety pilot. So he can feel what the actuators do and can at any time engage his controls either by pushing a button or by introducing forces into the mechanical link.

In mode I and II the experimental system is not in the control loop and can be used for display and measurement purposes. In mode I and/or II the helicopter can be used for normal flight or as a technology demonstrator.

III. Evaluation pilot mode experiment on.
 (S1=d,S2=d,C1=on,C2=off)

This is the experimental mode in which the commands from the evaluation pilot are fed through the experimental control computer. In the computer the commands are processed and modified in order to conduct the experiment. This may be a new control law or a flight simulation algorithm. Then the output is fed through the cockpit interface computer to the actuators. In mode III the controls of the safety pilot are backdriven giving the pilot an indication of the actuator activity. He either can manually switch off the experimental system by pushing a button or he can force override by introducing forces into his controls. In both cases he gets full authority over the helicopter.

IV. Mechanical emergency mode
 (S1=don't care,S2=don't care,C1=off,C2=on)

The mechanical feed back link is also used for emergency cases if the redundant core system fails. In this case all the electronics of the core system are bypassed by the direct mechanical link of the safety pilot. Although the fly-by-light system has a full certification for the whole envelope of the series helicopter the mechanical emergency backup was left installed.

While at every time during flight it is possible to switch between modes I, II and III once mode IV has been activated, the helicopter must land using this mode before the other modes can be invoked again.

The Experimental System

The experimental system (Figure 4) consists of a data management computer, a flight control computer, a graphics processor, two multifunction displays, two control units and a variety of sensors and sensor interfaces. The role of the experimental system is to support the user of the helicopter with standard test environment of sensors, functions, hardware and software while allowing easily to add user specific SW and HW for a dedicated experiment.

Basic Considerations for Experimental System Development

At the start of the project a market analysis took place to find the adequate hardware platform. In addition to the specific user requirements, the following general requirements had to be met by the experimental system hardware and software:

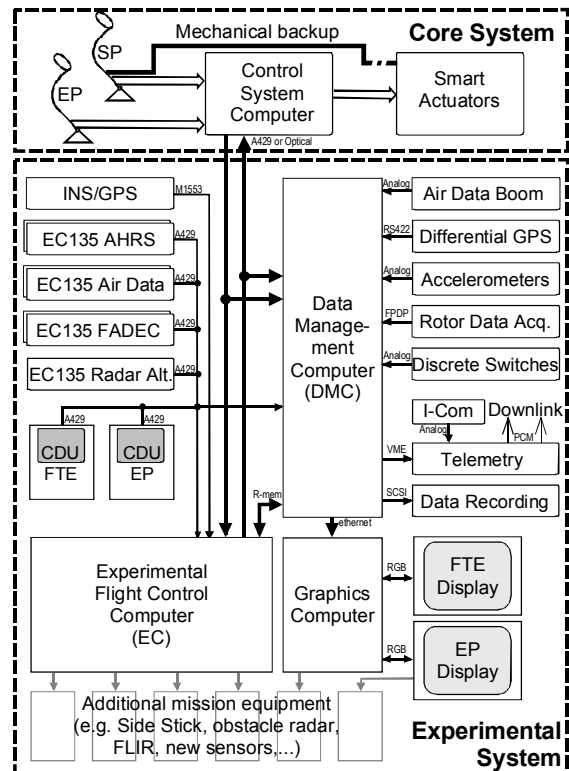


Fig. 4: Experimental System Components

Item	1	2	3	4	5
System Type	V M E	Dedicat. Airborne Duplex System	V M E	V M E	V M E
K.O. Criterias					
Price	o	-	o	-	o
Flexibility of Structure	+	-	+	+	+
Availability of Interfaces	+	o	++	+	++
Degree of Integration	o	++	+	o	+
Airborne Chassis Avail.	+	++	o	-	++
Other Criterias					
Performance	+	o	+	+	++
Operating Sys.	+	?	+	?	+
Computer to Computer Coupling	++	-	++	++	++
Cold Start Capability	++	+	-	o	++
Repair Cost, Turn Around Time	++	+	o	o	+
Development Environment	+	o	+	+	+
Redundancy Upgrade Capability	o	++	o	+	+

Table 1: Decision Matrix for System Selection
 (Legend: „++“ excellent, „+“ good, „o“ sufficient, „-“ bad, „?“ not enough information for assessment available)

- Widely used hardware standards for interfaces like ARINC 429, MIL-BUS 1553B, FPDP, CAN-BUS, SCSI etc.
- A well known and widely used processor and bus architecture ensuring future upgrades and changes of the system.
- A widely used operating system supporting the processor platform as well as all the different interfaces.

Different HW/SW manufacturers have been compared using a decision matrix (Table 1) [6]. The result of the selection process was a VME Bus system using Motorola processors (PowerPC) and running the operating system VxWorks (selection 1 in table 1).

This combination is world wide in use and a very large variety of interfaces is available from different hardware manufacturers. Components from Radstone (a British company) were selected and interface cards from other manufacturers were added, as long as they support the platform with driver software. Radstone delivers the same HW-functionalities in different build levels (Table 2). Build level 3 - the hardest air cooled level - was chosen for FHS because the next level is conduction cooled which cannot be combined with air cooled hardware.

In general one has to deal with the trade off between dedicated flight control computers which are very compact but are also rather inflexible and general purpose computers which are built somewhat larger but provide a high level of flexibility.

Data Management Computer (DMC)

The DMC receives, redistributes and stores all information from the connected base systems as well as from all subsystems of the experimental system. This information is not only sensor data but also calculated data from the user algorithms running on the experimental computer (EC). The DMC acts as the center of the whole experimental system. As opposed to most of subsystems the DMC has to be present to give the experimental system any functionality. It distributes the program code to all connected processors and takes care about the presence of subsystems. The most important feature of DMC is to fulfill the communication requirements in terms of bandwidth and latency time. Table 3 shows the communication requirements for the DMC. To meet these numbers the DMC holds two CPUs and is connected with the EC with a very fast shared memory technique which is implemented using a fiber optic communication channel. Thus data arriving at the DMC or the EC are available at each other after a few microseconds.

Interface Type	Devices Connected	Approx. Data Rate
ARINC 429	Cockpit Interface, Radar Altimeter, Air Data Systems, Standard AHRS, Engine Sensors, CDUs	50 KB/s
MILBUS 1553B	Experimental AHRS	30 KB/s
Analogue	Accelerometers, Noseboom Air Data Sensors	10 KB/s
FPDP	Rotor Telemetry	up to 96 KB/s
RS-232	DGPS, Displays	20 KB/s
Digital Switches	Pilot Switches	<1 KB/s
SCSI-2	Data Storage	300KB/s (magnitude)
Specific Interface	Telemetry System	100KB/s (magnitude)
Shared Memory	EC	up to 500 KB/s

Table 3: Communication Requirements for the DMC

	Build Standard	Temp. Range	Vibration	Notes
1	Standard Air Cooled	0 to +55°C	0.002g ² /Hz 10 to 2000Hz random	Commercial Grade
2	Extended Temp., Air Cooled	-20 to +65°C	0.002g ² /Hz 10 to 2000Hz random	Similar to Standard but conformally coated
3	Rugged, Air-Cooled	-40 to +75°C	0.04g ² /Hz	Wide temp. rugged, conformally coated
4	Rugged, Conduction Cooled	-40 to +75°C	Random 0.1g ² /Hz 5 to 2000Hz MIL-STD-810	Designed for severe environment with restricted cooling supplies
5	Tactical, Conduction Cooled	-55 to +85°C	Random 0.1g ² /Hz 5 to 2000Hz MIL-STD-810	Similar to rugged, mil temperature components. Environmental Stress Screening (ESS)

Table 2: Radstone "Build" Standards

In each system cycle of 5 ms the DMC accumulates all system data and transfers it to the EC. Vice versa the EC gathers all experiment specific data which are needed for storage and/or telemetry and sends it to the DMC. Further the DMC has to exchange information

with the graphics computer (GC) and the CDUs.

Experimental Computer (EC)

The experimental computer EC is the environment for the users' experiments. It is a VME bus computer running a 200 MHz PowerPC. It provides a direct link to the core system (COS) via standard ARINC 429 connections with 100 kbit/s. An upgrade to an optic interface with 2 Mbit/s speed between them is installed at the COS side and can be added later at the EC side.

As the EC is a simplex system but the core system is quadruplex (COS), one ARINC transmitter inside the EC drives all four receivers of the four COS lanes. In the opposite direction (COS to EC) all outputs of the four lanes are received by both the EC and the DMC. Thus it is possible to get information from each individual COS lane, but in the opposite direction all COS lanes get identical commands from the simplex EC. In future configurations it is possible to drive the COS by a redundant EC (duplex or quadruplex). The EC is connected to the DMC via a reflective memory interface and can receive data from the basis AHRS systems via ARINC 429 directly and is connected also directly to the experimental Honeywell platform via MIL BUS 1553B. It also provides ARINC links to the 2 CDUs residing at the EP's (evaluation pilot) and the FTE's (flight test engineer) place. Inside the EC about 10 VME slots are held free in order to provide space for additional interfaces of user defined experiments. The software running on the EC has a cycle time of 5 ms and provides software interfaces to integrate user defined software.

Multifunction Display (MFD)

The two displays (Figure 5) are mounted in the console in front of the evaluation pilot and in the flight test engineer's station. The high brightness display MPRD126HB is manufactured by BARCO. It has a resolution of 800 by 600 pixels (SVGA) and is night vision goggle compatible. Around the screen 12 keys are arranged for inputs like mode selection. Both displays are equipped with an additional scaler input allowing to overlay video signals of any resolution by scaling them down to a free selectable area on the display.

Graphics Computer (GC)

Until 2000 the graphic computer driving the MFDs was a ruggedized Silicon Graphics O2 Workstation. Silicon Graphics was selected because its operating system supports the

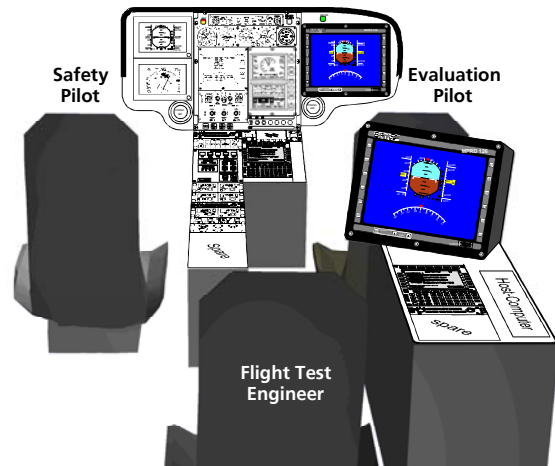


Fig. 5: Cockpit View, Displays

rapid prototype development tool VAPS. Unfortunately the Silicon Graphics hardware, especially the dual head card worked very unreliable and had to be exchanged several times. In 2001 it was decided to use a normal PC, an INTEL Pentium III 800 MHz in combination with a dual head ELSA Synergy III graphics card. This in combination with WINDOWS NT which is nowadays supported by VAPS showed to fulfill all requirements and runs very stable and fast. The PC was equipped with special mechanics and cooling to become airworthy.

Control and Display Units (CDU)

The pilot's station as well as the flight engineer station are equipped with airborne control and display units from Smith Industries. They have a character display with restricted graphics features and have been equipped with a user specific keyboard layout. Via 6 ARINC 429 inputs different systems can log in and then are able to communicate with the CDU using the ARINC 739 standard protocol. The EC and the DMC are connected to the CDU in this manner.

Telemetry and Data Storage

The telemetry system uses a PCM encoder residing on a PCI Mezzanine card on the CPU board in the DMC. This encoder has been developed by Hentschel Systems [7]. Table 4 shows features of this fully software parameterized encoder. It also allows to merge audio/intercom with the PCM data stream. Video information can also be added using a combiner from Teledyne. Telemetry signal integrity is assured by using two transmitters operating in frequency diversity mode. Also polarization diversity is possible. The antenna arrangement can be selected from a variety of

Parameter:	lower limit	upper limit
Syncword: Value	any	any
Syncword: Length	10 Bit	64 Bit
Position of MSB	first	last
Bit polarity	true	complement
Subframelength	Syncword + 1 word	1024 words
Mainframelength	1 subframe	256 subframes
Bitrate	100 KBit/sec	3 MBit/sec
Position Subframecounter	after syncword	last word within frame
Word: Frameposition	after syncword	last word within frame
Word: Subcommutated	yes	no
Word: Subframeposition	first word within frame	last word within frame
Word: Contents	dataspezific	dataspezific
Word: Length	8 Bit	32 Bit
Word: Parity	no	even/odd

Table 4: PCM Encoder Features

prepared mounting places (fin of the tail boom, upper or lower side of the fuselage, nose boom). A packet telemetry interface with its corresponding up link receiver is under development and will be available in 2002. This will provide even more telemetry flexibility.

All data which is designated to be recorded on board is represented in digital form inside the DMC. Thus an exchangeable 1 Gbyte solid state disk is connected to the DMC via a SCSI link allowing data to be recorded with a sustained rate of 18 Mbytes/s (Figure 6).

Sensors

Sensors fall into two categories: Base system sensors and experimental sensors. The base system sensors are connected to the DMC by a careful isolation to ensure that the base system can not be disturbed by the experimental system.

Base System Sensors

All base sensors provide their information using ARINC 429 Bus. The isolation between these safety relevant sensors and the DMC was made by simply introducing isolation resistors into the link to the DMC. The same was done for the intercom.

The following avionics systems of the base helicopter are observed by the DMC:

- AHRS 2x
Two systems : SFIM APIRS 2001, Interface ARINC 429, update rate 128 Hz (acceleration, angular rate), 64 Hz (attitude, heading), etc.
- FADEC 2x
Two engine control systems providing generator speed, free turbine speed, gas



Fig. 6: Data Storage Device

temperature, fuel flow etc. with an update rate of 40 Hz using ARINC 429 interfaces.

- Radar Altimeter
Bendix/King KRA 405B delivering height up to 2500 feet with a rate of 50 Hz, ARINC 429 Interface
- Air data unit (ADU) 2x
Two Sextant Avionique ADU 3000 systems delivering temperature, static pressure, diff. pressure, mach number, altitude, altitude rate, TAS, CAS using ARINC 429 interface.
- Intercom as an analog signal isolated by resistors and sampled in the analog to digital converter of the DMC.

Experimental Sensors

The following additional sensors are needed for many experiments and therefore have been

integrated as part of the standard experimental system [8]:

- Attitude heading and reference system (AHRS)
Honeywell H764G, update rate up to 256 Hz, MIL BUS 1553 B connection for angular rates, linear accelerations, attitude and heading, altitude, vertical speed. The integrated GPS system adds position, altitude, timecode and figure of merit to the Mil Bus data stream.
- D-GPS system Sharp XR6
- 3-Axis accelerometer
MSA 100, ENDEVCO Corp., micromachined silicon servo sensor with excellent linearity and adjustable measuring range. In this application it is adjusted to ± 10 g.
- Air Data Sensor (see Figure 7)
Swivel head air data boom (Type 100510, Space Age Control Inc.). It measures pitch angle, roll angle, true airspeed and static pressure and is equipped with a temperature sensor.

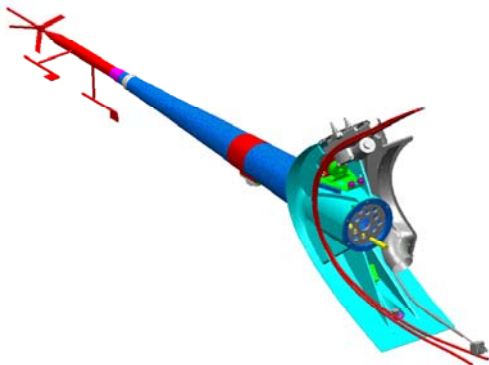


Fig. 7: Nose Boom with Swivel Head Air Data Sensor

- Rotor telemetry with data acquisition
Developed by Manner Inc., 24 channels, sample rate up to 2000 Hz. This system samples data from sensors on the rotor and transfers them into the DMC.

Cabling, EMC, Shielding, Grounding

Special emphasis was directed to the EMC (electromagnetic compatibility) characteristic of the system. All connections were made by specialists with long term experience in the field of certifiable airborne equipment. A well defined grounding concept which was developed in cooperation with the helicopter manufacturer is the basis for the cabling. Further the Institute for EMC of the Technical University of Braunschweig was involved. Double shielding for all wires and careful filtering especially of all power supply connections resulted in a complete system on a mockup which was carried in a radiation chamber of the Institute. While operating the system it was exposed with all relevant frequencies in the range of :

- 2.3 GHz pulsed, 2.5 ms, 150 ms, 800 V/m
-> no errors
- 100 MHz..1 GHz in 25 MHz steps not pulsed, 50 V/m
-> no errors
- 1.2 .. 2.6 GHz in 50 MHz steps not pulsed, 150 V/m
-> no errors
- 0.1 .. 1GHz in 50 MHz steps not pulsed, 100..200 V/m
-> errors at about 225 MHz
- ESD continuous discharge against computer cases, voltage : 12 KV
-> reproducible errors

The effects at 225 MHz were badly shielded power inputs and badly filtered logic inputs to an input card. After adding a shielding cap on the main power input and after adding filters at

the I/O port of the interface card the system worked well. A final test in the chamber is planned for fall of 2001.

Software of the Experimental System

The software which has been developed for the experimental system uses the operating system VxWorks and is written in C. The software provides a collection of system services to the user. These will be programmed once and are expected to not be changed significantly in the future:

- service to all connected interfaces,
- manages boot of all connected subsystems,
- changes configuration depending of malfunctioning or absent subsystems,
- provides services to the user like sensor data acquisition, display, CDU operation, storage and telemetry operation, display features for the multifunction displays,
- manages the interprocessor connection,
- realizes a cycle time of 2 ms and
- delivers a well defined software interface for the experimenter's algorithms and modules.

"Software Changes by Parameters"

The whole software system has been designed to change the functionality by changing parameters instead of changing code. Thus the code itself has to be developed and tested once. Of course the effort to develop more generic type software which gets its specific functionality by parameters is much larger than developing dedicated software. But the advantage is that the code itself may remain unchanged for a long period of time. All changes in terms of signal storage, telemetry, subsystem presence or configuration, display features and modes are made by sets of parameters. These parameters can be edited by the user and/or are derived automatically from databases.

The Software Development Model

Although the experimental system – at least in this simplex stage of the system – is not safety critical and has **not** to be certified the RTCA-DO-178B [9] standard for development of certified airborne systems has been used as the guiding standard. All procedures of the development process are observed but not all documents needed for certification are written and not all tests are performed. Additional standards used are the internal software development standards of DLR [10] and for the

Controlled Software Development Process

based upon RTCA/DO-178B, ESA- and DLR-standards

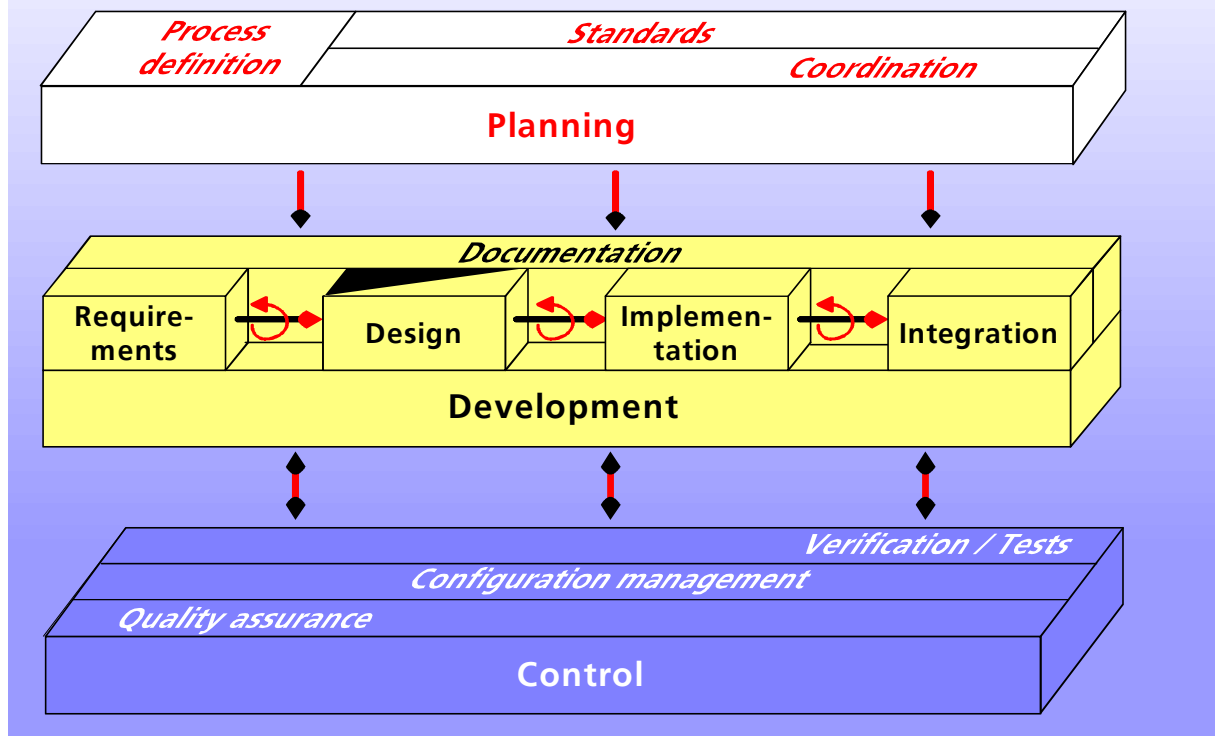


Fig. 8: Software Development Process

requirements phase the software engineering standards of the ESA [11].

According to the standards used the SW development process falls into three sub-processes (Figure 8):

- Software Planning process

In the planning process the methods and standards to be used are defined:

- Quality assurance standards
- Configuration management methods
- Software development standards
- Verification procedures
- Standards for requirements, design and implementation

- Software development process

This process consists of five phases

- Requirements
- Design
- Implementation
- Integration
- User documentation

- Software Control process

- Tests
- Configuration
- Quality assurance

- Completeness
- Traceability

All stages of the SW development process are carefully checked by a software quality assurance process if they conform to the standards

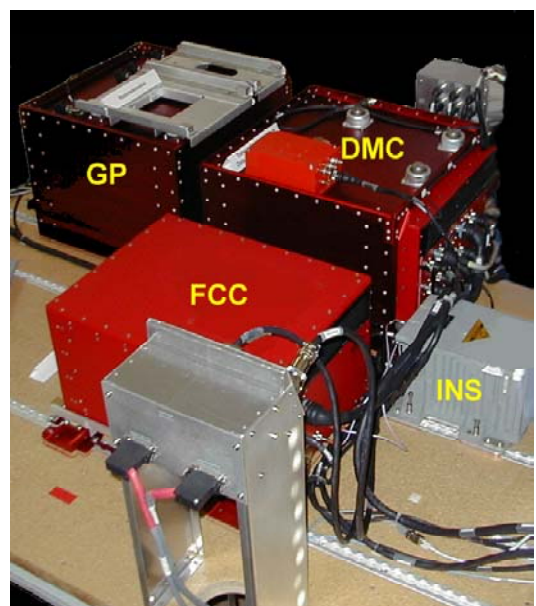


Fig. 9: Components in the Mock Up

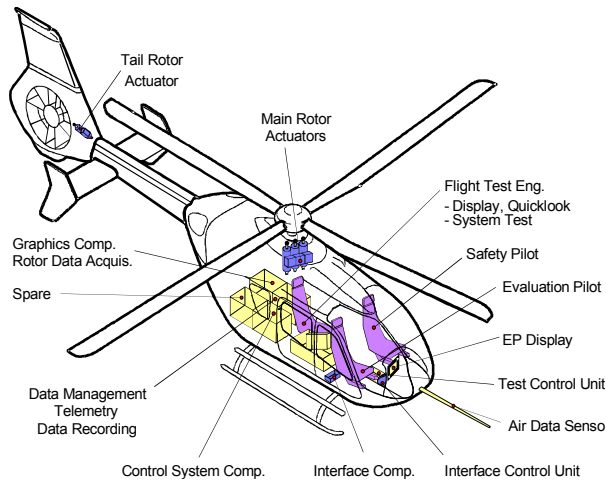


Fig. 10: The Integrated System

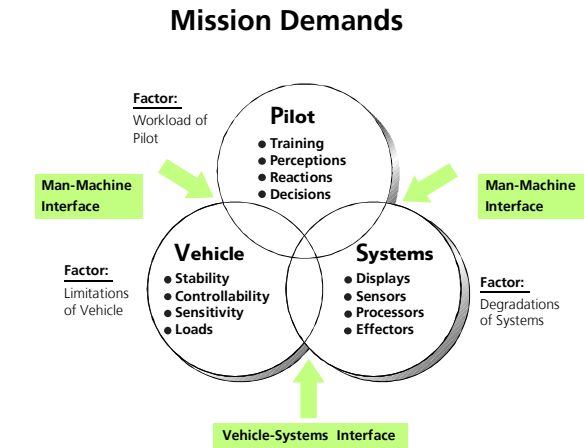


Fig. 11: Integrated System Aspects

in each step.

Several tools are used to gain the software development process:

- **VxWorks** as operating system.
- **C** as programming language.
- **CVS** for configuration management.
- **Xlint** as a code checker against implementation standards.
- **ObjectTime** as a design entry tool.
- **VAPS** for design and program of instruments to be displayed.
- **ORACLE** database for signal and configuration storage and for storage of dependencies between requirements, design and programs.

Schedule and Development Status

During the whole development process for the experimental system a mock up (Figure 9) simulating the mechanical and electrical interface to the helicopter was used. With a simple simulation for necessary components, which are connected from outside with the experimental system the software and hardware could be tested. In October 2000 the complete system has been successfully integrated into the helicopter. Figure 10 shows a sketch of the overall onboard system. About 90 percent of all software has been finished. The software was exercised for 1 month in the helicopter environment and showed no major errors. Currently the software of the experimental system software is completed. After the final EMC test the system will be ready to use in time when the helicopters core system is certified at the end of 2001.

Application Areas

In the fixed wing research and industry, the value of piloted flight demonstration has been exploited more extensively compared to the rotorcraft community. For helicopters, flying demonstrators and flying simulators become increasingly important with digital system technology for active control and advanced vision sensors being part of the overall design. The tailoring of the overall dynamic response characteristics are allowing to fulfil the mission demands and to adapt the characteristics to the pilot's capabilities. The pilot station design undergoes fundamental changes with the availability of the advanced technologies. An overview of the status and future directions for helicopter flight control concepts is given in [12] and the needs for airborne simulation facilities are discussed. Extensive experience with the operation of flying helicopter simulators have particularly been made in the United States, in Canada, in Germany and also in France. Nearly in parallel the helicopter research and industry in US, Canada, and Germany are being engaged in the development of advanced flying simulators of demonstrators. External demands on the helicopter system design are the defined mission to be performed in a specified environment. For future helicopters the extension of the operational envelope is strongly considered. Helicopters shall be allowed to be operated in extremely bad visual environment at night and in adverse weather close to the ground over unknown terrain and obstacles. These operations have to be performed without any reduction of the flight safety.

The extended operational demands with a requirement to increase the flight safety dictate functional requirements which can be allocated to a well balanced design of the integrated

system elements and the baseline helicopter characteristics. To not violate the safety of flights, the capabilities of the human pilot have to be observed. Limitations of the pilot in his control task have to be considered especially within delicate and critical flight tasks and in possible degradations due to failures of the integrated systems. Figure 11 sketches the interfacing aspects. Indeed, it is necessary to use the full capabilities offered by active control, digital cockpit, fused sensors and smart actuators which support the pilot to improve the performance in extended missions.

The FHS is designed with the objectives to support the system technology development and to cover the interface aspects illustrated in figure 9. The long term perspective of the FHS utilization addresses the vision oriented goal to improve the overall helicopter efficiency in the direction of

- 24h all weather helicopter and
- autonomous helicopter.

Additional aspects will be covered with

- qualification and certification of new technologies related to active control of the helicopter,
- improvement of mission efficiency and
- overall optimization of the helicopter platform with advanced control, intelligent displayed information, and pilot assistant systems related to performance and cost trade off.

In the near future and after delivery of the FHS to DLR the activities will concentrate on following impacts of technologies.

- In a first step the flying simulation capability will be realized with the design and implementation of the explicit **Model Following Control System** (MFCS). Based on accurately identified models of the basic EC135, a feedforward controller is designed which compensates the dynamics of the basic helicopter. Together with a feedback for disturbance rejection and feedforward error correction the command models define explicitly the response of the overall system on pilot control inputs. The MFCS approach was realized in the BO105 ATTheS system. High model following accuracy will be achieved up to frequencies over 10 rad/sec and will allow to simulate the broad band characteristics of today's and future actively controlled helicopters.
- The flying simulation capability will be used for generating an extensive database with the objective to specify the handling qualities requirements for future helicopters. Main direction is to extend the existing

ADS33 specification to transport type helicopters [13]. A flight test program with an operational CH53 helicopter has been launched this year with the objective to identify deficiencies and gaps in the ADS33 for a transport helicopter and to define the needs for improvement.

- For expanding the field of application of FHS, active side sticks will be integrated. A concept study for defining user areas and system requirements has recently been finished with an evaluation of candidates. The active side sticks shall be programmable to allow the investigation of the definition of mission oriented characteristics of active controllers, dual pilot aspects and carefree handling features. The integration of a right hand stick is scheduled for 2002/2003 followed by the integration of a left hand stick.
- Based on the developed full envelope MFCS, advanced control laws will be investigated. These include control laws in the context of a pilot assistant system. Especially in the approach phase, advanced control laws are needed to augment the pilot in his piloting task. In addition, the performance of limited authority has to be investigated corresponding to the possibility to realize higher order control laws.
- In a German-French cooperative effort an experimental system control computer with higher redundancy will be integrated. This duplex processor will replace the developed simplex experimental computer for specific studies.

Concluding Remarks

The FHS development program was launched in 1996. After development the first flight in the electronic control mode is scheduled for fall of this year. The FHS onboard system is designed in a hierarchy architecture.

The modification of the EC135 helicopter and the development of the core system is being performed by industry. The experimental system has been developed by DLR.

The experimental system is designed to meet the requirements for a broad application functionality, with high flexibility and with features to allow future extension. The experimental system is composed of the main elements

- data management computer (DMC),
- experimental computer (EC),
- multifunction displays (MFD),
- graphics computer (GC),
- control and display units (CDU),

- telemetry and data storage and
- basic and experimental sensors.

The FHS will be able to cover a broad spectrum of use for cockpit and pilot augmenting technologies, development, evaluation and demonstration. First application programs are launched:

- development of explicit model following control systems,
- active sidestick integration,
- pilot assistant features and
- integration of duplex explicit computer.

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