



**THE FLY-BY-WIRE CONCEPT
AND
ITS APPLICATION TO THE NH90 HELICOPTER**

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ABSTRACT

The scope of the NH90 programme is to design a new helicopter intended for use in the first decades of the second millennium.

The performance level required of the two NH90 versions (Tactical Transport Helicopter, TTH and NATO Frigate Helicopter, NFH) has led the Industry to recommend a number of technologies which although advanced have been fully mastered by the European manufacturers.

As far as the flight controls are concerned, the conventional mechanical solution, hybrid solutions as well as a fully electrical solution were analyzed comparatively and the fully electrical quadruplex concept was selected as a result.

This solution offers a satisfactory technical and commercial compromise while meeting the users' requirements.

The expertise acquired by the four Industrialists, namely Aérospatiale, Gruppo Agusta, Fokker and MBB on similar fixed wing programmes to begin with and, more recently, rotary wing programmes ensures that the fly-by-wire concept can be developed with a low level of risk on helicopters.

The fly-by-wire system's analysis was initiated during the Project Definition Phase and helped define more accurately the NH90 specific architecture, functional requirements and major Flight Control System (FCS) components. Higher Harmonic Control (HHC) was selected as the vibration reduction concept and is included in the system's definition.

INTRODUCTION

NH90 is a single rotor, twin engine, 9 metric tons class helicopter.

The cockpit has been designed for operation with 2 crewmembers plus a number of specialists in accordance with mission requirements.



Figure 1a NH90

Two NH90 versions are being developed simultaneously :

- A Tactical Transport Helicopter (TTH) designed for troop transport as well as Search and Rescue (SAR); TTH will operate close to or even beyond the Front Edge of Battle Area (FEBA).
- A NATO Frigate Helicopter (NFH), this is the shipborne version designed for Anti-Submarines Warfare (ASW), Anti-Surface Units Warfare (ASUW) and Search and Rescue (SAR).

NH90 will enter into service in the second half of the 1990ies for operation with European NATO Armies and Navies over the first decades of the 2000nd. This means it will have to compete with helicopters not yet designed and should include the most advanced technologies fully mastered by the industry to meet this challenge. These advanced technologies are detailed on the following figure.

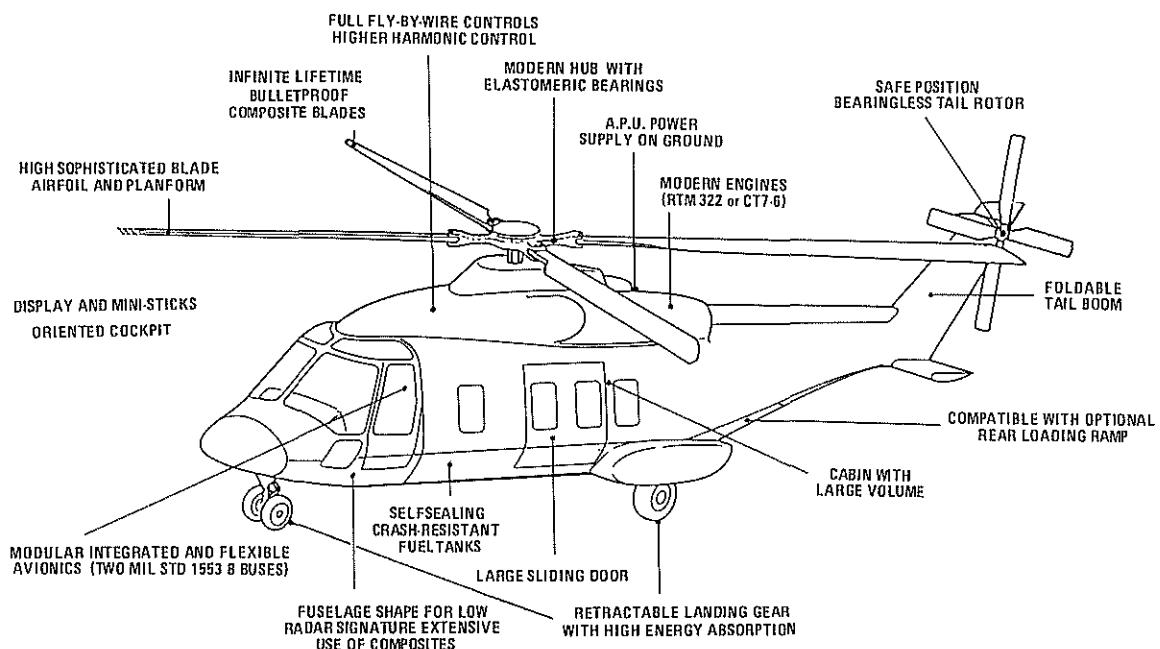


Figure 1b NH90 will be the first helicopter ever designed with an integral fly-by-wire control system

WHY WAS THE FLY-BY-WIRE TECHNOLOGY SELECTED ?

1. OPERATIONAL PERFORMANCE REQUIRED

The fly-by-wire technology was initially selected to meet the operation requirements of an 8 to 10 tons helicopter designed to operate on a 2000nd battlefield.

To give an example, TTH missions require all-weather as well as night and day troop transport capabilities close to or even beyond the FEBA. To do this, the helicopter should be able to fly at low altitude, close to the Nap Of the Earth (NOE), to avoid detection by enemy radar and thus prove less vulnerable. Probabilities of contact with hostile aircraft are higher as the final dropping zone is approached and the helicopter should then be able to perform quick evasive manoeuvres to avoid them. TTH handling qualities should then be

higher than those of a current 8-10 tons class helicopter and the FBW Control System including a 100% authority Control and Stability Augmentation System offers this agility. Likewise, the mini-stick concept allows for higher piloting accuracy and crew comfort. Reducing the crew's workload is essential when flying NOE or in hostile conditions.

Although not as demanding as those of TTH, the NFH missions are also highly stressful for the pilot. Those long and complex missions may have to be performed with 3 crewmembers only; they can last up to several hours and may include in-flight refuelling; they have to be performed in difficult weather and operational conditions and involve hovering over high seas as the helicopter comes to land on the frigate's deck.

The crew's workload must therefore be reduced upon those long missions and the helicopter's handling qualities must be improved for higher hovering accuracy.

It must be noted that the copilot also assumes the Tactical Operator's role on most missions and the pilot is often left alone to supervise flight safety.

Engine shutdown in flight is also a concern for both TTH and NFH pilots. This type of failure occurs quite frequently (the failure rate is 10^{**-4} per flight hour approximately) and the helicopter may be lost as the mechanical limitations are exceeded if not properly controlled. The FBW control system and the Full Authority Digital Engine Control System (FADEC) authorize resetting full power automatically to the engine remaining in operation after the first shutdown in flight.

The industry had for all those reasons to improve the helicopter's handling qualities and agility they also had to make special efforts to reduce the crew's piloting workload and this only became possible with the FBW control system.

2. IS FLY-BY-WIRE THE BEST SOLUTION FOR THE NH90 HELICOPTER ?

2.1. THE FOLLOWING SOLUTIONS WERE ENVISAGED FOR THE FLIGHT CONTROL SYSTEM:

- Simplex mechanical flight controls along with a conventional dual AFCS (basic modes only)
- Fly-by-wire controls.
- Numerous hybrid solutions as:

FBW/L control system with mechanical back-up, mechanical control system with FBW/L back-up and redundant mechanical flight controls were the hybrid solutions envisaged.

Those solutions have a number of common features :

- Clutches are necessary to synchronize the different control systems. These clutches are unreliable and difficult to develop; they are a weight penalty and do not necessarily improve safety (clutches themselves are critical components).

They call for the development of two different technologies, at least for the hybrid electrical/mechanical solutions, thus generating high development, manufacturing and maintenance costs as well as significant weight penalties.

These solutions were not then examined in any detail.

2.2. REMAINING ALTERNATIVES

The remaining two solutions i.e. simplex mechanical flight controls along with dual AFCS and quadruplex FBW system were examined in accordance with the operational requirements and design targets described above.

Simplex mechanical flight controls along with conventional dual AFCS (basic modes only)

This solution is now used on every 8-10 tons helicopter.

The pilot controls the helicopter with cyclic and collective sticks/pedals mechanically linked to main and tail rotor's servo-controls. The Control and Stability Augmentation System (CSAS) as well as other workload reduction devices are made available by a dual Automatic Flight Control System (AFCS) activating commands limited to 10% of the authority applied by the pilot on the servo-controls (serial actuator) while transmitting the AFCS commands to the pilot's stick via the parallel actuator.

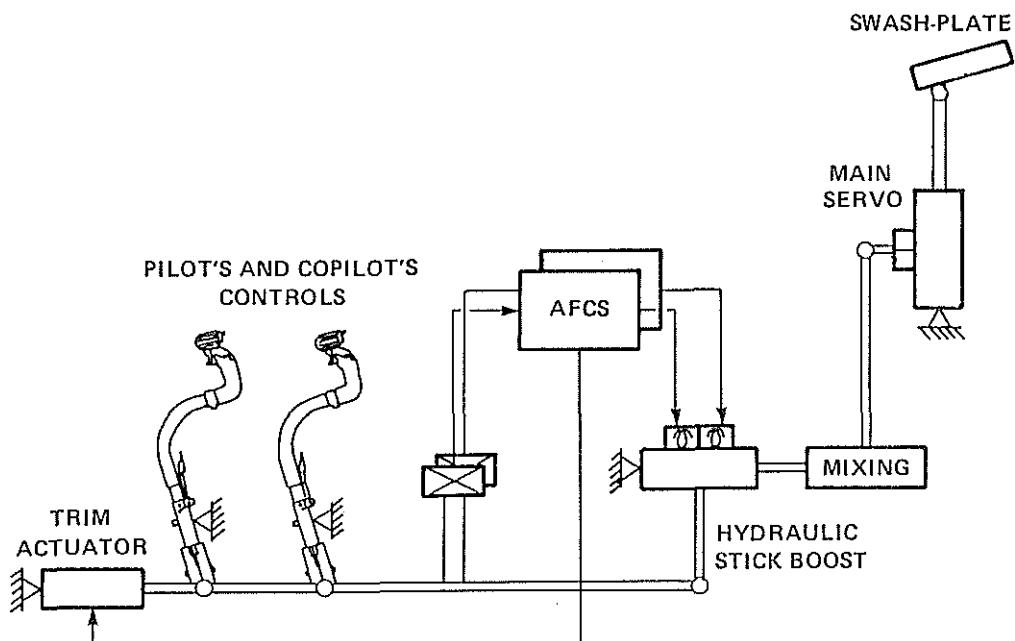


Figure 2 Architecture of a mechanical FCS - dual AFCS

The functions taken into account in the dual AFCS are basic modes only i.e. CSAS, turn coordination, attitude, heading and airspeed hold.

FBW flight controls

In this solution, the pilot controls the helicopter via either conventional mechanical or electrical inceptors (side-arm mini-sticks). The pilot's commands are sensed electrically and transmitted to 4 digital Flight Control Computers (FCC) generating position commands for the servo-controls with 100% authority. The modes, which normally are the lower ones e.g. CSAS or turn coordination on a conventional AFCS may be included in the flight control computer with higher authorities (up to 100%).

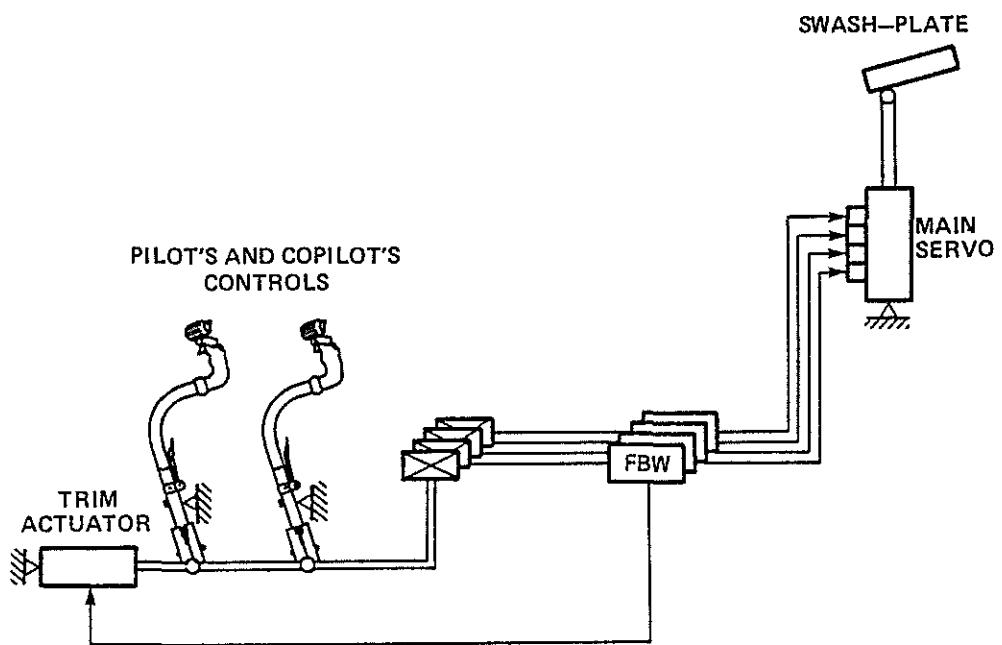


Figure 3 Architecture of a quadruplex FBW control system

NOTE : The quadruplex FBW control system is the solution compared in the evaluation below since this system meets the dual failure operational requirement. A triplex control system could meet this requirement too according to the complexity of the monitoring system.

2.3. TECHNICAL EVALUATION OF A QUADRUPLEX FBW CONTROL SYSTEM COMPARED TO A CONVENTIONAL MECHANICAL CONTROL SYSTEM WITH DUAL AFCS

CRITERIA	SIMPLEX MECHANICAL SYSTEM WITH DUAL AFCS	QUADRUPLEX FBW SYSTEM
A/C HANDLING QUALITIES	Limited improvement because of the AFCS 10% authority limitation	Max. improvement with the FBW control system's 100% authority
PILOT WORKLOAD	Heavy in some operational modes e.g. NOE and contour flight	Reduced with full control axis decoupling and limitations
COCKPIT ERGONOMICS	Poor piloting comfort because of mechanical stick	Improved with mini-stick
OPERATIONAL AVAILABILITY	Satisfactory mechanical availability with well known technology; AFCS features are single fail operative and dual fail safe only	System is made dual fail operative by design
SAFETY	Mechanical loss is extremely improbable	FBW loss is extremely improbable i.e. $10^{**-8}/hr$ or $10^{**-9}/hr$
HANDLING QUALITIES IMPROVEMENT AVAILABILITY	Extremely remote i.e. $10^{**-6}/hr$ or $10^{**-7}/hr$	Extremely improbable i.e. $10^{**-8}/hr$ or $10^{**-9}/hr$
VULNERABILITY	The mechanical system, as a whole, is vulnerable	Limited to servocontrols
WEIGHT		Reduced
ADDITIONAL FEATURES		The AFCS becomes less critical. Easy integration of active vibration control system <HHC>

The main conclusion of this technical evaluation was that the fly-by-wire control system helps meet the operational requirements, namely :

- Greater agility needed to meet the most demanding handling tasks i.e. NOE and contour flying
- Designing an optimized cockpit to reduce the pilot's workload even with limited crew

The second conclusion that may be drawn is that all the lower modes of a conventional AFCS can now be made available with the reliability of a quadruplex system.

The above operational requirements excepted, the industry also imposed design objectives to be met by the flight control system of a 2000ND helicopter :

- The system must be dual fail operational i.e. it must remain fully operational after a second failure.
- Since the Flight Control System significantly modifies the basic helicopter's dynamic response, the loss of this system must remain extremely improbable.
- Every up-to-date aeronautical concept includes modular design constraints as well as built-in test (BIT) capabilities.

Maintenance improvements are important and modular design helps reduce the components' Mean-Time-To-Removal (MTTR) while built-in tests help localize failures on Line Replaceable Units (LRUs).

The constraints mentioned above i.e. dual fail operation, extremely improbable loss, modular design and built-in test capabilities are met by design with a quadruplex flight control system.

2.4. COMMERCIAL EVALUATION OF A QUADRUPLEX FBW CONTROL SYSTEM COMPARED TO A CONVENTIONAL MECHANICAL CONTROL SYSTEM WITH DUAL AFCS

2.4.1. This comparison bears on a mechanical flight control system with dual AFCS (basic modes only) against an FBW control system with equivalent functions but an improved performance level

The following criteria are analyzed below :

- Non-recurring costs
- Manufacturing costs
- Operating costs

CRITERIA	QUADRUPLEX FBW VS MECHANICAL SYSTEM
Non recurring costs (Note 1)	20% higher
Manufacturing costs (Note 2)	Lower
Direct Operating Costs <DOC>	Similar

NOTE 1 :

The development costs of an FBW control system are estimated to be 20% higher than those of a mechanical control system.

These costs do not include preliminary probatory developments budgeted for in research programmes (Aérospatiale Dauphin FBW development helicopter) but cover development phases up to the FBW system's military qualification.

This 20% difference results from the use of new techniques such as the development of new piloting laws, of the configuration logic of the Flight Control System and of the electrical flight control system's equipment e.g. trimmable mini-stick and electrical servo-controls.

NOTE 2 :

Manufacturing costs are reduced

Direct operating costs are similar

The reason for this is that modular design as well as built-in test capabilities allow for improved failure identification and thus reduce the impact of higher system complexity on maintenance.

2.4.2. The FBW Control System offers an additional advantage in that it makes the HHC system financially attractive whenever the latter is included.

The commercial comparison then bears on mechanical flight controls with dual AFCS and passive anti-vibration system vs quadruplex FBW control system with HHC features.

The results are summarized below :

CRITERIA	QUADRUPLEX FBW <WITH HHC> VS CONVENTIONAL SYSTEM
Non recurring costs	Lower
Manufacturing costs	Lower
Direct Operating Costs <DOC>	Lower

NOTE : HHC development costs will only include the development and validation of the NH90 algorithms as well as the development of one Printed Circuit Board (PCB) for the FBW computer.

Manufacturing costs will include accelerometers, HHC PCB and PCB integration in the FBW computer.

Adding the HHC function in the FBW computer will not significantly increase the FBW system's direct operating costs; on the other hand, the direct operating costs of the mechanical Flight Control System with dual AFCS will increase significantly as those related to the passive anti-vibration system are taken into account.

Integrating the HHC function makes the FBW solution even more cost effective

3. IS THE INDUSTRY READY FOR A FBW CONTROL SYSTEM DEVELOPMENT ?

3.1. FIXED WING EXPERIENCE

The industry initially gained FBW experience with similar fixed-wing projects :

A320 digital flight control system

This system was developed by Aérospatiale and the experience thus gained will be used in terms of system architecture (both FBW and electrical generation) and industrial engineering aspects.

The distinct aspects of helicopter design with highly coupled aerodynamics, specific missions and maintenance organization should not be underestimated however.

TORNADO analog flight control system

MBB developed the Tornado jet fighter's analog flight control system in the same manner.

3.2. HELICOPTER MANUFACTURERS EXPERIENCE

Helicopter manufacturers mainly gained experience with simulation and flight tests.

Pilot-in-the-loop simulations have been undertaken by Aérospatiale in the CEV and CELAR flight dynamics simulators.

These simulations have been undertaken as part of a French research contract and under the responsibility of a French Government agency (STTE).

These control laws are of the full authority, 4-axis fly-by-wire type.

The laws evaluated here are :

- Control laws equivalent to a direct mechanical link
- Attitude command control laws
- Attitude rate command control laws

These control laws are being experimented with in different stick configurations i.e. conventional mechanical stick as well as mini-stick designed especially for helicopters.

Pilot-in-the-loop simulations with FBW control laws have now been running for 5 years.

Flight tests with a 4-axis full authority fly-by-wire control system on an Aérospatiale SA 365 Dauphin helicopter.

These flight tests have been undertaken as part of a French research contract and under the responsibility of a French Government agency (STTE).

The objective here is to define how the helicopter's handling qualities can be improved with advanced control concepts changing its natural response.

Flight tests were started with an SA 365 helicopter S/N 6001 in April 1989. The same control laws initially tested in the flight dynamics simulators are now being experimented in flight.

The control laws suggested for the NH90 helicopter are currently undergoing evaluation with a mechanical stick; mini-stick evaluation will proceed as soon as the latter is available i.e. by the end of 1989.

Further advanced control laws i.e. attitude rate command control laws will be evaluated with the mini-stick.

A schematic diagram of the SA 365 helicopter's FBW control system is presented below together with a photograph of this helicopter in flight (See Fig. 4 and 5).

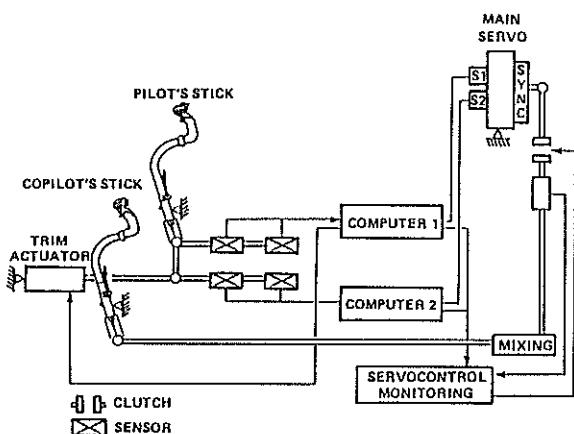


Figure 4 DAUPHIN FBW system architecture

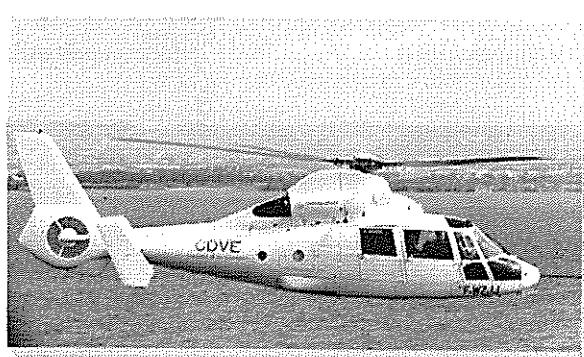


Figure 5 FBW DAUPHIN in flight

4-axis control laws flight tests performed on a BO 105 helicopter by DFVLR and MBB

The DFVLR laboratory and MBB have developed a 4-axis control system with off-the-shelf components including AFCS computers and trim motors, serial actuators and mechanical servo-controls. These flight tests are intended to reproduce the required helicopter transient response whatever it may be, but with the inherent limitations of an AFCS system.

Flight testing the fly-by-light triplex system controlling the directional system on the BO 105 helicopter by DFVLR and MBB

The same BO 105 helicopter is used to test a triplex optical system controlling the directional axis; optical technologies are used for signalling purposes only.

HHC concept flight tests on an SA 349 Gazelle helicopter by Aérospatiale

Various HHC algorithms were tested in 1985 throughout the entire flight envelope, take-off and landing included. The conclusion was that the Higher Harmonic Control (HHC) system is more efficient than any passive anti-vibration device (See Ref. No 1).

3.3. DEVELOPMENT WITH MINIMUM RISKS

The equipment manufacturers currently working on the technological solutions selected for the NH90 helicopter :

- Direct-drive servo-controls meeting the HHC dynamic requirements are being developed
- A mini-stick meeting the helicopter's functional requirements i.e. a force stick with a position trim capability is being designed in parallel during the transition period preceding development initiation.

Risks are minimized in the development scheme itself where :

- Full use is made of the Dauphin FBW experimental helicopter
 - Flight laws will be assessed on the helicopter with a conventional mechanical stick to begin with and a mini-stick at a later stage.
 - The mini-stick will be flight tested on the helicopter.
- Tests with the SA 365 Dauphin FBW helicopter excepted, risks are also minimized as NH90 development is mastered as demonstrated in Para. 5 below.

3.4. HELICOPTER MANUFACTURERS' INDUSTRIAL EXPERIENCE

The industry's ability to master a complex development is being proved with the AS 332 Super Puma Mk 2's IFDS, the HAP/HAC's basic and MEP systems and the EH101's systems.

This calls for :

- The use of system design methodology.
- The use of computer aided specification tools e.g. SAO to design control laws.

These tools were validated during industrial programmes previously undertaken by Aérospatiale's Helicopter Division e.g. AS 332 Super Puma Mk 2's digital AFCS (See Ref. No 2) and Aircraft Division e.g. Airbus A320's digital Flight Control System.

- The use of general-purpose computer aided tools e.g. REBECCA that help make the data processing system more user friendly.
- The use of a software development methodology suitable for equipment in accordance with MIL-STD-2167, level 1.

4. PRELIMINARY SYSTEM DEFINITION

4.0. SOLUTION OF THE INDUSTRY :

4.0.1. The architecture is a quadruplex fully electrical fly-by-wire control system.

Each FBW computer is composed of a digital control unit as well as an analog direct link, if required.

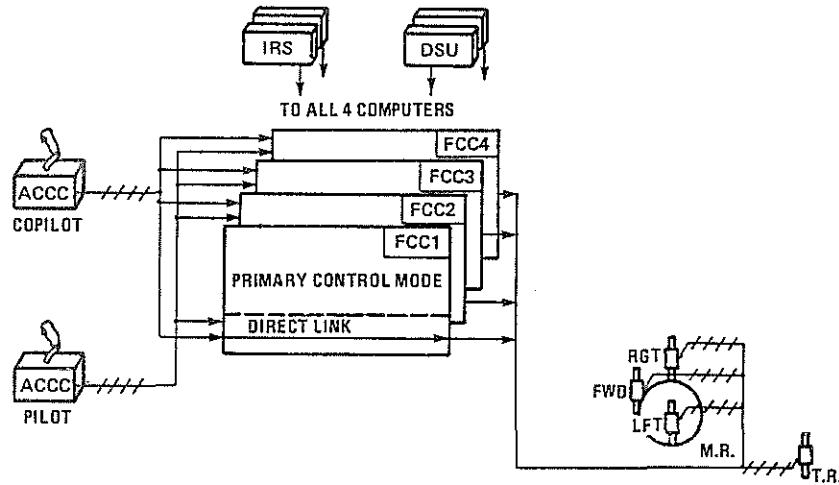


Figure 6 NH90 FBW control system architecture

This digital architecture is meeting the dual fail operational requirements by design via four self-monitored channels.

Full use of the system's dissymmetry will be made to guarantee FCS safety either with a dissymmetrical software in the digital FCCs or the direct analog link.

4.0.2. Helicopter control with mini-stick inceptors

Control stations in the cockpit will be equipped with :

- A RH cyclic mini-stick (longitudinal and lateral axis)
- A LH collective mini-stick (1 axis)
- Conventional, mechanically-linked pedals.

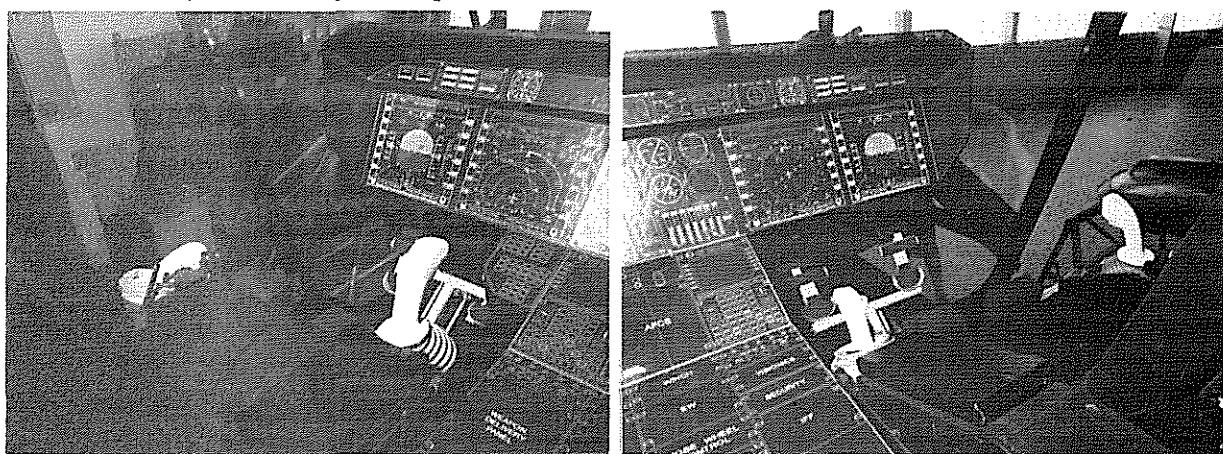


Figure 7 Cockpit

It can be noted that although advanced technologies (mini-stick) are used, helicopter handling remains conventional.

- Cockpit controls have not been grouped i.e. there is no 4-axis or 3+1-axis configuration and the pilot is still operating the well known cyclic and collective sticks as well as pedals.
- The cockpit controller positions represent the main rotor position when necessary and the crew is informed of the remaining control margins by the stick and pedal positions.
- Electrical sticks are synchronized to reproduce the behaviour of pilot-actuated mechanical rods.
- A back-up mode with less efforts and larger displacements is available.

4.0.3. Main and tail rotor actuators are driven electrically (No mechanical input)

4.1. FUNCTIONS APPLIED :

The fly-by-wire control system includes :

Interfaces with cockpit controls :

- Input sensing of control efforts applied by pilot and copilot.
- Addition of pilot and copilot forces used as input commands to control laws.
- Both sticks are synchronized by motorization authorizing normal AFCS trim motor functions.

Basic FBW handling modes

- Long term control similar to that allowed by conventional, direct mechanical controls.
- Positive static stability, at least from medium to high speed range.
- Dynamic stability augmentation identical to that of a CSAS.
- Agility improvement via control augmentation.
- Automatic turn coordination (no longer will the pilot have to coordinate the different axes).
- Selective control axis decoupling.

The high aerodynamic coupling effects induce an action on a perpendicular axis up to 30% of its authority. In a mechanical control system, this coupling has to be corrected by the pilot and thus requires special training.

Back-up modes : a direct link will be fitted at least for the preliminary flight test.

Additional features

- Basic AFCS modes.
- Higher Harmonic Control i.e. reduction of the vibrations induced by the main rotor with adequate 4* Nr servocontrols' commands.
- Engine control systems' optimization.

The major functions and their relative positions are shown on Fig. 8

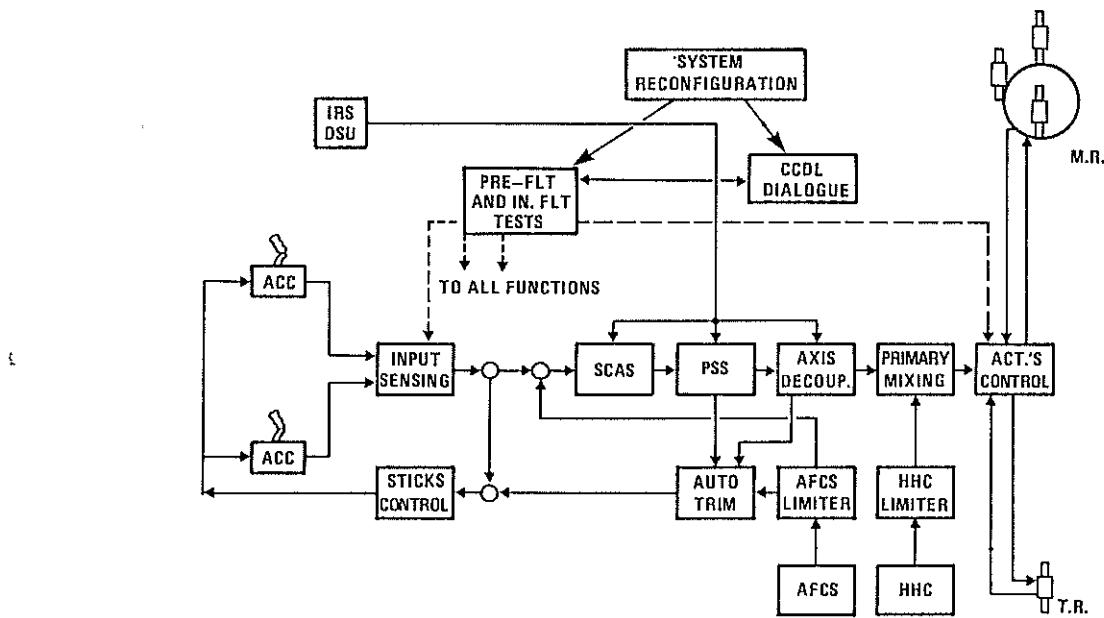


Figure 8 Schematic of fly-by-wire functions

4.2 F.C.S COMPONENTS

4.2.1 Pilot control

CONTROL STATIONS ARE DIFFERENT FROM THOSE AVAILABLE IN FIXED WING SYSTEMS

The NH90 pilot and copilot control stations are identical i.e. the cyclic mini-stick is always on the seat's RH armrest and the collective mini-stick on the LH armrest. The RH (cyclic) armrest is directed horizontally; the LH (collective) armrest is tilted 20° forward.

The mini-stick concept suggested by the industry for the NH90 helicopter is a force stick with limited displacement as well as position trim features. Non trimmable mini-sticks such as those available in fixed-wing fly-by-wire systems cannot be installed in the helicopter because the pilot wants to know the main rotor position or, at least, have an indication of the remaining control margins in some flight conditions i.e. upon take-off, landing, when flying close to the ground and in the hover.

When in a secondary mode, the mini-stick's displacement becomes large (-20°, 20°) without any proportional effort.

The mini-stick's back-up mode reproduces the conventional (mechanical) stick's behaviour with :

- A large displacement i.e. 120 mm from one stop to the other.
- Low control forces below 500 g.

The mini-stick concept has been compared to that of a conventional one with the following results :

CRITERIA	ELECTRICAL VS MECHANICAL STICK
COCKPIT ERGONOMICS	+ with improved seat access, improved control panels and displays visibility, piloting comfort
MISSION COMPLETION WITH REDUCED CREW	+ with additional room for the Tactical Operator in the copilot's seat
HANDLING QUALITIES	+ with efforts added upon control laws design
SAFETY	May be + according to design solution. Mechanical segregation between pilot and copilot station is a positive point

Legend: + indicates an improvement over the mechanical solution.

The mini-stick's most outstanding advantage is related to cockpit ergonomics with improved seat accessibility, improved control panels and displays visibility, piloting comfort, additional room for the Tactical Operator in the LH (copilot) seat, lower risks of injury upon crash.

Another advantage, although not so obvious, is that the mini-stick allows for more accurate and sensitive piloting as long as the appropriate control laws are applied.

4.2.2 DIRECT-DRIVE SERVO-CONTROLS

The selected design calls for duplex tandem actuators with direct-drive servo-control technology (See general overview on Fig. 9). The main actuators will be designed for full normal piloting as well as HHC capability.

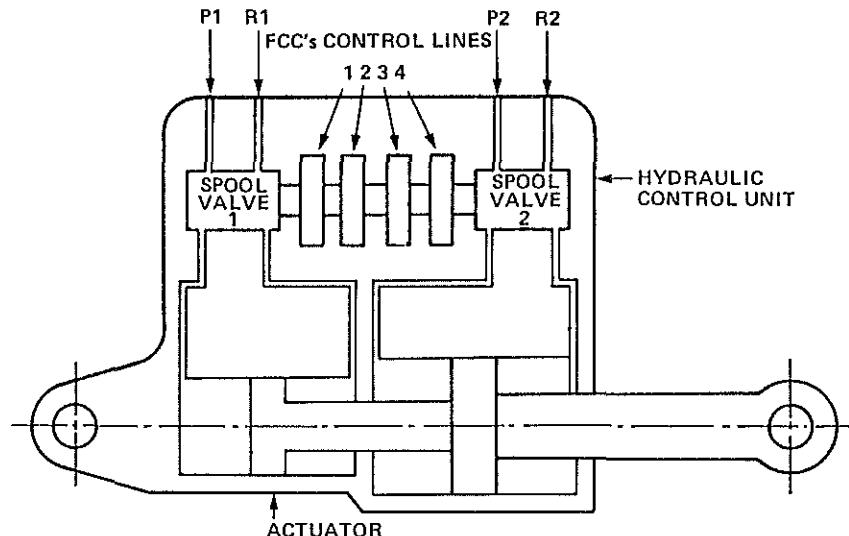


Figure 9 Main rotor servo-control overview

The first characteristic noted in the overview is the mechanical simplicity of the servo-control and experience has proved that simplicity also often means safe design.

The other characteristics will become apparent as the overview is examined further.

The servo-controls are run by all 4 FBW computers via a torque motor. All 4 torque motors are mechanically interlinked and connected to 2 spool valves power supplied by 2 different hydraulic generations. The combined power developed by the 4 torque motors is quite high with the first undetected channel failure being covered by the other 3 servo-loops.

The system thus remains capable of normal piloting even if the first actuator's servo-loop failure remains undetected. Likewise, should a second failure occur and the related channel be disconnected, it will again be covered by the combined power of the torque motors without any need for a complex servo-control hardware or servo-loop monitoring. The design simplicity allows the system to survive two hardware and servo-loop failures, if the latter do not occur simultaneously, without complex monitoring.

4.3. SYSTEM GROWTH POTENTIAL

The system's functions can be upgraded. The flight controls system's architecture authorizes upgrade to more advanced rate command control laws.

The pilots can be informed of the control authority limitations. The mini-stick accepts either rate command control laws (non trimmable stick operation) or position command control laws (trimmable stick operation). The flight envelope limitations can be reported either with a force increase or vibrations developed by the flight control system.

Some of the basic AFCS modes e.g. attitude, airspeed and heading hold could be integrated in the fly-by-wire control system.

5. FBW CONTROL SYSTEM DEVELOPMENT MILESTONES

5.1 NH90 FCS SCHEDULE

The FBW control system's development process (See Fig. 10) is mastered as follows :

Maximum use is made of the Transition Period throughout 1989 approximately

- To validate technical choices i.e. servo-controls and mini-sticks
- To further define the flight control system's functional requirements i.e. FBW, AFCS and HHC.

1990 should include :

- D&D Phase initiation
- Detailed design and specification for every FBW system component i.e. computers, cyclic and collective mini-stick, main and tail servo-controls and pedals.

1991 should include :

- Component hardware manufacture
- 1st software version development.

1992 and 1993 should be devoted to testing

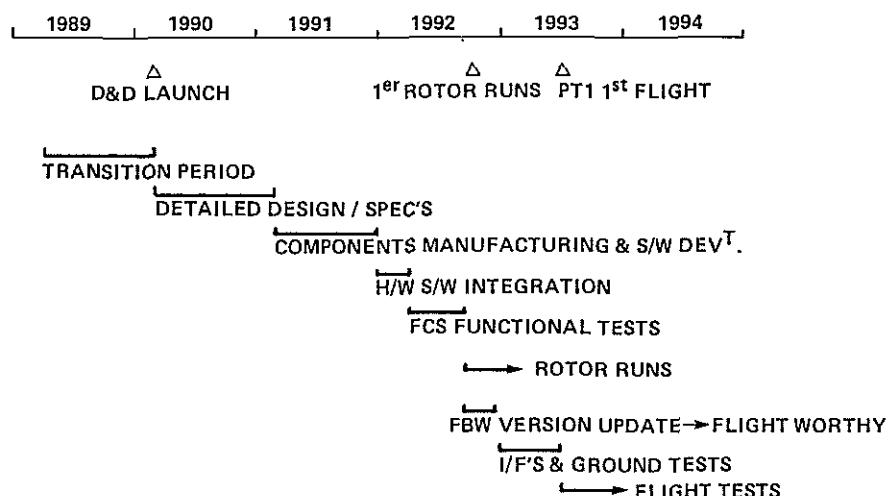


Figure 10 FBW activities up to PT1 first flight tests

5.2. FCS TESTING LOGIC :

- The flight control system's manufacturing activities will include acceptance tests i.e. the system's equipment functional tests in accordance with specifications as well as environmental tests.
- The computers, software included, will be input/output tested in a dedicated integration rig.
- The FCS components will be fitted in the FBW rig for the following tests :
 - FCS components interface tests

- Servo-controls and mini-sticks' servo-loops functional tests whenever hardware is remote from the equipment.
- Functional tests for the flight control system as a whole, including :
 - "Open loop" i.e. without closure of the helicopter simulation loop
 - "Closed loop" i.e. with closure of the helicopter simulation loop
 - in normal and degraded operating mode.
- . Interfaces testing with the electrical generation.

The flight control system is then fitted in the prototype helicopter which undergoes interface and ground tests with blades, helicopter tethered, and without blades.

The following tests are to be performed prior to undertaking flight testing :

- . FCS components pre-qualification
- . EMI/EMC testing for the whole FCS system
- . FCS lightning resistance tests.

5.3. FBW SOFTWARE DEVELOPMENT LOGIC

The first flight tests will be undertaken with a control law reproducing direct mechanical control. This first control law will help explore the flight envelope, authorize a preliminary analysis of the clean helicopter's handling qualities as well as of the basic helicopter's performance.

The handling qualities will possibly be optimized with a segregation from the above tests by progressive adaptation of the piloting laws part of the fly-by-wire system and the clean aircraft.

The final validation of the fly-by-wire control system has thus no bearing on the normal execution of the prototypes' flight tests.

6. CONCLUSION

The high performance level as well as the increase in operational capabilities required by the NH90 users have led the industry to use FBW technology to meet the objectives set in the NATO Staff Requirements (NSR). The fixed-wing solutions already available were adapted to the 8-10 tons helicopter and are now quite familiar to the European helicopter manufacturers who have been following the demonstration programme including simulation, hardware manufacture, flight testing, etc.

The development of the NH90 FBW system was started during the transition period and the D&D programme has been organized in such a way that FBW development will proceed in parallel with other helicopter technologies to minimize development risks.

NH90, the first FBW operated production helicopter, will have improved handling qualities and its modern cockpit designed with the latest human engineering state of the art will set the way for future helicopters.

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- 6. ADVANCED FLIGHT CONTROL TECHNOLOGY**
by J.A. Macrino, J.L. Terry, U.S. Army Aviation Research
- 7. HANDLING QUALITIES EVALUATION OF THE ADOCS PRIMARY FLIGHT CONTROL SYSTEM**
by S.I. Glusman, K.H. Landis, C. Dabundo, BOEING Vertol
(Paper presented at the 42nd AHS Annual Forum)
- 8. EVALUATION OF ADOCS DEMONSTRATOR HANDLING QUALITIES**
by S.I. Glusman, C. Dabundo, K.H. Landis, BOEING Vertol
(Paper presented at the 43rd AHS Annual Forum)
- 9. TESTING OF THE ADVANCED DIGITAL OPTICAL FLIGHT CONTROL SYSTEM ADOCS**
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