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DIGITAL A.F.C.S. FOR AS 332 MK II HELICOPTER

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THIRTEENTH EUROPEAN ROTORCRAFT FORUM DIGITAL AFCS FOR AS 332 MK II HELICOPTER

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1 – INTRODUCTION

The new AS 332 MK II helicopter will soon be flight tested with a digital Automatic Flight Control System which is part of a new avionics package so-called IFDS (Integrated Flight Display System). The IFDS includes Electronic Flight Instrument Systems (with four cathode ray tubes), two Primary Reference Systems (AHRS/ADC) and the digital AFCS. This AFCS is the outcome of an outstanding cooperation between Aérospatiale (helicopter manufacturer) and SFIM (equipment manufacturer) under research contract with the STTE (government technical administration).

This paper provides a survey of the project development, the main features and a brief operational description of the AFCS.

2 – SFIM'S BACKGROUND IN THE FIELD OF HELICOPTERS DIGITAL AFCS

2.1 – GENERAL

The research and development work performed by SFIM over the last ten years has mainly concerned computer technology, including the adoption of digital techniques based on microprocessors ; in addition, the refinement of flight control laws was made possible through the intensive use of simulation on ground with well adapted design technique.

On the other hand, utilization of the airborne software through dedicated and structured high order languages, within high performance digital computer enhances reliability and quality of such systems. This approach has led to improvements in safety and performance to an extended range of uses and a reduction in the total cost of an AFCS.

This research which is still going on, is based on the close cooperation between a multi-discipline team of engineers and provides an answer to the new problems resulting from the ever increasing intimacy with which the autopilot is integrated into the navigation and display systems.

2.2 – PAST EXPERIENCE

In 1982 SFIM has successfully concluded flight tests for a fully digital 3-axis basic stabilization autopilot (PAD1) installed on a French Flight Test Center's (CEV) Alouette III. Moreover, such an experiment allowed validating the PAD1 performance, when this autopilot is coupled to an AHRS (SFIM 26 SH).

The experience gained in digital couplers started with the development jointly with AS/DH of an SAR/ASW coupler (CASM 2000/2100) as tested from 1981 to 1983. SFIM delivered the first mass produced digital CASM 2100 couplers in 1984 for Navy helicopters.

SFIM simultaneously designed the AFCS 155, a 4-axis Automatic Flight Control System, incorporating a digital coupler and an analog basic stabilization computer, integrated with EFIS. This all-weather, all-mission system designed jointly with AS/DH for the SA 365 N1 and AS 332 helicopters already entered its mass production stage from early 1986.

2.3 – AFCS NEW GENERATION

Looking ahead, SFIM is designing with the Aérospatiale Helicopters Division and with the support of the French government (DGA) an AFCS family for the new generation of helicopters, based on all this experience and the progress made in multiprocessor techniques. The first application is foresighted on the Super-Puma MK II.

3 – DEVELOPMENT OF DIGITAL AFCS

3.1 – MAJOR PROJECT STEPS

The first step of the project was a feasibility study including a wide comparison of possible architectures as made by SFIM in 1985. In may 1986, a first draft of a document so-called «Needs and prior requirements for a digital AFCS» was issued by Aérospatiale/DH ; this document included requirements issued on the following items :

- marketing aspects (aircraft, missions, performance/cost ratio ;
- functions ;
- safety and operationality
- applicable standards ;
- quality aspects and methodology.

The last part was dedicated to the description of the AFCS and included :

- the ergonomic aspects with a description of the flight control unit faceplate ;
- a requirement for a dual duplex AFCS architecture based on a computer with two synchronous processors as derived from safety and operational requirements of the first chapters ;
- architecture aspects with a specification of the relationship between computers and actuators.

By that time it has been decided to equip the AS 332 MK II with the IFDS including the AFCS. Subsequent to the technical discussions that took place between SFIM and Aérospatiale/DH, SFIM issued a technical proposal for a system meeting the requirements specified in the document «Needs and prior requirements», and Aérospatiale/DH issued a first draft of the technical specifications in December 1986. These specifications, using CAS (Computer Aided Specifications), a software tool made by Aérospatiale (Airplane Division) cover a wide variety of aspects and specify more thoroughly the following subjects : operational description, general design principles, environment (characteristics and functions related to the AFCS of the peripheral equipment in regards to the AFCS), interface specifications, monitoring and pre-flight test.

The specifications of the flight control laws also result from close and successful cooperation between Aérospatiale and SFIM. At this stage, the entire aircraft environment has been simulated including sensors actuators and helicopter modeling.

3.2 – DESIGN PROCEDURE BY SFIM

From the technical specifications, SFIM issued Software and Hardware Requirements which detail the exhaustive set of functions involving the realization of either a software or a hardware. An adequate software methodology has been applied according to the state of the art (DO 178 A standard) in order to guarantee quality and reliability of the software design. The software development included top-level design, detailed design and coding mostly using high-order language.

The software verification process, based on open loop and closed loop simulations, enabled to check that the software meets the requirements.

Concurrently with this development, the hardware resources have been built and checked independently, particularly real time operation and safety devices.

Then, the next phase consisted in integrating the operational software within the hardware resources. For this phase, a test bench was used which allowed the operator to stimulate independently all the inputs equipments and to check the real time operation, the I/O handling and the good implementation of the software.

The last phase consisted in validating the equipment with respect to the technical specifications. This validation phase used a real time test bench which allowed to stimulate compatible evolution profiles of the helicopter in real time.

3.3 – VALIDATION BY AEROSPATIALE

This equipment will then be tested at Aérospatiale facility on a test bench so-called «SISYPHE», an acronym for simulation of flight control system for helicopters : it is a closed loop test bench where each equipment (AFCS, FDC, associated control unit) can either be simulated in real time or physically integrated on the bench when available. Besides this versatility, stimulation of equipments' outputs can also be performed on SISYPHE, thus facilitating a thorough validation of the equipment.

The AFCS will undergo a large range of tests covering different aspects as logics, control laws, reconfiguration ; they will ensure thorough validation of hardware and software

functions, except for the gains of stabilization control laws which need test flights to get definitely set. After significant validation on test benches, the equipment will be integrated in the helicopter to go through another test phase which will ensure a complete checking of the flight test installation ; the AS 332 MK II aircraft will then be able to perform its flight tests with the new avionics.

Such a development process involves a certain number of modifications. These modifications may affect specifications, equipments as well as test benches. This prospect led Aérospatiale to establish a modification procedure aiming at a proper configuration management throughout the process. This modification procedure is described in the paper entitled «A GENERAL APPROACH TO THE COMPLETE DEVELOPMENT OF COMPLEX AIRBORNE SYSTEMS» (M. SLISSA).

4 – MAIN FEATURES

4.1 – AIRCRAFT AND MISSIONS CONCERNED

The digital AFCS is first designed to equip all future versions of Aérospatiale helicopters of either medium-size (SA 365) or large-size (AS 332).

The AFCS is basically capable of the following missions :

- commercial and military transport
- sling transport

as an option :

- Search and rescue
- Anti-submarine warfare
- Anti-surface warfare
- Tactical military missions.

4.2 – PERIPHERAL ENVIRONMENT

The digital AFCS is basically designed to be fitted on aircraft provided with the following equipment :

a) Primary sensor identified as FDC (Flight Data Computer) consisting of an integrated AHRS/ADC which provides :

- on AHRS part : attitudes, heading, angular velocities and accelerations ;
- on ADC part : indicated airspeed, vertical speed and altitude ;

b) Electronic flight instrument system with :

- display units fitted on the instrument panel and which - regarding the AFCS - display active modes, reference orders, warnings and Flight Director cues ;
- a symbol generator driving these displays and which also stands for concentrator unit in regards to the AFCS for radio-navigation and radio-altitude data.

The AFCS computers drive parallel and series actuators ; conversely to the previous paragraph about aircraft concerned, it is capable of accommodating either servo-actuators or dual input servovalves.

4.3 – SAFETY AND DEPENDABILITY

The safety and dependability objectives of the digital AFCS are as follows :

- instantaneously and fully operational after first failure ;
- fail passive upon second failure.

4.4 – FUNCTIONS

The digital AFCS achieves three main functions :

- Automatic flight control after autopilot engagement on basic or optional modes ;
- Monitoring of sensors immediately after setting power on
- Elaboration of power margin and flight envelope limits immediately after setting power on.

4.4.1 – Automatic Flight Control

The aircraft equipped with the digital AFCS have four motorized axes. From autopilot engagement, the AFCS is active on all four axes ; the basic modes (available from engagement) are :

- on pitch axis : attitude hold ;
- on lateral axis : attitude and heading hold ; they also include coordinated turns, fly through steering functions and of course the control of the natural couplings.

On the basic version of the AFCS, the following modes are also available :

- IAS : Airspeed engagement hold on pitch axis ; the other modes which are active on pitch axis, become active on collective axis if IAS is engaged ;
- ALT : Altitude upon engagement hold on pitch or collective axis ;
- ALT.A : Selected altitude acquisition and hold on pitch or collective axis ; it should be noted that the introduction of this mode is an innovation on these aircraft.
- V/S : Selected vertical speed acquisition and hold on pitch or collective axis ;
- CR.HT : Selected radio altitude acquisition and hold on collective axis ;
- G/S : Glide slope acquisition and hold on pitch or collective axis ;
- HDG : Selected heading acquisition and hold on roll and/or yaw axis ;
- APP : Localizer beam acquisition and hold on roll and/or yaw axis during approach ;
- NAV : Hold of a VOR or TACAN radial or hold of a roll steering command issued from the navigation computer.

These modes also include possible «fly through» actions described in chapter 5. The AFCS is capable of CAT II approaches.

The optional modes refer to SAR or ASW/ASV missions or tactical military missions. The SAR modes are :

- HOV : Hover and height hold ;
- G.SPD : Ground speed hold ;
- T.UP and T.DWN : Automatic transitions.

The ASW/ASV modes include the SAR modes plus :

- CBL.HT : holding the dipping SONAR at a constant depth (by means of the collective pitch).
- CABLE : holding a definite orientation of the SONAR cable.

The military optional modes include among others :

- TAC : Tactical mode.

4.4.2 – Flight Director

The AFCS computers also output flight director cues data to the SGCU while at least one of the modes mentioned above is engaged. When the FD is engaged, the AFCS controls the attitude by means of its valid actuators, while the cues identify the action the pilot has to make for maintaining the trajectory according to the engaged mode.

An alternate use of the flight director cues is presented in the «operational description» section.

4.4.3 – Monitoring

As soon as power is on, the AFCS checks coherence of output data from duplex sensors : FDC, radioaltimeters, ILS receivers ; when the difference between homologous data exceeds a definite level, a warning is issued to the SGCU for display.

4.4.4 – Elaboration of Power Margin and Flight Envelope Limits

As soon as power is on, the AFCS processes output data from torque, NG and engine temperature sensors to compute the rotor power margin available. It is then issued to the SGCU for display.

Likewise, the AFCS processes the weight, and altitude to compute flight envelope limits (VNE, VTOSS) transmitted to the SGCU for display.

5 – SYSTEM DESCRIPTION

The following description applies to the Super Puma MK II application.

5.1 – GENERAL

The AFCS 165 system is designed to meet the above operationality and safety objectives. It incorporates two identical fail passive computers and two Control Panels (AFCP).

In nominal operation, both computers are simultaneously engaged to provide the immediate operationality after any computer failure.

When a computer detects its own failure it disengages itself automatically while the other computer carries on controlling according to the modes engaged.

The remaining computer is then able to complete the mission throughout the AS 332 MK II flight envelope, keeping the same safety level.

The two computers are synchronized and monitor each other through a Cross-Talk link.

5.2 – SYSTEM ARCHITECTURE Vs SENSORS/DISPLAYS

As indicated in Fig. 1, each AFCS computer is directly connected to both FDC's, both SGCU's and both AFCP's through ARINC data links, and to a vertical gyro through analog connections ; it is also connected to the power margin sensors, a test panel, a reconfiguration panel, and the control stick switches through the AFCP.

The four trim actuators are always controlled by one of the two computers. In nominal operation, one computer has the priority, but when this computer is disconnected, trims automatically shift to the second computer.

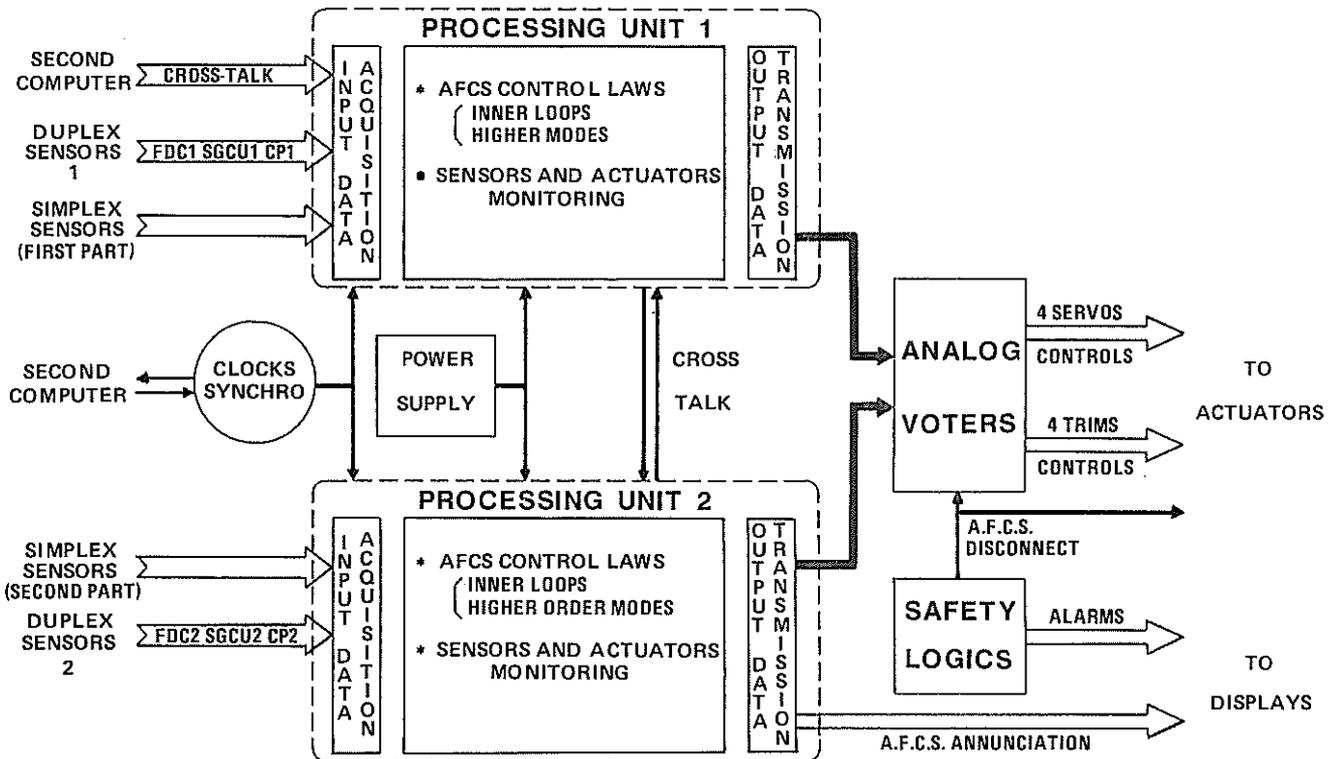


Fig. 1 : ARCHITECTURE OF A.F.C.S. 165 SYSTEM

In normal configuration, each AFCS computer processes the parameters output from both AFCP's, both FDC's and both SGCU's, while each SGCU processes only those data output from the computers of its half-system ;

When a reconfiguration occurs, the links handled by the shut-down computer are disregarded by the rest of the system.

5.3 – SYSTEM ARCHITECTURE Vs ACTUATORS

On every axis (pitch, roll, yaw, collective), the AFCS controls the rotor pitch through a series actuator (dual servo-valve) and a parallel actuator (electrical trim).

Each AFCS computer feeds one of the two inputs of each dual servo-valve, the actuator travel being proportional to the sum of the two inputs. Each servo-valve input authority is sufficient to provide control laws nominal performance within a single computer.

5.4 – DESCRIPTION OF AFCS 165 COMPUTER

Each computer (identified by SFIM as AFCS 165) is fail passive and incorporates two redundant and separate processing channels (cf. Figure 2). The critical tasks (e.g. inner loops control laws) are developed in dissymmetrical software).

In order to avoid actuator runaways in case of a processor failure (hardware or software), an analog device votes between actuators control signals output from the two processing channels.

Each processing unit is based on the utmost powerful MC 68020 microprocessor and associated circuits (memory, timer, ...). The cyclic Interrupts are produced by a synchronization clocks electronic connected to the second computer.

The two processing units communicate through a specific link, composed of dedicated memories, accessible by the two processors. This feature, associated with synchronization allows very close monitoring and immediate passivation by the voters in case of any computer failure.

The Power Supply is simplex and fail passive and works in a redundant way on both helicopter DC networks. Any failure is detected and causes the computer to be disconnected.

A set of safety logics controls the AFCS computer Disconnection and the Hands-On Recovery Alarm Request.

6 – OPERATIONAL DESCRIPTION

Each processor unit encodes one duplex sensors side and a part of the simplex sensors. The encoded measures are then exchanged through the inter-processors cross talk.

6.1 – DISTRIBUTION OF INFORMATION AND CONTROLS ON THE INSTRUMENT PANEL

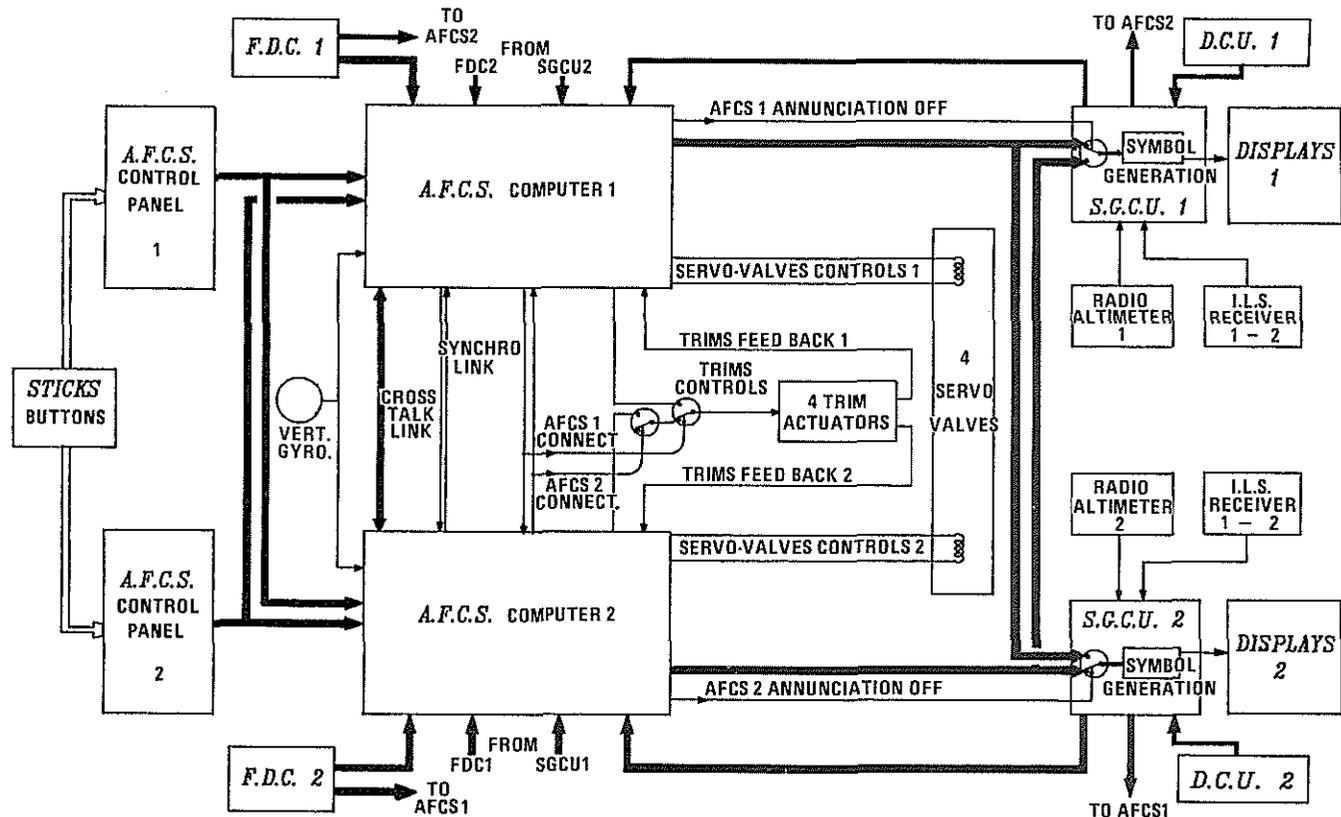


Fig. 2 : ARCHITECTURE OF A.F.C.S. 165 COMPUTER

One processor handles the Annunciation Link to the SGCU, the critical parameters are returned to the other processor for monitoring purpose.

The instrument panel is broken down into three sub-assemblies : pilot, copilot and centre sections ; the AFCS data and controls are duplicated on the pilot and copilot instrument panels ; each one incorporates a PFD (Primary Flight Display) screen and a NMD (Navigation and Mission Display) screen mounted side-by-side, a DCU (Display Control Unit) and an AFCP all mounted below the screens (see Figure 3).

5.5 – AFCS 165 SYSTEM VERSATILITY

The AFCS 165 System is designed for adaptation to a large variety of environments (helicopters, actuators, missions) while keeping the same internal architecture and without any major modifications.

The computation power can be increased in order to incorporate a new set of functions for a specific mission, just by adding or replacing components in the Processing Units Boards. As equipped with an additional board, the AFCS 165 can drive electrical series actuators.

The AFCS 165 can adapt itself to the helicopter configuration, in real time.

A single computer can complete all types of mission while keeping the duplex system's safety level. Thanks to this feature a simplex version may be derived for small aircraft where post-failure operability is not required. The AFCS provides the IFR single-pilot capability.

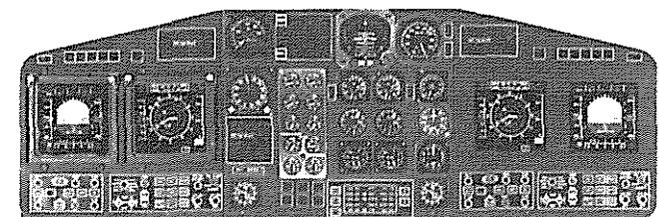


Fig. 3 : INSTRUMENT PANEL LAYOUT

The control items are mounted on control units and, with certain exceptions, all indicator lights are provided on screens.

The controls include :

- a) the controls for engagement of AFCS or modes without setpoints : these are the STAB, ALT, IAS, NAV, APP and O.FLY (optional mode) pushbuttons.

b) the controls associated with those modes incorporating a setpoint ; these are the ALT.A, CR.HT, HDG, V/S and HOV (optional mode) rotary pushbuttons.

Pressing the pushbuttons momentarily causes the associated mode to engage or disengage ; rotating a rotary pushbutton causes the setpoint to be modified.

In addition, the unit incorporates two indicator lights : an amber light coming on when AFCS is disengaged and a CTL light associated with radio/nav. modes.

The engaged modes and setpoints are displayed on screens.

6.2 – UTILIZATION OF AFCS CONTROLS

6.2.1 – Principles

Both control panels are active and can be used at any time whatever the function selected ; in fact, these control panels are considered as a single dual-control panel by the AFCS.

As to the NAV, APP (and not directly G/S) functions for which sub-modes and TRACK setpoint can be displayed separately on pilot's and copilot's instrument panels - from relevant DCU's – the illumination of CTL light on an AFCS features which instrument panel is used.

6.2.2 – Setpoint Display

The HDG, V/S, CR.HT, H.HT and ALT.A mode setpoints are displayed independently of the engagement of these modes. They appear opposite or close to the relevant scales :

– on PFD (see Figure 4) for selected vertical speed or altitude data.

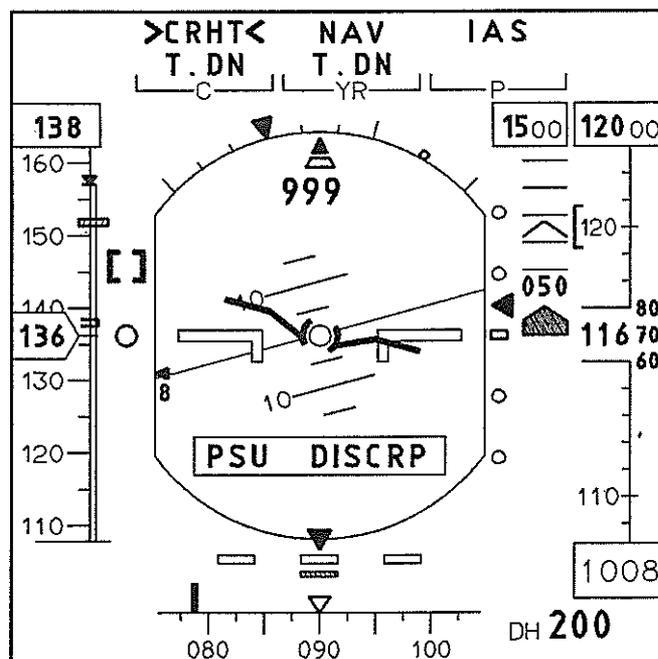


Fig. 4 : PRIMARY FLIGHT DISPLAY

– on NMD (see Figure 5) for selected heading or height data

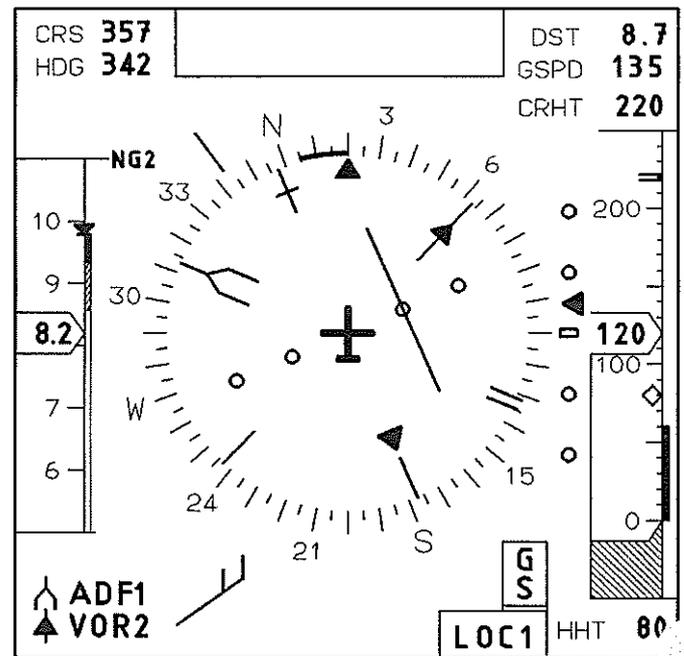


Fig. 5 : NAVIGATION AND MISSION DISPLAY HSI MODE

The IAS and ALT mode setpoints are displayed only when the mode is engaged. They appear opposite the relevant scale.

6.2.3 – Display Associated With the AFCS Logic-Status

The alarms and indicators specific to the AFCS function are located within the upper area of PFD (see Figure 4) ; however, a discrete signal is provided which allows repeating the alarms (involving a pilot's action) as necessary on a separate light.

The AFCS area of the PFD incorporates three lines and three columns. These columns are associated with the piloting axes :

- one column for collective axis (C) ;
- one column for lateral axes (Y, R), i.e. yaw and roll ;
- one column for pitch axis (P).

The data are distributed on the lines according to their type :

- on the first line, the higher order modes engaged,
- on the second line, the «armed» modes,
- on the third line, the system status collecting all data concerning the coupled axes and the channel(s) which may not be engaged as well as the alarms involving pilot action.

Three data levels with three associated colours are considered according to the following general principles :

- green : normal state
- amber : crippled state requiring pilot's attention or differed action
- red : alarm state requiring immediate pilot action.

In addition, the armed modes are displayed in white.

Moreover, the engaged AFCS higher order modes are framed in green for differentiating them from those higher order modes controlled through the flight director.

6.2.4 – Operational Logic

The logic of modes remains in compliance with the philosophy adopted for the Aérospatiale aircraft equipped with a 4-axis AFCS except the new ALT.A mode. This mode includes an arming phase during which the pilot controls the procedure to be followed for reaching the preselected level. After capture, the AFCS shifts to the ALT mode, with the present altitude setpoint corresponding to the preset altitude setpoint.

6.3 – COMPLEMENTARY CONTROLS

Two units are used for AFCS implementation : a maintenance unit and a reconfiguration unit.

The maintenance unit is provided with the test controls, especially that of preflight test ; it should be noted that this test is common to both the AFCS's and SGCU's.

The reconfiguration unit provides trim, AFCP and computer reconfiguration. As mentioned above, the reconfiguration of the AFCS computers is automatic ; this feature relieves the pilot from checking out which computer goes wrong and stabilizing the aircraft at the same time!

6.4 – FLIGHT DIRECTOR (FD)

Two cues may appear on PFD (see Figure 4) to identify respectively :

- the flight director command bars on cyclic axes,
- the command on collective axis.

These cues can come into view while the AFCS is engaged with the higher order modes through the CUES control on DCU (monitoring function). In this case, the colour of cues is green.

Engaging the FD is achieved separately for cyclic axes and collective axis using the controls provided on the reconfiguration unit ; the cue colour associated with the engagement of an FD is a specific colour.

6.5 – FLY-THROUGH STEERING

When the AFCS is engaged, the fly-through steering refers both to mere stick movements (as identified by the AFCS through load detection) and operation of the controls on sticks', such as beep, release, or even combination of stick movements and operation of controls.

The fly-through philosophy is somewhat innovated as compared to those AFCS generally operated : they incorporate a beep function on collective modes which is made possible through EFIS. In these conditions, the ALT, IAS, V/S, CR, HT and HDG mode setpoints (later called «synchronizable modes») can be modified from the stick when these modes are engaged.

The effort on stick allows modifying the aircraft attitude immediately and temporarily while limiting the AFCS reaction.

Operating the beep allows making fine and final attitude or setpoint corrections according to logic state.

Operating the release function allows making rapid and final attitude or setpoint corrections according to logic state.

Combining a stick load and a beep action allows combining fineness and rapidity of final corrections.

6.6 – MONITORING THE SENSORS AND COMPUTER PERIPHERALS

Alarms due to discrepancies between those sensors detected by the AFCS's appear in the form of an «XX DISC» type condensed message within the PFD horizon sphere and where «XX» is replaced by the name of incriminated sensors. Such monitoring applies to the following equipment items : FDC, PSU (pressure and sensor unit), ILS, radio-altimeter, AFCS, AFCP.

Similarly, detecting a peripheral anomaly such as trim actuator or AFCP by the AFCS's results in the display of an «XX FAIL» type condensed message presented in the PFD horizon sphere and where «XX» is replaced by the name of incriminated peripheral.

6.7 – POWER MARGIN AND FLIGHT ENVELOPE

The available power margin is displayed to the pilot in a synthetic form on the NMD screen (see Figure 5) as a collective pitch-degrees graduated scale. The «power limits exceeded» alarm is displayed in the upper LH corner of PFD. The airspeeds (VNE, VTOSS, VY) are displayed on PFD.

7 – CONCLUSION

This digital AFCS should permit to reduce the pilot's workload significantly and to greatly contribute to the aircraft flight safety thanks to :

- the new functions covered (power margin, flight envelope, monitoring),
- the introduction of new features in the piloting modes,
- its integration in the IFDS.