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AUTOMATIC FLIGHT CONTROL SYSTEM TIGER

BY

U. BUTTER
EUROCOPTER DEUTSCHLAND

AND

E. MEISSIREL
EUROCOPTER FRANCE

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U. Butter, Eurocopter Deutschland GmbH
E. Meissirel, Eurocopter France

Abstract

The Automatic Flight Control System (AFCS) of the combat helicopter Tiger is presented. The AFCS is a digital autopilot, which is superimposed to the mechanical flight control system of the aircraft. The system and equipment design and the operational modes and functions of the AFCS are described. The system development, including flight test, is addressed.

Fig. 1: Eurocopter Tiger

1. Introduction

The Tiger is a combat helicopter, which is being developed by Eurocopter under a French/German government contract.

The helicopter is a twin-engine, 5.5 tons aircraft, operated by a two-man crew, pilot and gunner, who are seated in two cockpits in a tandem configuration (Fig. 1).

The roles of the Tiger are antitank and ground support/escort. The antitank version is equipped with antitank missiles and air-to-air missiles. The ground support/ escort version is equipped with a chin-mounted cannon and air-to-air missiles or unguided rockets.

To fulfill mission requirements, the aircraft is required to have an Automatic Flight Control System (AFCS), which provides

- command and stability augmentation/ attitude hold, to stabilize the aircraft as a weapon platform, and reduce gust sensitivity,
- tactical modes, including three axis hover, a line-of-sight mode for weapon aiming/ weapon delivery, and gunfire compensation,
- standard cruise modes, providing four axis control.

2. System Design

Performance and operational requirements have led to the system concept described below (Fig. 2).

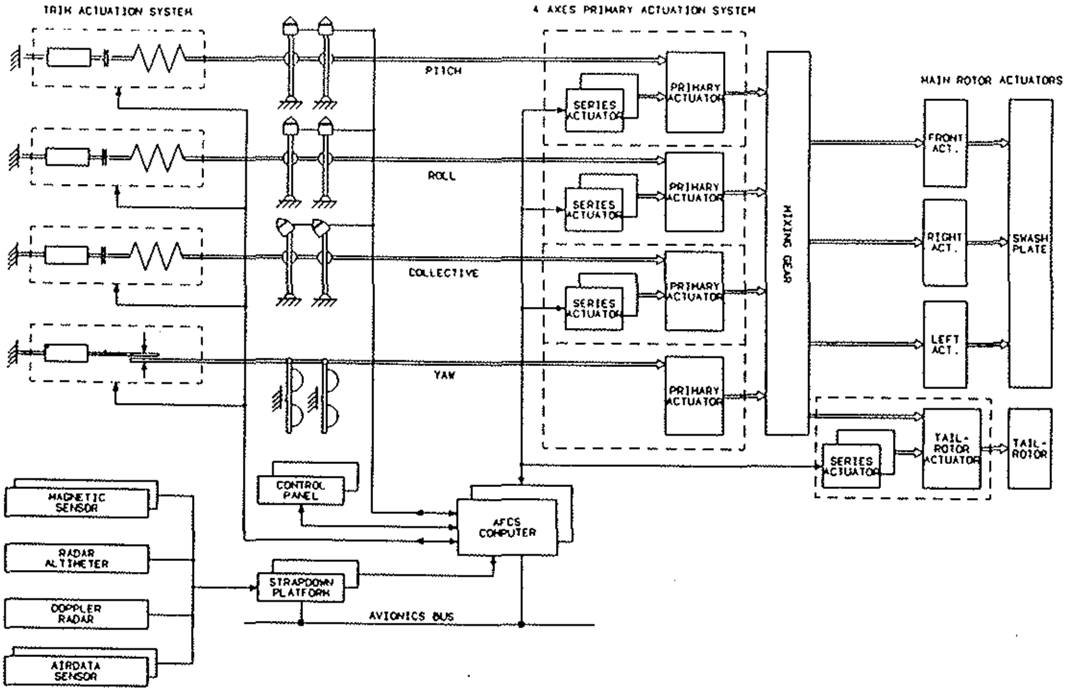

Fig. 2: Block Schematic of Flight Control System

The basic aircraft is equipped with a conventional mechanical flight control system. Actuation is achieved with a two-stage hydraulic actuation system with duplex hydraulic supply and electrical trim actuators. The aircraft can be flown from the front and rear cockpit. The trim system for the pitch, roll, and collective axis includes springs, to simulate cyclic and collective stick forces, and trim clutches. In the trim system for the pedals the spring is replaced by a slip clutch.

A duplex digital AFCS is superimposed to the mechanical flight control system, acting on all four axes. AFCS steering commands are coupled into the mechanical flight control system through series servo-actuators with limited authority and the parallel trim actuators with full authority. Stick/pedal and trim actuator positions as well as series actuator positions are measured by inductive position transmitters (RVDTs, LVDTs). Each of the two Flight Control Computers (FCCs) controls four series actuators (one per axis). The trim actuators, which are simplex, are normally controlled by FCC1, but are switched to FCC2, should FCC1 fail.

The control authorities of the AFCS are

± 10 % in the pitch, roll, and collective axis,
± 20 % in the yaw axis.

The control authority is distributed on the two AFCS channels. Therefore, after the loss of one channel, the authority is automatically halved in the affected axis. The control authorities have been chosen to achieve the required accuracy for weapon aiming/ weapon delivery during flight in turbulence and to ensure, that transients after failures are sufficiently small. During automatic flight, steady state commands of the AFCS are passed to the parallel actuators. Therefore, the authority of the series actuators is fully available for dynamic manoeuvres and stabilization.

Flight state data are supplied by the Navigation Sub-System. As the AFCS, this system is duplex. It consists of two Strap-Down Computers with integrated strap-down inertial sensors, as well as air data sensors, magnetic sensors, a Doppler radar, and a radar altimeter. The flight state signals are transmitted to the AFCS via a dedicated ARINC 429 bus.

The Flight Control Computers communicate with each other via a cross-channel data link. The AFCS can be controlled from either of two Control Panels, which are installed in the front and rear cockpit.

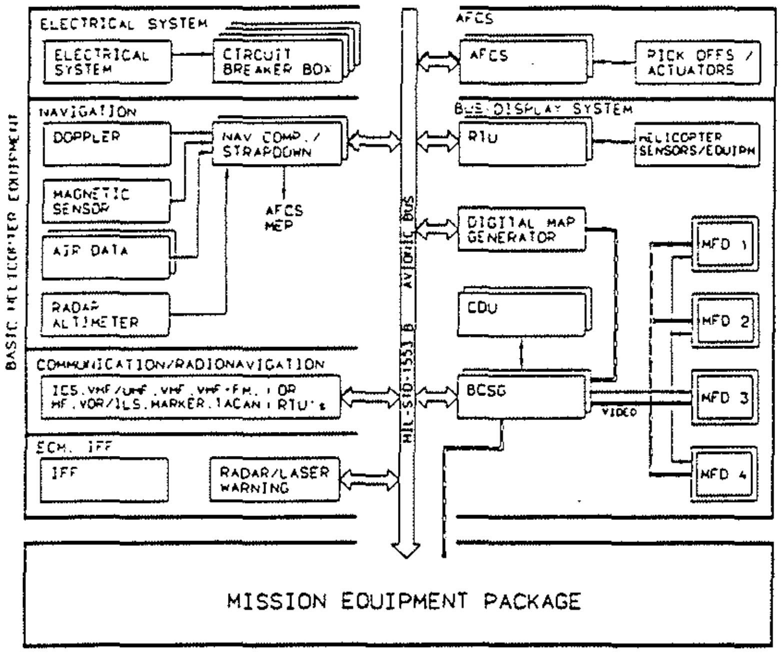

Fig. 3: Schematic of Avionic Systems Architecture

Apart from the ARINC link, communication between avionics equipment and the AFCS is established with a MIL-STD-1553B bus (Fig. 3). Through this data link, the AFCS is connected to the Bus and Display System, which includes a Bus Controller/ Symbol Generator (BCSG), Multi-Function Displays (MFDs), and Control and Display Units (CDUs).

Data, received by the AFCS through the MIL-Bus, are references for acquisition modes, target position and gun azimuth and elevation, as well as aircraft and engine data. Data, transmitted by the AFCS on the MIL-Bus, are status information and warnings, and test results from built-in test.

3. Operational Modes and Functions

The AFCS contains a number of operational modes, which can be divided into basic and higher modes.

Basic operational modes are:

- Stability Augmentation, which provides damping and short time attitude stabilization,
- Attitude/Heading Hold, i.e. pitch and roll attitude hold, and heading hold or co-ordinated turn, depending on flight conditions,
- Manual Steering, which provides command and stability augmentation, axis decoupling, and automatic turn co-ordination,
- Tactical Mode, providing automatic follow-up trim during manual steering,
- Gunfire Compensation.

Higher operational modes are:

- Hover Modes:
  Doppler Hover (DOP)
  Radar Height Hold (RHH)
- Line-of-Sight Mode (LOS), i.e. automatic alignment of the aircraft towards a target, which has been acquired through the mast-mounted sight or the helmet-mounted display,
- Cruise Modes:
  Indicated Air Speed Hold (IAS)
  Barometric Altitude Hold (ALT)
  Barometric Altitude Acquire (AAQ)
  Vertical Speed Acquire (VS)
  Heading Acquire (HDG)
  Navigation (NAV)

Air Speed Hold is operated through the pitch axis. Altitude Hold, Altitude Acquire, and Vertical Speed Acquire are operated through the collective or pitch axis, depending on whether the mode is engaged with or without Air Speed Hold.

The AFCS can be operated by either crew member from one of the two Control Panels (Fig. 4), which control the following functions:

- AFCS engagement/disengagement
- selection of trim functions
- engagement of cruise modes
- Pre-Flight Test

The following functions are controlled with stick-mounted switches:

- engagement of hover modes and Line-of-Sight Mode
- AFCS Emergency Cut-Off

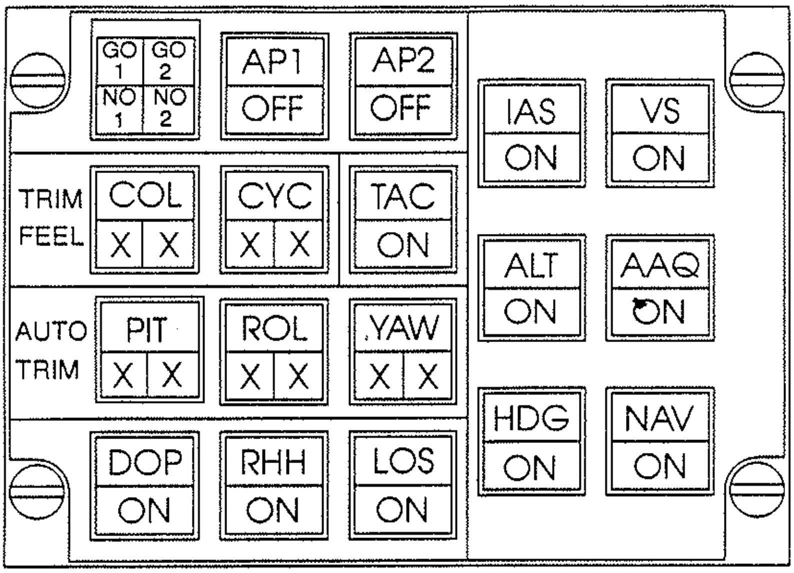

Fig. 4: AFCS Control Panel

AFCS warnings and status information are displayed on the Multi-Function Displays and the Control and Display Units, which are installed in both cockpits.

The MFD displays warnings, system status information, and references for the acquisition modes and hold modes. As complementary information, the equipment status is displayed on the CDU. One of several MFD formats, which can be selected, is the Primary Flight Display (Fig. 5). Warnings, if present, appear on the top line. Status information is displayed in a special window in the centre.

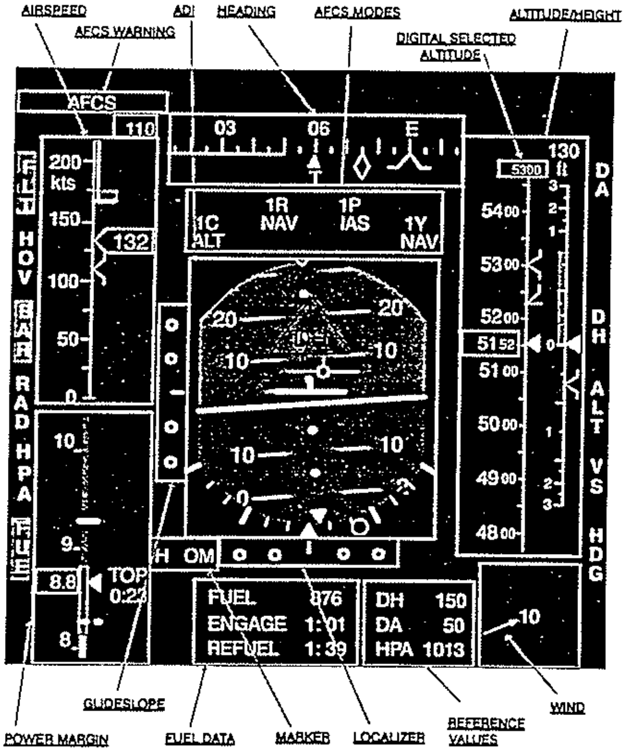

Fig. 5: Primary Flight Display

After power-up, an automatic self-test (Initial Test) and initialization of the Flight Control Computers is performed by the AFCS. The pilot can then start a pre-flight check of the actuators (Pre-Flight Test). Except for the initiation, the test does not require the pilot's participation. The test can be performed with running rotor. The commands to the actuators are fully compensated, to maintain zero blade angle throughout the test. The Initial Test and the Pre-Flight Test can be interrupted, in case that a quick take-off is required.

The AFCS is activated by engaging the Flight Control Computers. Under normal operating conditions the AFCS remains permanently engaged in the Attitude/Heading Hold Mode or any one or combinations of the higher autopilot modes.

Override of the automatic modes, to enter the Manual Steering Mode, is possible at any time for either crew member. When the stick is released, the AFCS returns to the previously selected automatic mode.

References for the acquisition modes are preselected with a turning knob on the MFD. References for acquisition modes and hold modes can be adjusted with the beep switches.

Under normal conditions the AFCS is operating in the duplex configuration within its operational limits.

In case of abnormal conditions, such as actuators in saturation or excessive deviation from reference, the crew is alerted by a warning.

In case of system degradation due to failures, the AFCS generates warnings and system status information and performs an automatic system reconfiguration. The reconfiguration depends on the type of failure:

- At a loss of redundancy due to the failure of a Flight Control Computer, Strap-Down Computer, or series actuator, the AFCS reverts to simplex configuration.
- After the failure of a trim actuator, the AFCS in the affected axis reverts to the Stability Augmentation Mode.
- After the complete loss of a sensor, which is required for a higher mode, the AFCS reverts to a degraded higher mode.
- In case of a non-localized first failure, the actuator commands are frozen.
- At the complete loss of the AFCS after a second failure, the AFCS is disengaged and the series actuators are centered.

4. Equipment Design

The AFCS consists of two identical Flight Control Computers and two identical Control Panels (Fig. 6).

The mechanical design of the Flight Control Computer is shown in Fig. 7. The computers open to the front. This allows exchanging modules without having to remove the computers from the aircraft.

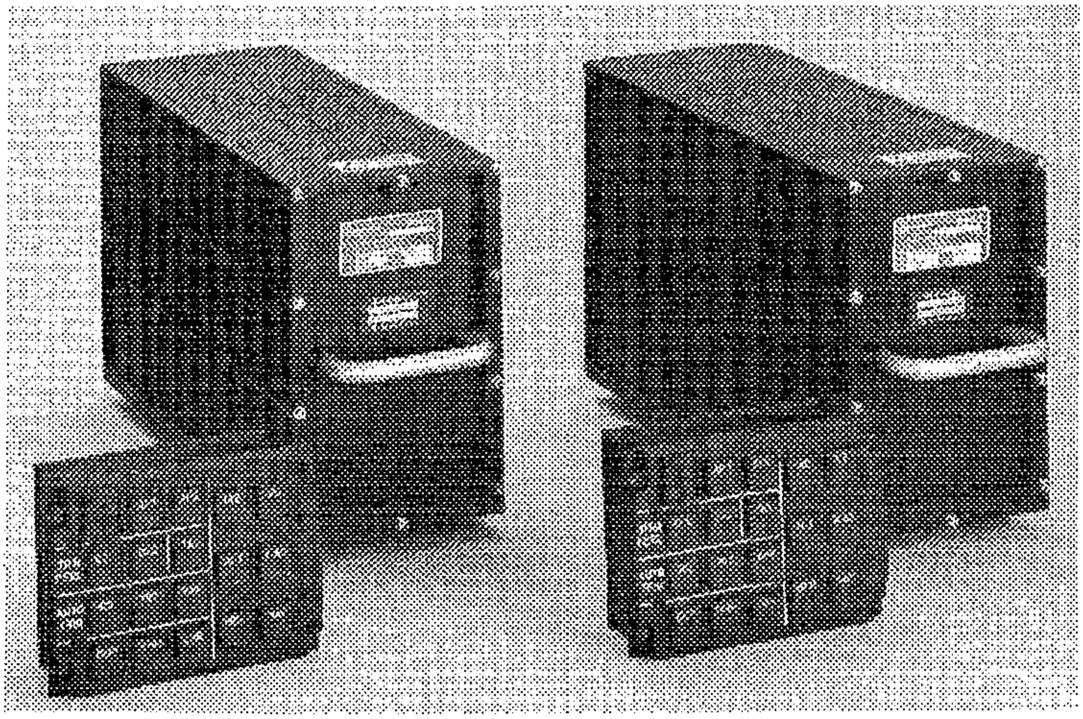

Fig. 6: AFCS Equipment

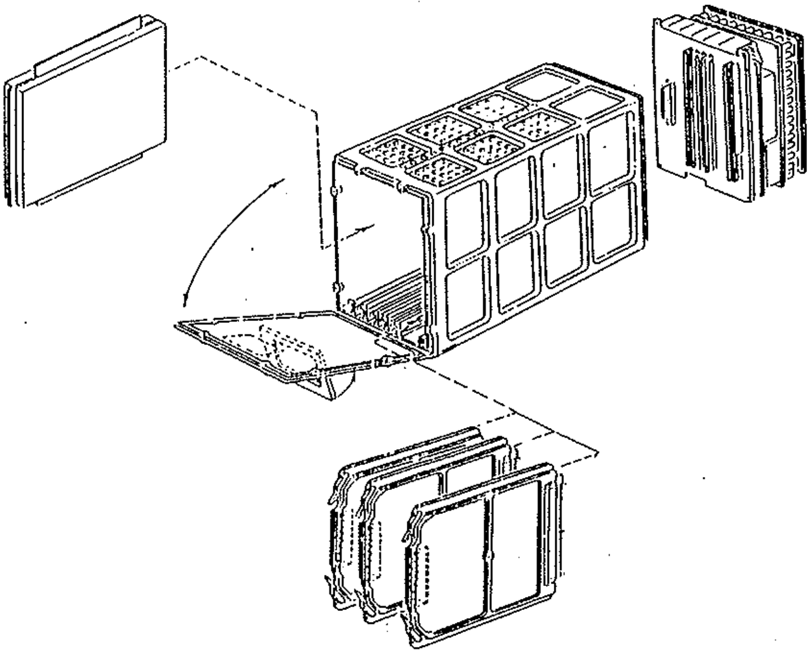

Fig. 7: Mechanical Design of Flight Control Computer

A schematic of the computer architecture is shown in Fig. 8. Each computer contains five modules with elements/functions, as listed below:

- CPU Board with a system management prossesor, a control law processor, and bus interface,
- IOC Board for input/output control, analogue I/O, cross-channel communication, and hardware synchronization,
- I/O Board for discrete I/O,
- Power Supply Unit for the generation of internal voltages and LVDT/RVDT excitation,
- Rear Module for HF filtering and lightning strike protection.

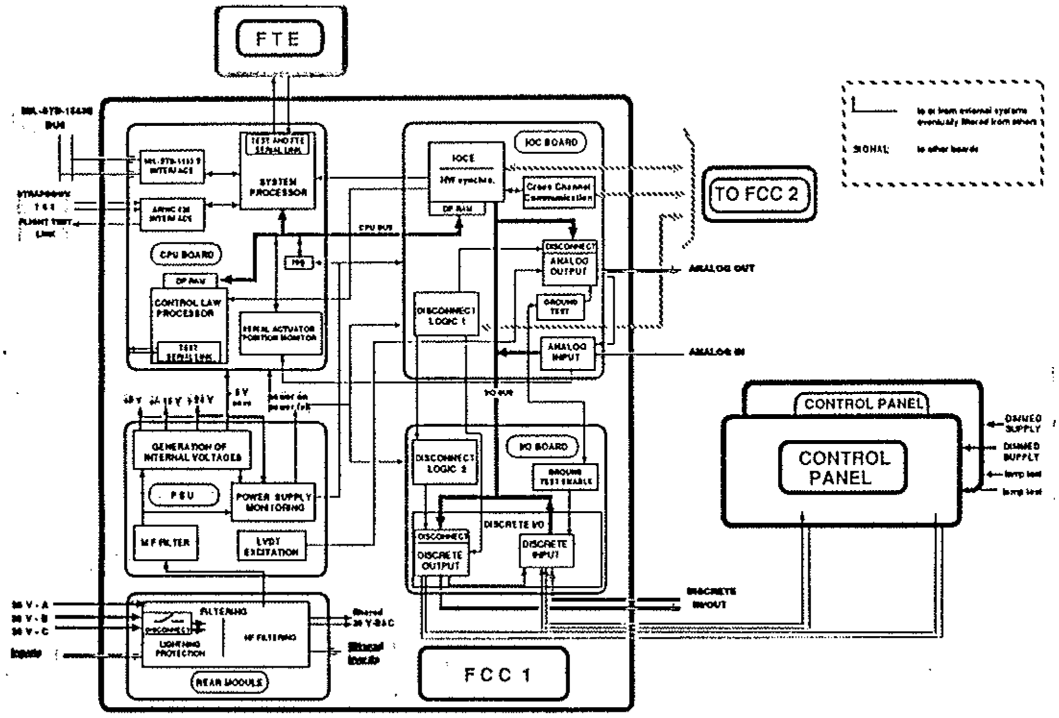

Fig. 8: Schematic of Computer Architecture

Fig. 9 shows an opened computer with the electronic modules. The component technology, beside standard components, is SMDs and ASICs.

The programming language is Ada. The software is classified as level 1 according to RTCA/DO-178A and is being developed according to the requirements of DOD-STD-2167A.

To fulfill safety and reliability requirements, the AFCS has been designed as a fault tolerant system. The safety concept is based on the following functions:

- sensor fault detection by cross-channel monitoring of sensor signals,
- computer fault detection by synchronous, bit-identical data processing within both computers and cross-channel monitoring of actuator commands,
- fault localization and isolation by in-lane monitoring within each computer.

In-lane monitoring is performed with a variety of functions:

- The sensors are monitored with signal validity checks and RVDT sum check.
- The computers are monitored with watch dog timers, CPU tests, memory tests, power supply tests, and wrap-arounds.
- The actuators are monitored by cross-comparison with computed actuator models.

Failure states due to failures, occurring in flight, are transmitted to and recorded by a Data Insertion Device in the aircraft and stored in non-volatile memory within the computers for later evaluation, if necessary.

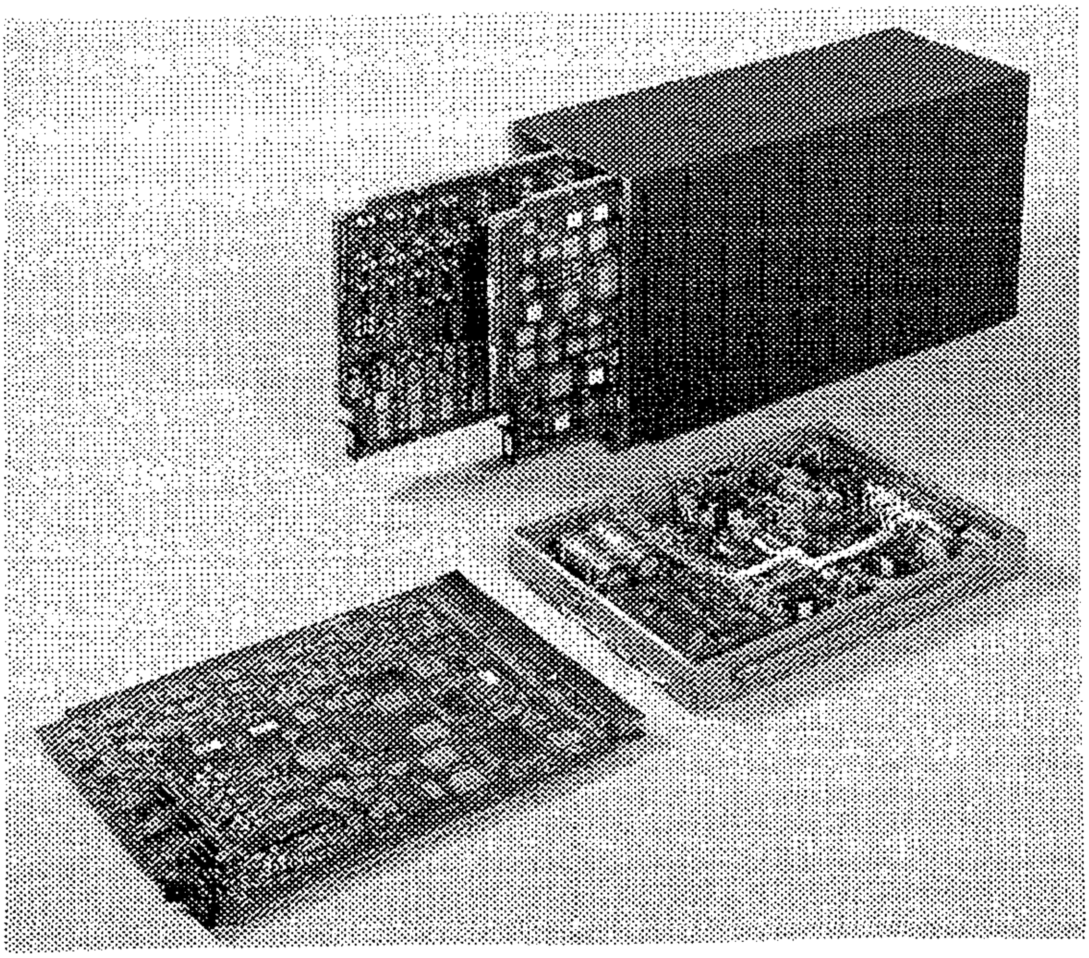

Fig. 9: Computer Modules

Maintainability/testability requirements are fulfilled by efficient built-in test functions, which provide fault localization down to moldule level. The Maintenance Test, beside the Flight Control Computers and Control Panels, includes the actuators, control switches, and bus interface. Maintenance is supported by good accessibility to the computers and computer modules.

5. System Development

Eurocopter is responsible for the system specification, control law design, and system integration and test.

The sub-system/equipment development (hardware and software) was subcontracted to the supplier consortium Nord-Micro/Sextant.

Development and test tools, as listed below, are applied to support the development.

Software development tools:

- HOSTESS (High Order Structuring Tool for Embedded System Software) for specification, documentation, and configuration control of the control laws
- GALA (Génération Automatique de Logiciel Avionique) for automatic code generation

Ground test facilities:

- STTE (Special-to-Type Test Equipment) for acceptance testing of the equipment
- AFCS Test Bench for functional tests and AFCS integration with the mechanical flight control system
- Integration Rig for AFCS integration with avionic systems
- Simulation Cockpit for man-machine interface assessment

6. Flight Test

The objectives of the AFCS flight test as the final step of the development are

- fine tuning of control parameters, in order to achieve best performance,
- in-flight demonstration of simulated failures, as required by the AFCS safety analysis.

An AFCS Test Rig is used for ground support during the flight test phase, which allows to test all functions in a closed-loop configuration, using a flight dynamics model to simulate the aircraft. The aircraft model has been optimized with the results from an identification process, conducted in flight with a sine-wave generator.

A special Flight Test Equipment (FTE) allows the modification of 120 internal parameters and the injection of simulated failures in flight. The development team can via telemetry communicate with the flight test engineer on board the aircraft. With this, changes for optimizing the system can be defined and implemented during flight. Flight test instrumentation allows in-flight recording of all data, which are needed for off-line investigation.

Fig. 10, as an example of flight test, shows a change of the roll attitude reference during cruise and the resulting co-ordinated turn.

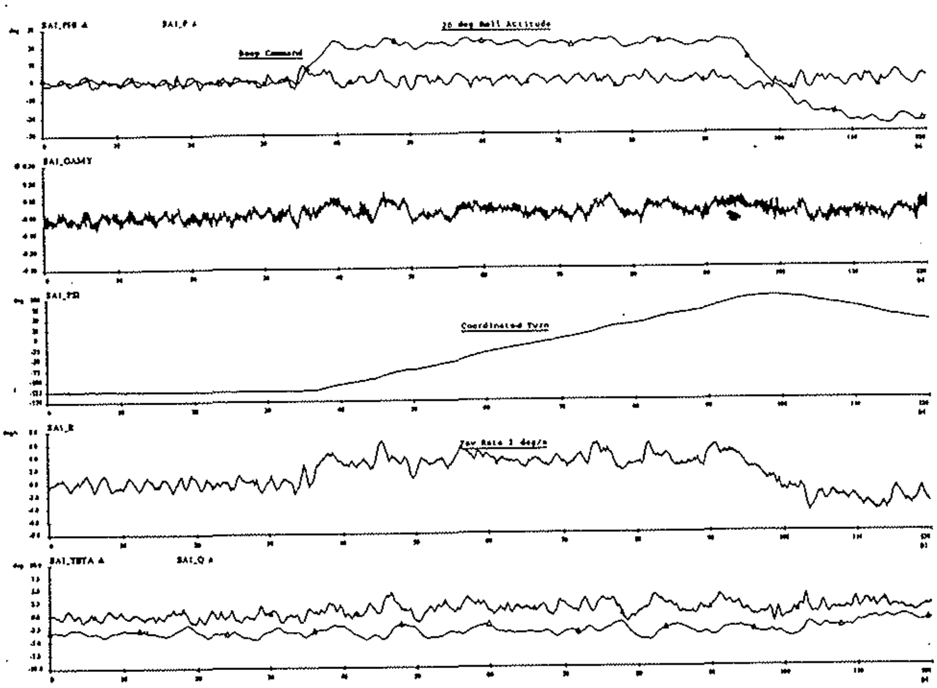

Fig. 10: Flight Test Record of Turning Flight

7. Summary/ Concluding Remarks

The AFCS of the Tiger, which provides command and stability augmentation and a number of tactical and cruise modes, is essential for the weapon system to fulfill its mission requirements.

The AFCS is designed to use the full capability of the avionic systems: Flight state sensors are shared by the Navigation Sub-System and the AFCS. Digital data links provide access to all necessary data of the weapon system and connect the AFCS to the integrated test and monitoring system.

The AFCS computer design provides special features: With individual processing elements for system management, control law computation, and autonomous input/ output control, a clear task separation is achieved, which simplifies control law changes and software modifications. With powerful in-lane monitoring, a fail-operate/ fail-safe capability is achieved with a system, which is only duplex.

Ground test and flight test results, achieved so far, have confirmed the chosen concept of the AFCS.

8. Acknowledgement

Figs. 6, 7, 8, 9 have been reproduced with kind permission of Nord-Micro/Sextant.