Integrated Monitoring and Diagnostic in Fly By Wire Control System

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Abstract

The NH90, developed by NHI (joint venture between Eurocopter, Agusta and Fokker), is the first European production helicopter fitted with a full Fly By Wire (FBW) system. The Flight Control System (FCS) is developed under Eurocopter responsibility and has strongly taken into account the maintenance aspects from the beginning of the design.

In order to meet the stringent safety objectives, the FCS is designed with a high level of redundancy including numerous monitoring features for failure detection and passivation. Consequently, each electronic FCS equipment includes dedicated Built In Test (BIT). In addition such a complex system has to offer a high level of availability and mission reliability without inducing high maintenance cost. To achieve this goal, a test and diagnostic system is included in the FCS.

The FCS test and diagnostic system is highly distributed among each sub-system. In addition of above mentionned safety purpose, testability has been taken into account since the beginning to design the BIT capabilities. Actually failures detection devices are used to provide as much as possible on-line failure localization in real time at Line Replaceable Unit (LRU) and Shop Replaceable Unit (SRU) level. All FCS diagnosis features are centralized at helicopter level in the Plant Management System (PMS). In parallel, system status and some BIT results (PreFlight BIT) are displayed to the crew.

In flight, the PMS performs failure report storage in the Maintenance Data Base. A failure report includes failure identification (code, occurrence time, …) and localization (LRU/SRU). Furthermore, when other systems are involved (potential interfaces failures), the PMS knowing all systems, provides complementary failure localization. Then, the PMS provides a post flight report. On ground, during Initiated BIT, PMS and FCS cooperate in order to detect and to localize dormant failure by making use of intrusive tests (when needed) in particular for periodic maintenance.

Preventive and on-condition maintenance allowed by diagnostic system implemented inside FCS plus PMS, improves availability, mission reliability and safety for this critical system. The fact that testability is taken as a design constraint from design beginning, enables on-line failure localization, makes maintenance operation easier and minimizes maintenance costs.

1. Introduction

In 1992, NAHEMA representing France, Germany, Italy and the Netherlands signed a contract with NHI, a joint venture between Eurocopter, Agusta and Fokker on the design and development of the NH90. The production contract was signed in July 2000. This helicopter is the first European production helicopter fitted with a full fly by wire system. In the work sharing Eurocopter is responsible of the Flight Control System.
The design specification of the system included stringent requirements in terms of safety, mission reliability and maintainability. All these aspects have been taken into account since the beginning of the design.

This paper deals with solutions developed, in terms of system architecture and functional definition, to design the FCS in compliance with above listed constraints.
The document starts with a functional presentation of FCS. Then, mainly taking into account safety and mission reliability constraints, the hardware architecture is presented. After that, maintainability requirements are identified and the functions developed in accordance with all the objectives are detailed.

2. FCS functional breakdown

The FCS of NH90 is broken down into the following main functions :

- Primary Flight Control System (PFCS),
- Automatic Flight Control System (AFCS).

The system also includes inceptors, force feel trims and control panels (fig 1).

2.1 PFCS

The PFCS (developed under Eurocopter responsibility) provides the basic control of the helicopter. It elaborates main and tail rotor actuator commands depending on flight sensors information and pilot inputs (sticks position, requested control law, …).
The PFCS is divided into :

- control law processing implemented into a digital computer (PFCDC) and an analog computer (PFCAC),
- actuators control loop (ACC).

The PFCDC provides enhanced handling qualities with different control laws from basic SAS to attitude hold.

The PFCAC provides, as back-up control law, a one to one control law (sticks to actuators) improved by an elementary SAS on pitch and roll axis using embedded gyros.

The ACCs ensures the control of actuators in accordance with the active FCC redundancy outputs.

2.2 AFCS

The AFCS (developed under Agusta responsibility) provides Hands Off capabilities with upper modes for cruise, navigation and approach, and mission aspects. AFCS integration at system level (with PFCS) is performed by Eurocopter.

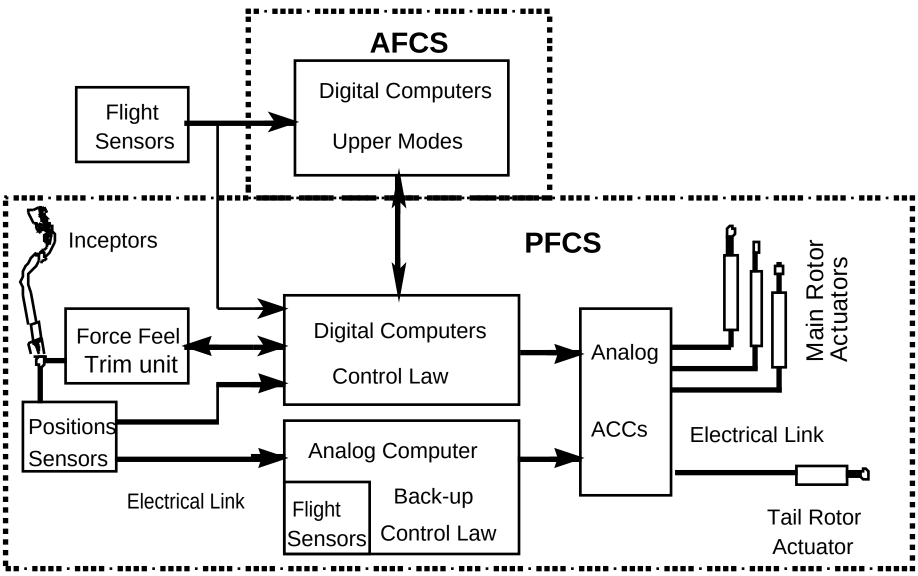

Figure 1 - NH90 Flight Control System layout

3. FCS architecture design

The FCS is a critical system; therefore the stringent safety objectives constitute the major driver for the design. Actually, the probability of occurrence of any catastrophic failure condition in the PFCS must be less than 10^{-9}/FH.
Furthermore, the system must ensure a high level of availability and mission reliability, and provide as long as possible a high level of handling qualities using digital redundancies.

In order to meet these objectives, the PFCS is based upon a quadruplex architecture using digital (PFCDC) and analog (PFCAC) technology while the digital AFCS is duplex. Each redundancy is dual in order to allow in-line monitoring. The monitoring implemented for safety and mission purposes will be called safety monitoring. The monitoring implemented for testability aspects will be called testability monitoring.

In order to minimize weight and ensure wiring segregation the flight control processing functions are packaged into two FCC boxes. Each one including a PFCAC, a PFCDC and an AFCC.

For the same reasons, ACC channels are packaged into two ACC boxes, each one containing two dissimilar redundancies.

PFCACs and ACCs are based on analog technology. Therefore, to drive and synchronize test sequences at system level, a digital computer board, dedicated to testability aspects is added in each of them. This digital capability is called test function.

The control panels, also designed to provide standalone monitoring and diagnostic, use digital capabilities for testability aspects.

The detailed layout of FCS architecture is presented in figure 2.

In addition to safety and mission reliability aspects, such a system must fulfil maintainability requirements. To achieve this goal, a Monitoring and Diagnostic System has been defined at helicopter level. In the general design principle the MDS cooperates with all systems. After an overview of MDS purposes the choice for the FCS in terms of functional allocation between FCS itself and MDS is presented and justified.

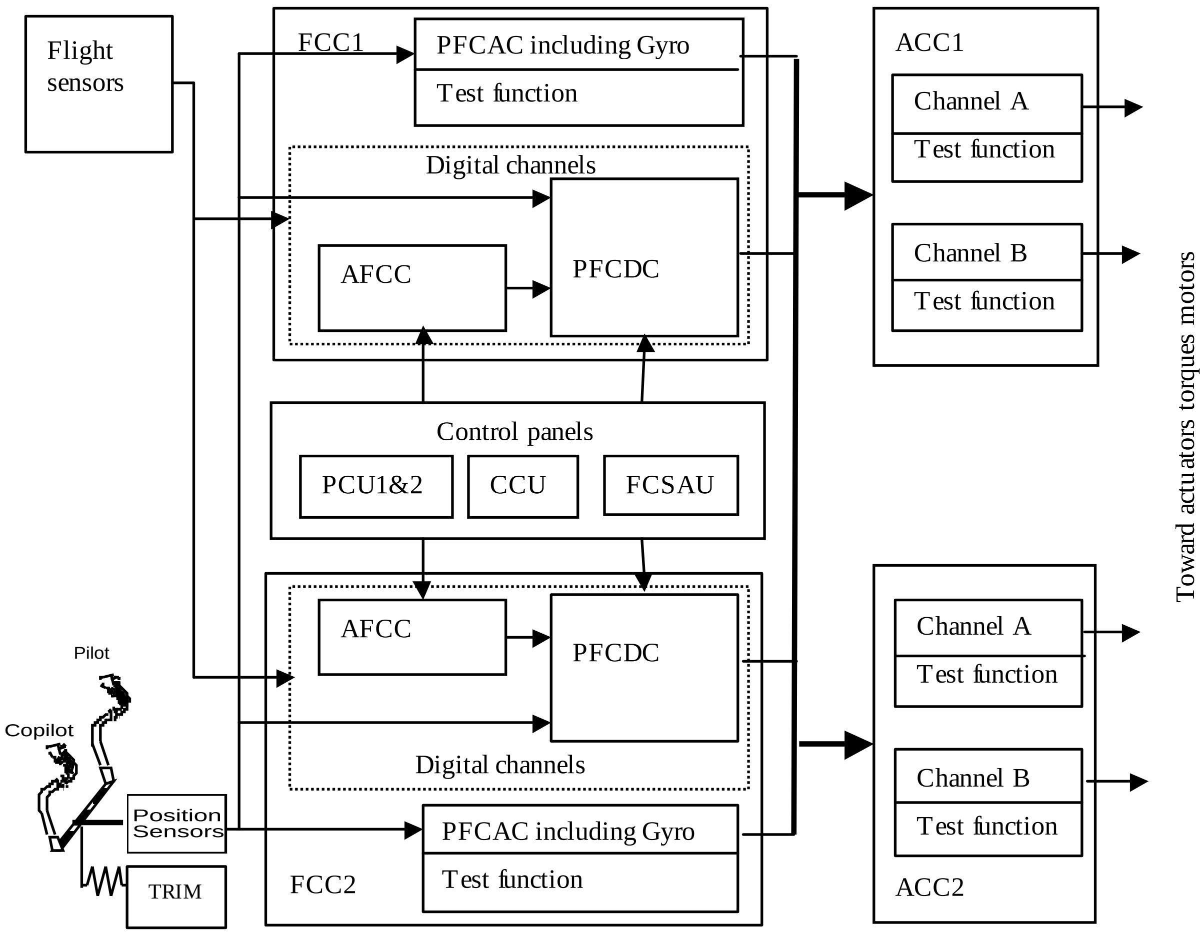

Figure 2 : NH90 Flight Control System architecture

4. Monitoring and Diagnostic System

At helicopter level, as general requirements, the MDS must perform :

- system testing and, when feasible, failure localization,
- evaluation and display of results,
- memorization of failure, date and associated parameters,
- post-flight report and maintenance operation.

The heart of the MDS is the Plant Management System, broken down into two PMCs and a Maintenance Data Base (MDB). In addition, for maintenance operation, a man machine interface capability (Display Keyboard Unit, …) allowing maintenance crew action is added. The interface between MDS and FCS is provided via PFCDCs. The general organization is presented on figure 3.

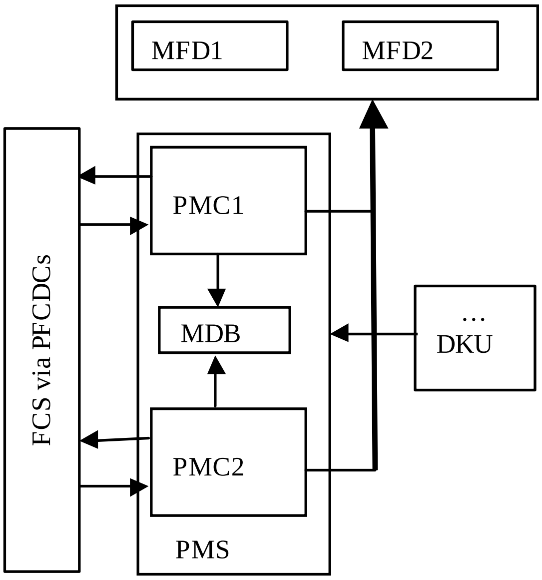

Figure 3 : PMS organization

In the helicopter MDS philosophy, the PMS provides :

- data acquisition for MDS purposes,
- alarms and advice to the crew using MFD and DKU,
- data treatment and storage in MDB for maintenance purposes and post-flight analysis,
- interface with MFD and DKU for MDS data presentation and entry/editing relevant parameters.

For the FCS, the following paragraph presents his functional organization and allocation inside hardware resources.

5. FCS Monitoring and Diagnostic : functional breakdown and system allocation

In order to cover all requirements the FCS monitoring and diagnostic is broken down into monitoring, system status management, failure report, failure storage in MDB and post-flight report, and maintenance operation. For each sub-function, depending upon constraints and/or advantages, the functional allocation is presented. The result is presented figure 4.

Monitoring

The monitoring must detect any failure which could occur in the system before and during flight and could have an impact on safety or could compromise the mission. All other remaining failures must be detected for maintenance reasons.

For safety and mission monitoring, in addition to detection, the monitoring must passivate the failure. That means that the system must exclude from commands processing any faulty sensor, or faulty function or faulty computer in order to avoid or minimize failure effect on the helicopter.

When possible, a system reconfiguration is provided in order to keep the best level of handling qualities possible and to ensure the mission effectiveness.

The testability monitorings are only designed to improve system maintenance operation. Then, generally, they cover failures without direct effect on safety or mission reliability even if combined with another failure occurring after. Therefore, in most of the cases, neither system reconfiguration nor passivation is needed.

The monitoring is divided in PBIT, PFBIT and CBIT. Each BIT including safety and testability monitoring.

As several monitoring functions (mainly safety monitoring) induce automatic failure passivation, they is naturally implemented in the FCS computers.

System status elaboration

This sub function manages system configuration depending on detected failure and displays FCS status on MFD. The system management and/or reconfiguration is distributed among the different computers, the annunciation is mainly managed by PFCDC.

Failure report

The failure report function performs failure localization and characterization.

As almost all the failures have to be detected for safety reasons, localization inputs are automatically available in the FCS computers (without data exchange), and Eurocopter has chosen to implement as far as possible the failure report in real time inside FCS.

The FCS already embodies intelligent items and it has appeared more efficient to distribute among the FCS equipment the task of monitoring and localizing failures of their dedicated peripherals rather than implement such algorithms in an aircraft centralized maintenance computer.
At the end, the FCS including localization is an autonomous system. It is a help for development by minimizing failure investigation time even when PMS is not yet available. Actually, the failure reporting function provides directly detected failures and the possible reasons.

Failure storage and post-flight report
This function performs failure storage and report to the crew on MFD.
The data base is managed by the PMC, thus failure storage and post-flight reports are implemented inside PMS.

Maintenance operation
Maintenance crew initiates the maintenance operation (IBIT).
The maintenance operations, due to the helicopter general maintenance policy, is managed by maintenance crew using DKU and PMS. Dedicated tests are implemented in the concerned FCS computer.

6. Detailed functions design

The main characteristic of each sub-function is the following.

6.1 Monitoring and system management

PBIT
The target of PBIT is to check computer resources availability and integrity. This test, implemented in each computer, is automatically launched at power up.
For digital computers (including test function) the check covers microprocessor, memory, inputs/outputs, …
For analog computers the test is managed by the test function, by checking analog values and providing intrusive stimuli in analog hardware (for example to check that monitorings are able to trip).
In case of a failure detected during PBIT, the computer validity is turned off and the redundancy is lost.

All detected failures during PBIT are sent to Failure Reporting.

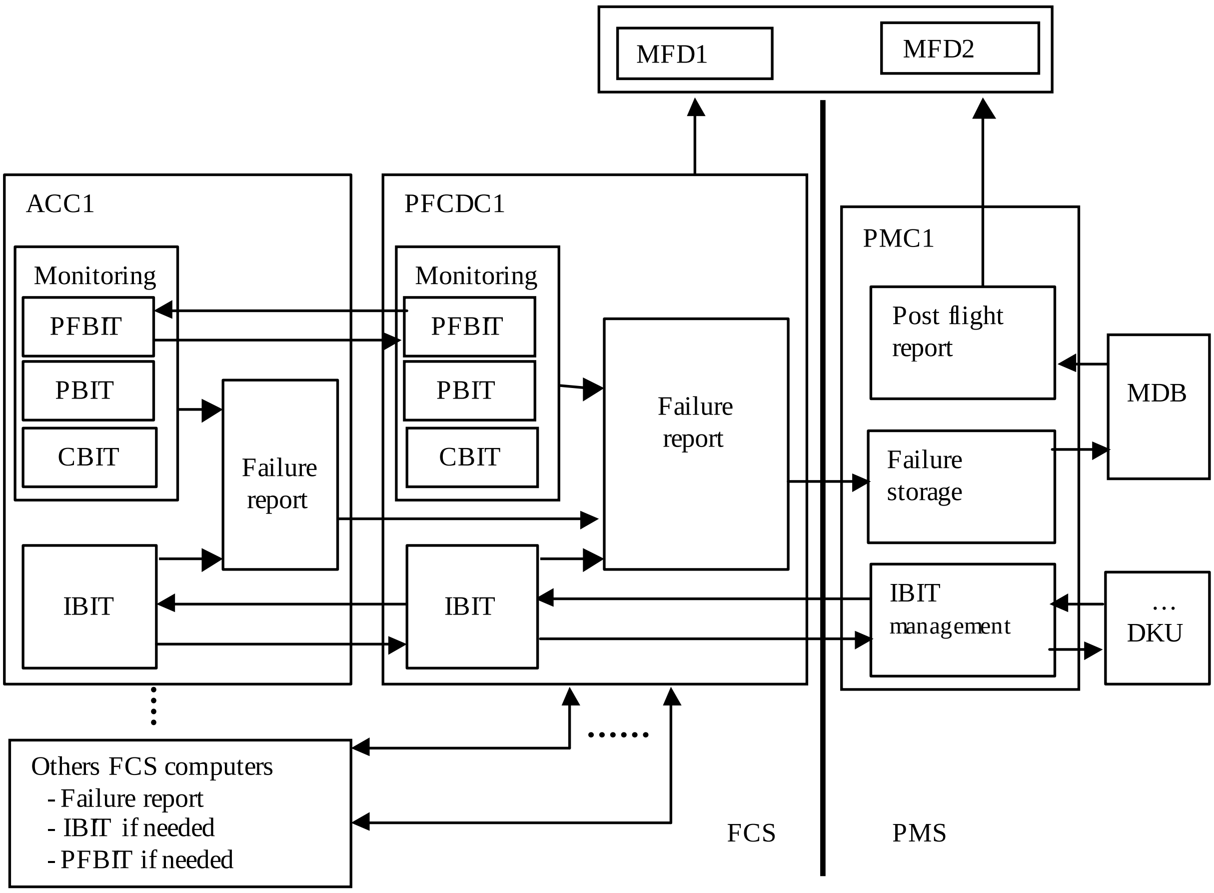

Figure 4 : FCS monitoring and diagnostic functional allocation

PFBIT

The target of PFBIT is to check system integrity before flight. This test must detect before flight dormant failure in order to reduce latency, and avoid possible catastrophic effect due to combination with a failure which could occur during flight. It covers system test involving several computers at one time and autonomous equipment test. This last kind of test could be considered as a PBIT extension, but not allowed in PBIT because they needs a specific system configuration (as power supply availability) or take too long time to be compatible with a power up phase.

The test is initiated, on ground and rotor stopped, by the pilot using a dedicated push button on FCSAU. Then the test is managed by one of the PFCDCs called master PFCDC. The test involves the other PFCDC, both PFCACs, both ACCs, the FCSAU and the CCU.

This test checks mainly :
- power supply switching capabilities for each computer,
- dormant failure lack on signals between computers (as computer validity)
- sticks and actuators authority,
- PFCAC embedded gyro slaving loop

The master PFCDC communicates with the other PFCDC, PFCAC, ACC and CCU using serial links in order to schedule the different test sequences.

Except the CCU which runs the test itself on master PFCDC request, other computers are synchronized by master PFCDC. In fact, as the test checks dormant failures (e.g. wiring, computer inputs/outputs) at least two computers are involved at the same time.
At test end, the master PFCDC collects the results from involved computers and elaborates a synthetic result GO/NOGO. This result is displayed on FCSAU front panel and on MFD. Some details are also displayed on MFD as the kind of detected failure and/or crew action to perform in order to run another test with increased chance of success.

On failure occurrence during PFBIT the reaction depends on the impact on safety. If the failure has effect on safety, the computer involved is invalidated. In other cases, the failure could lead to a degraded configuration before take off.

In any case all detected failures are provided to Failure Reporting.

CBIT

The target of CBIT is to check continuously all active failures as loss/malfunction of signals, discrepancies between channels, …
In case of a detected failure, the reaction is (depending on criticality) :
- sensor or actuator (TRIM only) excluded from computation,
- sub-function inhibited, leading to a degraded configuration,
- computer invalidated if its integrity (including sensors) is lost.

Depending on the situation the adequate annunciation is provided.
The detected failures are used for on-line localization by the failure reporting function.

6.2 Failure reporting

This function performs failure localization, then provides for each failure:
- a failure code,
- the date of occurrence,
- the number of occurrence,
- the type of BIT where the failure is detected,
- the possible LRU where the failure could appear (up to 3),
- if possible the faulty SRU (up to 3) inside the LRU.

In addition, this function provides, for each computer, some other maintenance oriented parameters as :
- part number and serial number,
- software version,
- functioning time.

In each computer the failure reporting collects the failure provided by each type of BIT. Its uses the failures and current system status to perform localization in real time.
For each failure, the computer generates a data package containing all failure characteristic data. All the data packages are stored in the computer each time a failure is detected. Then they are cyclically sent to the PMS.
In the FCS the PFCDCs are the only computers connected to PMS, then they act as data transmitter for other FCS computers as AFCC, PFCAC, ACC, …

6.3 Failure storage and post-flight report

These functions are performed by the PMC. It receives failure reports from all computers; directly for PFCDC and forwarded by PFCDC for others computers. Subsequently, the PMC stores the failure in the MDB.
Knowing the history of each failure, the PMC determines also if a failure is an intermittent or a steady one.

On ground and on request, the PMC displays on the MFD the failure detected and stored during flight for the selected system.

6.4 Maintenance operation : IBIT

The IBIT, performed on ground and rotor stopped, covers preventive and on-condition maintenance, and calibration. This BIT concerns PFCDCs, ACCs, and PFCACs.
The IBIT is an interactive mode where maintenance crew decides to perform the test. For that purpose the crew uses a dedicated keyboard and display (DKU). The FCS is accessible via the PMC.

Depending on the crew request, the PMC sends the request to the selected computer (possibly via the PFCDC) inside FCS and get the test result OK/KO also via PFCDC. The test result is displayed on DKU as a synthetic result (OK/KO). If the test result is failed, a failure report is sent, as in operational functioning mode, by the computer which performs the test and the PMC displays this result on MFD.
If PFCAC or ACC are involved, the PFCDC acts as a mailbox forwarding messages in both directions.
The maintenance test could be an interactive test involving maintenance crew, in this case the procedure displays which human actions are needed.

Preventive IBIT

The preventive IBIT is launched with a predetermined periodicity. The main objectives are to detect dormant failures with an acceptable long latency time or to detect a failure with an effect depending on time as analog filter characteristic will drift.

On-condition IBIT

The on-condition IBIT is launched when a failure has been detected in flight, but the system is not able to localize the failure between several computers. In this case, a dedicated test with stimuli injection is performed in order to determine in which computer the failure is really localized.

Calibration

The calibration is a tuning capability allowing DSU bore sighting.

7. Conclusions

The stringent and multiple objectives from safety to maintainability have been taken into account to develop the FCS. So far, all the monitorings have been developed and validated in flight. The developed failure reporting function have been validated on test rig

On line monitoring and diagnostic in each FCS computer provides, at flight end, the equipment to repair or to change; thus the maintenance operation is easier. Even when the diagnostic is undetermined between LRUs, the maintenance work is easier by the knowledge of the kind of failure and the list of LRUs involved.

At the end, as the detection devices, needed for safety reasons, provide a major part of the data for localization the diagnostic integration within each FCS computer minimizes the development effort.

Acronyms

ACC : Actuator Control Computer
AFCS : Automatic Flight Control System
BIT : Built-In Test
CBIT : Continuous BIT
CCU : Central Control Unit
DKU : Display and Keyboard Unit
DSU : Dynamic Sensor Unit
FWB : Fly By Wire
FCC : Flight Control Computer
FCS : Flight Control System
FCSAU : Flight Control System Auxiliary Unit
IBIT : Initiated BIT
LRU : Line Replaceable Unit
MDS : Monitoring and Diagnostic System
MDB : Maintenance Data Base
NAHEMA : NATO Helicopter Management Agency
NHI : NH Industry
PBIT : Power-up BIT
PCU : Pilot Control Unit
PFBIT : Pre-Flight BIT
PFCAC : Primary Flight Analog Computer
PFCDC : Primary Flight Digital Computer
PFCS : Primary Flight Control System
PMC : Plant Management Computer
PMS : Plant Management System
SAS : Stability Augmentation System
SRU : Shop Replaceable Unit

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