SYSTEM ARCHITECTURE FOR NEW AVIONICS ON EUROCOPTER FLEET BASED ON IMA SUPPORTING CIVIL AND MILITARY MISSIONS

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ABSTRACT

The system presented in this article allows to EUROCOPTER helicopter fleet to adopt the latest generation digital integrated avionics system, with a "glass cockpit", a 4 axis autopilot and coupled with a Flight Management System that allows flying the helicopter automatically from the take off to the landing.
It is a step further in system redundancy using latest technology.

1   INTRODUCTION

While keeping features and using experience acquired on the previous programs such as "Avionique Nouvelle" [1] and "AHCAS" (EC225) [2], this avionics suite has been launched by EUROCOPTER after a deep market analysis. It has allowed identifying key requirements for a full avionics suite covering the entire range, from the light single engine VFR helicopter up to the medium twin engine, for single or twin pilot IFR, compliant with ICAO [3] and JAR-OPS [4] requirements. Supported by a deep functional analysis, for both civil and military missions, the development has been based on qualification of hardware and software components that are used to build various applications, applying DO 297 [5] incremental certification process.

Enhancing safety and reducing workload for the end customer, this avionics, designed for a maximal reuse objective, allows decreasing development costs by applying major rules as:

- a scalable, modular and flexible architecture which support different system configurations via loadable software (application software, configuration files, databases),
- a very integrated system minimizing weight, volume, number of equipments, and part numbers,
- a common basic avionics development for all helicopters with family concept,
- interconnectivity principle based on the use of standard interfaces
- an IMA approach, using SW partitioning techniques based on ARINC 653 [8]

Figure 1. System on board

2   SYSTEM OVERVIEW

The chosen open system architecture was selected in order to enhance reliability, to facilitate maintenance and to cope with various missions. This is resulting in a major reduction of the system weight and wiring complexity. This leads also to a reduction of direct maintenance cost by decreasing the amount of components and part numbers, and an easy plug and play access to mission options based on secured field loadable software method.

The basic system consists of modular components that can be integrated into a complete avionics system by adding or removing elements with system configuration updating, and without any impact on any other components.

The system is compatible by configuration of more than 40 different communication, navigation and mission sensors:

- Garmin suite
- Collins suite
- Canadian Marconi
- …

2.1   BUILDING BLOCKS

The following basic components allow building several configurations according to helicopter types and customization:

2.1.1   Glass cockpit Multi Function Display (MFD)

The MFD is a 6"x 8" AMLCD smart display providing colored pictures in high resolution XGA and extra wide viewing angles. MFD enables Portrait & Landscape orientations with the same optical module..

For full flexibility and operability of the display system, a mix of hard keys (hard-coded key), soft keys (dependent on the text shown near the key on the display) and rotary knobs is provided around the screen. This allows easy access to all necessary functions and lightens the workload of the crew.

In addition the functionality of the controls, that are used for display formats and sub-formats selection and for modification of crew adjustable parameters, are software configurable.

MFD has a modular design optimized for redundancy and maximum segregation between internal modules, with an Operation System ARINC 653 [8] providing spatial & time partitioning and APEX interface. The MFD embeds the Mission capabilities (DMAP, SVS, EFB, HTAWS).

Its specific design allows withstanding "extreme" (-45°C/+85°C) temperatures, increasing the "standard" mission reliability.

2.1.2   Aircraft Management Computer (AMC)

The AMC performs signal acquisition, conditioning and transferring the data to the MFD via a digital channel.

It offers a wide variety of interfaces: analog, frequency, resistance, discrete, ARINC 717 [9], serial communication, Ethernet, etc…

As for the MFD, it runs an Operation System ARINC 653 [8] and it is designed up to +85°C operating temperature.

The AMC incorporates static and total pressure sensors, temperature sensors and AHRS sensors interfaces which enable it to perform a complete ADAHRS functionality.

The AMC is internally dual redundant: two identical channels, each with full input/output capabilities, power supply and processing unit. Both half are totally segregated with no dependencies.

The AMC is designed to support configurations of single engine and twin engine helicopters by adding a second identical AMC to system architecture

2.1.3   Inertial sensor

The inertial sensor provides raw angular rates and body acceleration data to the AMC for computation of attitude parameters.

The attitude functionality is achieved by a set of stand-alone (autonomous equipment) inertial sensors and which are interfaced with the AMC.

2.1.4   Standby Instrument

For IFR configuration, it computes and display standby attitude, altitude, airspeed.

2.1.5   Magnetometer

The magnetometer provides heading tracking capability.

2.1.6   Control Panel (CP)

CP provides mean to control third MFD, for single pilot configurations with 3 MFDs, when it is visible but not accessible in single pilot configuration

2.1.7   Digital Transfer Device (DTD)

DTD is used for system data loading (databases, software images, fault logs, maintenance data and so on).

The DTD provides switching capability of 10/100Mbps Ethernet ports, integrated RTC with backup battery, front panel door mechanism providing access to removable memory device, USB interface, 1Gbit Ethernet interface.

AMC and MFD are platforms according to DO 297 [5] definition and host applications SW (partitions) to provide processing and displaying capabilities for functions supported by the system. Thanks to its Robust Partitioning, the platform provides its services to every partition in time and space domain regardless of the existence of other partitions in the same PTF.

These reusable building blocks are designed for covering all the avionics range and supporting all interfaces, safety levels and environmental constraints requested by various application contexts.

Thanks to its numerous interfaces, the basic system can be connected with other helicopter subsystems:

- AMC is interfaced with vehicle and engine sensors. It provides controls for AFCS actuators and gathers data for the CVFDR (when fitted).
- MFD is interfaced with radio navigation and radio communication sensors, external FMS or missions sensors such as FLIR, …
- DTD is interfaced via Ethernet with AMC and MFD, external PC, removable memory (Compact Flash). It can be connected to ground stations, test tools, or external equipments as dedicated mission computer and Health computer.

The primary reference sensors (inertial sensor, magnetometer and standby indicator) are the only sensors which are part of the basic avionics system.

3   FUNCTIONS DESCRIPTION

These building blocks, identified by complementary functional and material approaches, support a wide set of user and technical functions.

3.1   USER FUNCTIONS

3.1.1   Flight Monitoring

Flight monitoring function ensures acquisition, dispatching and monitoring (including graphic monitoring) of all primary data necessary for the flight control by the crew.

In particular it is to acquire and display the following parameters:

- Attitude (Pitch and Roll), Heading and Sideslip
- Corrected/Standard Altitude, Airspeed, Airspeed tendency, Vertical speed, VNE warning, Upper Limit
- AFCS references, modes and status
- Radio altitude, Decision Height, Upper Limit
- RadioNav data (main nav. source, single/double bearing pointers, Course selection, Deviation bars, ILS Loc/Glide bars, Waypoints and wind data)
- Alarms and discrepancy
- Weather Radar data
- HTAWS data
- TCAS data
- External FMS data

- Optional Video data such as external DMAP and FLIR

3.1.2 Vehicle and Engine Management function

The VMS function gathers information allowing engine and vehicle parameters monitoring and indication depending on the helicopter type:

- Processing and display of engines power and limitations
- Processing and display of transmissions and hydraulic information
- Processing and display of electrical system information
- Processing and display of caution and advisory
- Processing and display of fuel system indication
- Processing and display of mast moment indication for H/Cs requiring this information
- Processing and display of outside air temperature
- Processing and display of flight duration
- Monitoring of engine parameters
- Monitoring of vehicle parameters.

In addition it manages:

- the aural messages and the associated priority algorithm,
- the audio alarm and associated priority between signals coming from sensors/equipment, functions, cockpit controls, H/C configuration file, and convert them in audio signals which are sent to the intercom system.
- visual alarm generation to be displayed on the adequate equipments (display, Central Warning Panel (CWP), ...) according to an order of priority

3.1.3 ADAHRS sensors

The ADAHRS sensors function purpose is to elaborate the primary reference data. The data computed are the Roll, Pitch, Magnetic Heading, Computed Air Speed, True Air Speed, baro-altitude, pressure/inertial rate-of-climb, accelerometer and angular rate.

The ADAHRS function is performed by each AMC platform which is linked to inertial sensors, magnetometer sensor, temperature probe and embedded Air Data Sensors.

Embedded in each AMC, both ADC permit all air data computation as altitude data (standard pressure altitude), air speed data (Indicated Air Speed, True Air Speed, Mach), altitude rate data and atmospheric parameters (pressure, temperature). The baro correction setting is performed by Primary Flight Displays.

In addition, the standby indicator computes and displays helicopter attitudes and air data.

3.1.4 Automatic Flight Control System

The unique (dual) duplex 3 axis or 4 axis AFCS derived from EC225 with acknowledged superiority from all operators offers 'fail-operative' feature (piloting help provided after failure) thanks to redundancy of resources. A back-up stabilization is offered after second dual AFCS processing module default to insure a minimum helicopter stability if required.

The basic AFCS decreases significantly pilots' workload for hands-off flight. The AFCS offers functions such as basic stabilization mode and upper modes.

The AFCS has full capability to provide necessary information (i.e. "immediate recovery" alarm, state change, mode engagement, reference, excessive deviation and out of trim) to the Flight Display Sub system.

The part of AFCS function ensured by the basic system does not include the actuators.

3.1.5 Powerful data generation for efficient aircraft maintenance & operation

3.1.5.1 Usage and Monitoring Function

The UMS improves monitoring of engine surveillance, provides advanced failure detection thus reducing risk of in-flight failures, or minimizing its impact through crew early warning. Hence, it ensures optimization of helicopter safety, maintenance and availability and provides usage data concentration and recording. UMS data are used for analysis of context during over limitation.

3.1.5.2 Flight Data Recording

During the flight the basic system autonomously performs in continuous mode the FDRS data concentration process, composed by data acquisition of FDRS related inputs, formatting of the acquired inputs and transmission through the ARINC 717 [9] output to the external Flight Data Recorder.

3.1.5.3 Flight Data Continuous Recording

The FDCR function records about 1000 parameters in 12 categories with a period from 20 ms to 5 s during at least 16 hours in the avionics non volatile mass memory.

The data recorded and stored during the flight can be downloaded via the data loader to allow a post flight analysis on ground.

Thanks to these capabilities, the system is designed to integrate options as:

- Helicopter Flight Data Monitoring (HFDM), also called HOMP, for flight replay (curves, main cockpit instruments, 3D) + software on PC
- CVFDR
- Health monitoring in UMS (HUMS) for HMI and common data repository (DTD)
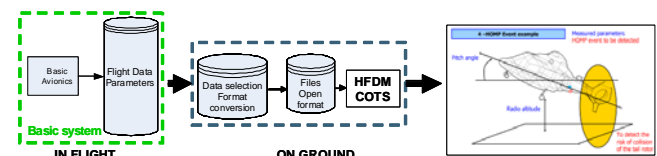

Figure 2. Helicopter operation monitoring with HFDM (HOMP)

3.1.6 Standard navigation package with integrated DMAP, SVS and HTAWS

3.1.6.1 Digital Map

The DMAP manages and displays raster map, and vector map. Several overlays can be managed including the flight plan overlay or aeronautic procedures (interactivity with FMS (CMA9000/GNS430) with Joystick to create routes but also additional mission superimposition). With digital elevation data the digital map is able to perform Height Above Terrain (HAT) computation as well as intervisibility functions. Standard control and moding are provided including zoom selection, map orientation, map centering mode, overlay control.

The function provides aeronautical database queries via DMAP & near list such as nearest Helipads/Heliports, radio & navigation communication, restricted areas & altitude limitations, nearest airways, VFR WPs.

The enhanced interactivity capabilities provides user database management, external NAV-COM control, virtual panels (HTAWS), geo-located contextual menus
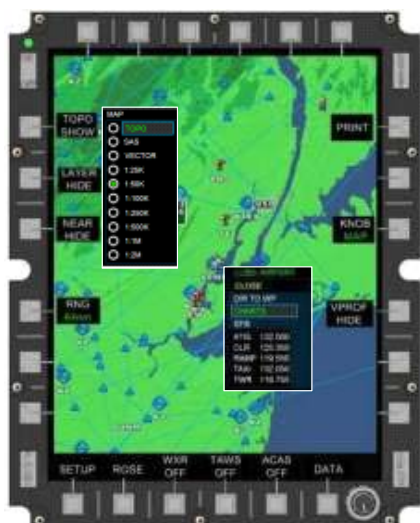

Figure 3. Aeronautical data base queries via DMAP

3.1.6.2 Synthetic Vision

The synthetic vision system (SVS) uses the aircraft's position and orientation in combination with the on-board high fidelity terrain databases to render a synthetically generated view. The synthetic world ahead of the helicopter is displayed even if the visibility of the real world is degraded due to weather, darkness, brown-out or other. This three dimensional perspective view changes as the pilot maneuvers the aircraft (in relation to speed, height, heading, roll and pitch) just as the view out-the-window does. As presented in figure here below, SVS presents an egocentric 3 dimensional terrain imagery on Primary Flight Display.

Figure 4. ADI above SVS

3.1.6.3 Helicopter Terrain Avoidance Warning Function

HTAWS function complies with DO 309 [11] and TSO-C194 [12]. Using a digital terrain elevation database, as well as obstacle database when available, HTAWS complies also with civil regulation defined in AC 29-MG18 [13], including basic GPWS function, Forward Looking Terrain Avoidance function and display of the terrain information in order to increase situation awareness.

Figure 5. HTWAS layer in DMAP display

The consistency with the DMAP and SVS is insured by the use of same data source and uploaded package (configuration management).

3.1.6.4 Electronic Flight Bag

The system provides an EFB class 3 function regarding the HW with type A and B applications according to AC120-76A.

This EFB function allows the crew to embed its own paper documentation, to customize the arborescence of his documentation and to have access to both official data (flight manuals and AIP (Aeronautic Information Publication)) and its own data (user manuals, documents, photos, others) on MFDs.

Figure 6. Airport map display

The manuals viewer provides the means to reduce paper manuals in the cockpit. Library & Smart search options (graphic search according to the cockpit arrangement) enables quick access to any requested manual.

3.2 TECHNICAL FUNCTIONS

3.2.1 Display/Control and Alerting Management function

The goal of the display/control and alerting management function is to mix information coming from different user functions and to show them to the crew. Conversely, it takes into account inputs from the crew and transmits them to user functions.

Crew can select several display formats among the basic formats available such as FND, VMD, NAVD, DMAP, EFB, MISSION.
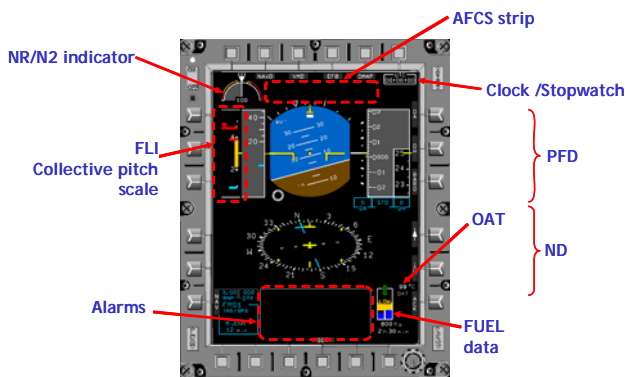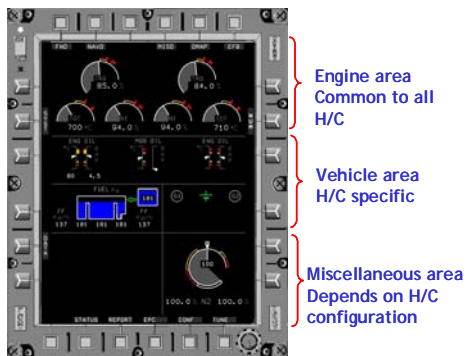

Figure 7. FND basic format

Figure 8. VMD basic format

The alerting function provides a consistent alerting system combining display, voice and tone. Easily adaptable taking into account the customer specific needs, it contributes to alleviate the amount of alarms, advisory and alerts that should be displayed. It manages priority between signals coming from sensors/equipment, functions, cockpit controls, H/C configuration file, and convert them in audio alerts which are sent to the intercom system.

3.2.2 Centralized Failure Management

The Failure Management function is a sub function of the Maintenance function. It is restricted to the avionics perimeter. It detects, via initialization tests, monitoring tests and if necessary initiated specific tests, any system faults concerning the systems and the sensors/equipments connected to them.

3.2.3 Data loading

The Data Loading function provides capability to upload and download softwares and files to the system.
Field data uploading/downloading is flexible via external PC or via DTD removable memory cartridge.

3.2.4 Operational System Monitoring

The OSM function alerts the crew about failures detected during the helicopter operational state (pre-flight and post flight on ground and in flight)

4 SYSTEM ARCHITECTURE DESCRIPTION

The system provides the functions summarized in previous chapter using a limited number of components while maintaining high modularity (using software partitioning concept) in order to ensure all sort of configurations.
A particular helicopter configuration is identified through:

- the number of building blocks
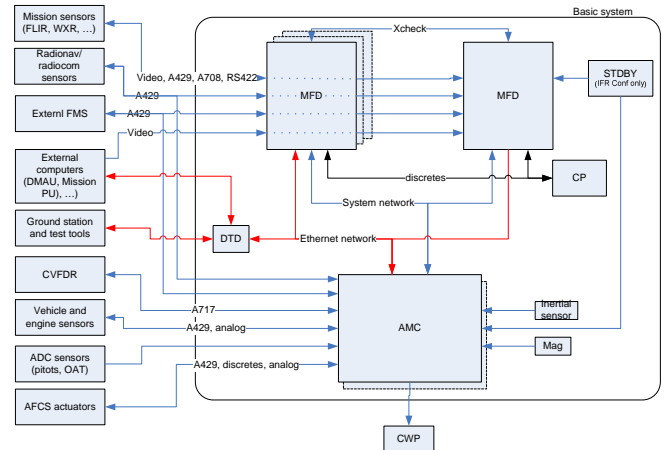- application software and configuration file

Figure 9. System overview

The architecture provides redundancy for safe mission completion, and sufficient MMEL. The rigid ARINC 653 [8] Operating System supports configurable functionalities customized per installation. The Ethernet network is expandable.

The system automatically detects failed or degraded sensors and performs automatic reconfiguration allowing

- quicker reaction
- decreasing helicopter effect and
- reducing pilot workload with improvement of failure management

More than 20 Patents are registered with this new system.

The following figure presents the cockpit for dual pilot, twin engine IFR configuration.

Figure 10. Cockpit design

5   DEVELOPMENT METHODOLOGY

The level of system complexity is increasing for avionics systems. New advanced functionalities make the integration activities less and less manageable at a level of a reduced team having the global view on the system. To compensate this lack of possibility, to master this situation and to manage more and more systems interactions, mature processes shall be put in place.

The International Council on Systems Engineering (InCOSE) defines a system as collection of different elements that, together, produce results not obtainable by the elements alone. The side effect of these systems couplings could create unexpected effects that are not acceptable for safety critical systems. DO 178 [6] has addressed this topic at software level, DO 254 [7] at hardware level but the system should also be a part of the process including the safety criteria for such an avionics system with more and more dependencies.

IMA goal is generally to reduce the number and types of equipments onboard through integration capability. It is achieved by replacing dedicated equipment supporting one dedicated function by generic computers supporting multiple applications. It allows common resources sharing, reducing equipments weight and cost and maintenance. But IMA, engaging the design into a daily run toward more integration, creates interdependent systems. These dependencies, induced by resource sharing, lead to potential technical and certification issues that could lead to planning delays and development over-costs. To avoid such problems, EUROCOPTER has applied, in the recent development of the new avionics suite presented in this article, the ARP 4754 [10] standard extended by the DO 297 [5] to optimize reuse of modules that can be applied on his helicopter fleet.

The initial heavy investment in documentation and methodology has been a key element to save money and to avoid losing time for the global application of this new avionics to the EUROCOPTER fleet. Incremental certification method allows working around the obstacle of the complex integrated systems. This is true not only during development but also for the life cycle and deployment of common product on multiple platforms.

IMA, and in particular ARINC 653 [8] standard, is capable of managing applications integrated on a common IMA platform as if they were alone on dedicated modules. In other words, it offers the benefits of traditional IMA without the problems of co-dependence between applications: interoperability without any unwanted interdependencies. With this approach, integrated functions can be presented for certification independently. When upgrading one application, it is not needed to re-certify others on the same platform. The ARINC 653 [8] is the service permitting this. The DO 297 [5] is the methodology allowing setting up the process supporting this.

Applying this process, EUROCOPTER expectation was also to increase the detection of inconsistency and specification errors or ambiguity at the early beginning by applying a strict validation process allowing to detect these issues when their correction have a negligible cost impact whereas their correction after integration cost 50 time more money with disastrous impacts on planning . For example some analysis of the US Army shows that 70% of the faults are introduced early in the establishment of the requirements but only 3.5% of those faults are found in the same stage.

The EUROCOPTER process is based on the synergies between system development and safety analysis according to process described in ARP 4754 [10].
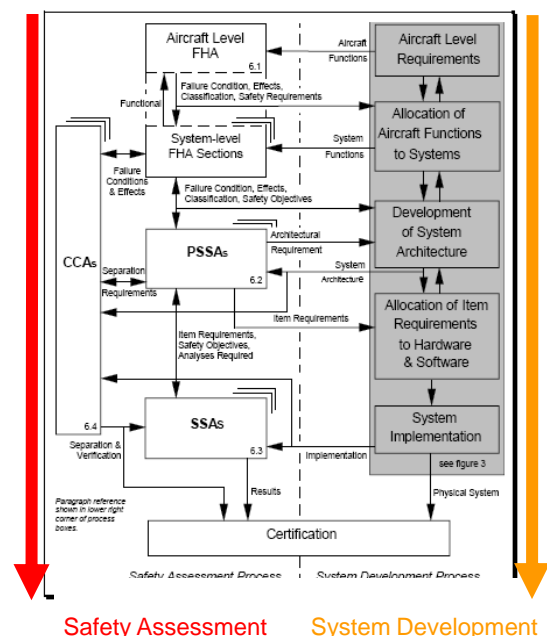

Figure 10. EUROCOPTER process (refer to ARP 4754 [10])

In addition, the DO297 allows defining tasks at different phases of the program in order to define and isolate unit modules that will represent reusable parts (a part being either a SW, a HW or a function definition). The use of ARINC 653 [8] allows structuring the SW modules in more

elementary independent elements with clear interfaces between them.

The figure below defines rules and specifications document tree adapted at avionics functionality level to ensure consistency, completeness and to allow Means Of Compliance for verification in the frame of the Validation & Verification process.
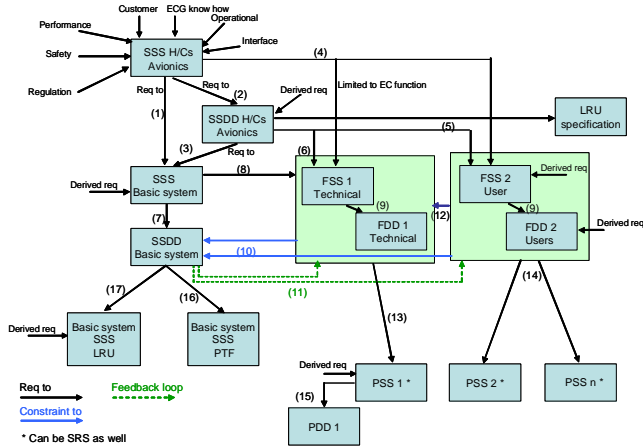

Figure 11. Specification tree for System/Functions/Partitions/basic system PTFs and LRUs

The specification tree shows the allocation of specifications to the functional units. It represents also the flow of requirements from top-level to detailed requirements for the subsystems:
(1) Allocation of H/C Avionics requirements to basic system requirements
(2) Allocation of H/C Avionics requirements to H/C Avionics design requirements
(3) Allocation of H/C Avionics design requirements to basic system requirements
(4) Allocation of H/C Avionics specific requirement to User Function requirement and technical function requirement
(5) Allocation of H/C Avionics design requirements to user function requirements
(6) Allocation of H/C Avionics requirements to technical function requirements
(7) Allocation of basic system requirements to basic system design
(8) Allocation of basic system requirements to technical function requirements
(9) Allocation of Function requirements to function design
(10) Allocation of Function design constraint to basic system design
(11) Feed back loop to fix design between basic system design and Function design
(12) Allocation of User function design constraint to technical function design
(13) Allocation of Technical Function requirement and design constraint to partition requirements
(14) Allocation of User function requirement and design constraint to partition requirements
(15) Allocation of Partition requirements to Partition design
(16) Allocation of basic system design constraint to basic system platform (AMC and MFD)
(17) Allocation of basic system design constraint to basic system LRU (inertial sensor, standby instrument, DTD, …)

6   CONCLUSION

Based on a redundant and open architecture with an unmatched basic range of capabilities such as:
- enhanced flight and vehicle parameters management (Flight and Navigation Displays (FND), Vehicle Monitoring System (VMS) and AFCS),
- enhanced situation awareness with integrated DMAP, HTAWS, SVS and EFB,
- enhanced Flight Data and Usage monitoring and recording (Usage Monitoring functions (UMS) and Helicopter Flight Data Monitoring (HFDM) associated to Flight data recorder (FDR)),

the innovative avionics presented in this paper offers solutions to reduce the risks through:
- FLI & Part time display of VMS reduce pilot workload
- Automatic sensor reconfiguration
- Alarm concept
- Improved autopilot modes and performances
- Reduced failure rate by reducing LRU
- More effective maintenance with better monitoring

Regarding development methodology, the system engineering process applied on the basic avionics system presented in this article is a way to manage complexity. Accurate functional analysis, clear partitioning and optimized architecture are key element to avoid complexity by changing a global complex product with multiple simpler independent elements qualified by a functional approach based on adequate specification tree.

This incremental IMA approach can be considered as the blueprint for the future avionics development and the system presented here is the first one to benefit from it.

The system development is now in its final phase:
- it has proven its versatility by having been flown on several helicopter types for over two years,
- certification is on-going on a new helicopter type.

7   ACRONYMS

ADAHRS	Air Data, Attitude and Heading Reference System
ADC	Air Data Computer
AFCS	Automatic Flight Control System
AMC	Aircraft Management Computer
AMLCD	Active Matrix Liquid Crystal Display
APEX	APplication EXecutive
ARINC	Aeronautical Radio INCorporation
CP	Control Panel
CVFDR	Crew Voice and Flight Data Recorder
CWP	Central Warning Panel
DCAM	Display/Control and Alerting Management
DMAP	Digital MAP
DTD	Data Transfer Device

EFB	Electronic Flight Bag
FDCR	Flight Data Continuous Recording
FDR	Flight Data Recorder
FDRS	Flight Data Recording System
FMS	Flight Management System
FDD	Function Design Description
FSS	Function Segment Specification
GPWS	Ground Proximity Warning System
H/C	Helicopter
HFDM	Helicopter Flight Data Monitoring
HMI	Human Machine Interface
HOMP	Helicopter Operations Monitoring Program
HTAWS	Helicopter Terrain Avoidance Warning System
HW	Hardware
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rules
IMA	Integrated Modular Avionics
JAR	Joint Aviation Requirements
LRU	Line Replaceable Unit
MFD	Multi-Function Display
OS	Operating System
PDD	Partition Design Description
PSS	Partition Segment Specification
PTF	Platform
SSDD	System Subsystem Design Description
SSS	System Segment Specification
SVS	Synthetic Vision System
SW	Software
UMS	Usage Monitoring System
VFR	Visual Flight Rules
VMS	Vehicle Management System

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