CHALLENGE OF MODERN HELICOPTER COCKPIT
Formal specification and real-time piloted simulation for avionics systems and Human Machine Interface design

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ABSTRACT

The extraordinary development of electronic and computing resources in the last decade has led to a significant increase in number and complexity of the avionics systems embedded on modern helicopters. The corresponding design & development process is thus facing the following challenge : to provide the crew with an easy access to an always increasing volume of information and functions, while maintaining the workload at the lowest possible level. Moreover, this development process has to cope with more and more severe schedule and budgetary constraints.

In order to meet this challenge, Eurocopter has adopted since several years a new approach with prototyping and simulation techniques based on efficient computer aided design & specification tools. These tools use high level formal language and technical data base management. Their sound implementation allows upstream prototyping and simulation while providing full permanent technical control of the data flows within and between the different system constituents. This methodology supports a "crew centered design" approach with early pilot-in-the-loop validation, thus ensuring optimum fulfillment of the user's needs.

An essential aspect of the specification through formal language is the associated Automatic Code Generation (ACG) capability. Its use allows a significant reduction of the software development cycle, not only for engineering simulation and testing, but also for embedded code generation when using qualified generators. A key point of the combined use of ACG and simulation is the "single digital specification principle". The whole method contributes to reduce the number of engineering iterations as well as their duration, while avoiding any discrepancy between simulation and embedded code. It brings therefore significant gains from technical, schedule and cost standpoints. It also leads to a reduction of Life Cycle Costs by making further software evolutions easier and contributes to an optimum synergy between engineering and training simulations.

The paper will present how this development methodology is being applied on development programs such as NH90 and EC225/725, highlighting the current benefits and the expected trends for the future.

ABBREVIATIONS

AC	Advisory Circular
ACG	Automatic Code Generation
ADBS	Avionics Data Base System
AP	Automatic Pilot
CAD	Computer Aided Design
CAGW	Computer Aided Graphic Workshop
COTS	Commercial Off The Shelves
FAR	Federal Aviation Rules
FBW	Fly-By-Wire
EC	Eurocopter
EIS	Electronic Instrument System
HFE	Human Factors Engineering
HMI	Human Machine Interface
HW	Hardware
IFDS	Integrated Flight & Display System
JAR	Joint Aviation Requirements
LSK	Lateral Soft Keys
MFD	Multi Function Display
PC's	Personal computers
R&D	Research and Development
SCADE™	Safety Critical Application Development Environment
SG	Symbol Generation
SW	Software
VAPS™	Virtual Avionics Prototyping System

INTRODUCTION

Thanks to the impressive evolutions of electronic and computing resources during the last decade, the variety and performance of the avionics systems capabilities embedded in modern helicopters have evolved in the same ratio.

As a consequence, the corresponding design & development process follows the same trend : the number of parameters managed and displayed by the system increases permanently and the complexity of the presentation requires optimisation loops with early crew members involvement in order to keep the whole crew workload at a reasonable level.

Not surprisingly, this increasing development process complexity must also cope with more and more severe schedule and budgetary constraints. The successful outcome of such developments becomes therefore a new challenge.

The paper presents the Eurocopter answer to this challenge : a design and development methodology, initially implemented few years ago when launching the NH90 program. The current benefits of the method and the expected trends for the future are also highlighted, using the EC225/725 development program as support to the presentation.

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CONTEXT

Since the end of eighties, Eurocopter has launched a large upgrade of its cockpits product line in order to equip them with modern avionics systems, allowing Customers to benefit from new capabilities provided by computer digital technology revolution.

This has been particularly true for the development of digital instrumentation based on screen display performing more and more complex functions (glass cockpits). The first example in this field was the Integrated Flight & Display System (IFDS), developed for the Super Puma MK2, which was the first certified helicopter glass cockpit in the early nineties (see figure 1). This IFDS system was the first step of cockpit evolutions still in progress today, and has been a key reference for further cockpit design and Human Machine Interface (HMI) concept.

Photo Eurocopter, G.Deulin

Figure 1 : SuperPuma MK2 instrument panel

Based on this reference, different cockpit systems developments have then been conducted such as the “Avionique Nouvelle”, fitted on the small and medium aircraft range from EC120 to EC155, or such as high end cockpit systems dedicated to military applications on Tiger and NH90 (see figure 2). These solutions aim at increasing the covering and the complexity of the system or optimising the application for the operational needs according the aircraft size and missions.

Photo X Eurocopter

Figure 2 : NH90 instrument panel

The recently launched EC225/725 development brings a new chapter to this story by going one step further while taking all the benefits of this fruitful experience.

THE PROBLEMATIC

These modern developments have created the need for new engineering skills. On the one hand, these skills must be oriented toward Human Factors Engineering (HFE) and Human Machine Interface (HMI). They aim at designing a crew centred cockpit optimising the flexibility and the power of graphic language provided by digital computer. On the other hand, they must also master Computer Aided Design (CAD) and development process management, in order to build and manage the specification package of the new integrated system, including the graphic symbologies replacing the conventional electro-mechanical instrumentation.

The initial developments, such as Super Puma MK2 IFDS system, had established a symbology development methodology characterised by the following steps :

- An upstream symbology design phase in order to perform prototyping of graphics.
- A simulation specification elaboration covering animation and graphics functions. This specification was then used by the simulation team to produce simulation software.
- A piloted simulation phase in order to validate the operational aspects of the definition by a panel a representative pilots before delivery to the supplier.
- A detailed system specification for animation and graphics for delivery to the supplier. This specification was then used by the display supplier team to produce embedded display software.
- A software development phase by the supplier using an iteration process coupled with integration tests until the final software qualification.
- A flight tests phase in order to validate the full application in the real environment using an iteration process until the final certification of the aircraft.

For these initial developments, the software tools available at that time to perform the development activities were generally simple :

- The upstream symbology design phase was performed using first generation graphics software tool allowing to prototype graphics in a static way only.
- The various specifications were made using first generation of word processing software tools.
- The software developments (simulation and embedded) were made in a conventional manual way by a team of programmers.
- Etc…

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This development approach has been efficient for the initial rather simple systems. However, for the current larger and more complex integrated systems, this approach faces several technical limitations :

- The static prototyping is not sufficient for complex symbology. The use of dynamic prototyping is needed to efficiently assess the definition.
- For complex symbology, the application processing cannot be described in an unambiguous way by using textual formalism into the specification. This leads to potential interpretation errors of the specification package with the consequence of possible bugs in the embedded software. Furthermore, simulation and detailed delivery specifications are both concerned by those potential interpretations. As a consequence, consistency problems may occur between simulation application and embedded application.
- For large systems including multiple functions, the amount of data managed by those systems is not compatible with a manual control. This is likely to generate errors or inconsistencies in the specification package and, as a consequence, errors also in the embedded software.

In addition to the above-mentioned technical limitations, the larger and more complex systems feature a high level of integration involving the aircraft functions (flight management, mission management, and vehicle management). The amount of information and the wealth of available functionality are such that the driving criterion becomes now the crew workload.

It becomes therefore compulsory to use a global approach centered on the crew needs and capabilities and addressing all the aspects of the aircraft design. This implies a fine analysis of operational needs and the ability to involve crewmembers in the upstream design activities as early as possible with an iterative process. It thus reinforces the need for representative prototyping and piloted simulation phases with good reactivity (i.e. minimum duration for each iteration).

Finally, modern development processes must also cope with more and more severe schedule and budgetary constraints (development schedule has been divided at least by two since 10 years). The optimization of each phase of the process become therefore a key point from both technical and economical standpoints.

EUROCOPTER ANSWER

In order to meet those challenges, Eurocopter has adopted at the beginning of NH90 program a new approach based on a more integrated methodology supported by the intensive use of computer aided design & specification software tools.

They provide high level formal language formalism allowing the symbology designer to describe easily and unambiguously the processing associated to the functional requirements of the desired application. These new tools provide also, most of the time, an automatic code production capabilities, additionally reducing the effort and time for producing the corresponding software.

This approach has been also complemented in parallel by the large development of engineering simulation activities on which Eurocopter has largely invested for more than ten years. Nowadays, R&D simulation has progressively become an essential engineering tool providing the whole range of simulation techniques from simple off-line simulation on work stations or PC's to full real time piloted simulation with dome immersion [1] (see figure 6).

The main objectives of this new approach are the ability to reuse as much as possible the work done for each phase in the following ones and the possibility to take all the benefits of new capabilities provided by the software engineering tools in term of automation of the process.

Several improvement axes have been identified and developed :

- Synergy between upstream symbology design phase and simulation specification phase in order to directly reuse design prototypes and models as a first step of specification items (especially for graphics items).
- Synergy between simulation specification and supplier specification package in order to reduce the effort by producing only one single specification applicable to both, thus also eliminating the risk of inconsistency between simulation validation and real equipment.
- Intensive automatic code generation to produce software both for simulation application and embedded application in order to reduce the human resource effort necessary to produce the software, improve the quality of the software production and decrease significantly the corresponding time cycle.
- Intensive use of simulation techniques in order to validate, from both functional and operational standpoints, the functional requirements included in the specification as early as possible and, anyway, before delivery to the supplier and flight test phase.

The integrated approach developed in order to implement these improvements is described on the following synoptic diagram (see figure 3) :

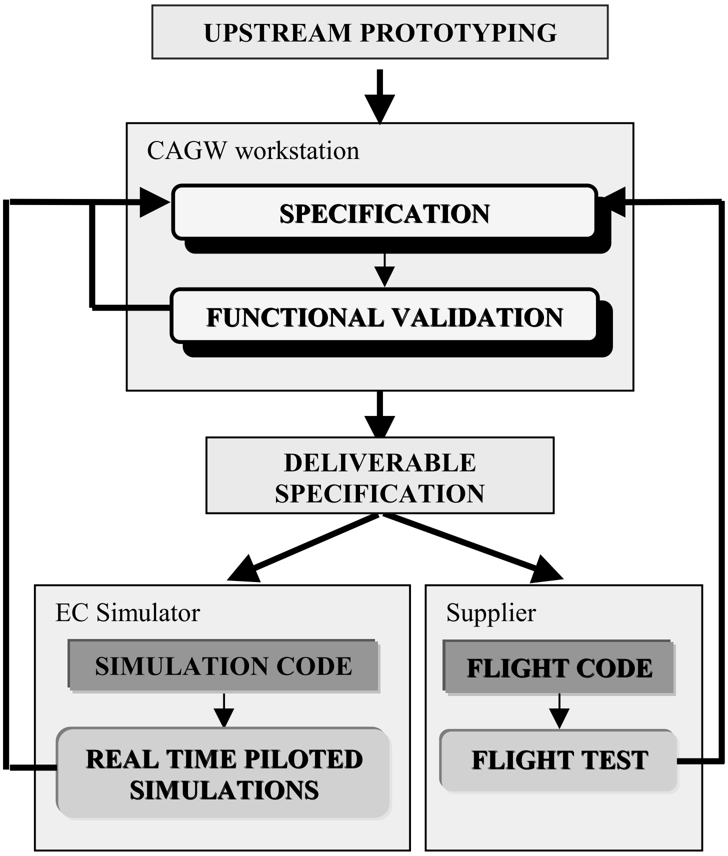

Figure 3 : Definition /specification/evaluation process

The main features are :

- The use of a unique high level formalized specification permanently applicable to both simulation and embedded applications.
- The use of upstream symbology prototyping outputs as inputs for Computer Aided Graphic Workshop (CAGW) formalized specification,
- The inherent use of simulation loops to validate the formalized specification,
  - as a first step from functional standpoint by testing functional requirements on workstation,
  - as a second step from operational standpoint by crewmembers assessment in a very representative environment on real time piloted simulator,

  before any delivery to the supplier, and therefore, before any flight test phase.

The engineering task analysis of such development approaches highlights four main engineering phases which must be conducted in the following order :

1) The upstream prototyping phase.
2) The formalized specification building using outputs of the previous prototyping phase.
3) The functional validation of the formalized specification by iteration on specification building phase.
4) The operational validation of the formalized specification by iteration on specification building phase.

All these activities are performed by Eurocopter in its premises due to the deep implication of crewmembers in the process. Of course, a fifth task covering the embedded SW production and integration in the HW, remains under supplier responsibility.

1) The upstream prototyping :

This very upstream phase has to be highly interactive between the symbology designer and crewmembers. The goal of this phase is indeed a quick building of a scale 1 symbology prototype allowing validation of main graphics features of the desired symbology.

Such phases use the following potential inputs :

- The result of the functional analysis of the system : types of operational functions taken into account in the display application : flight management, navigation management, vehicle management, mission management, etc…
- The application of general conceptual rules : design standards, technical guidelines, airworthiness rules and recommendations (FAR/JAR and AC), etc…
- The feedback experience acquired on other programs constituting the application of HMI policy and family concepts.
- The display environment constraints associated to the system program : number and size of the screens.
- The control and moding concept of the system : the way for the crew to control the display of the symbology : dedicated panels, Lateral Soft Keys (LSK) around the screens, tactile surfaces, designation devices, etc…

The use of a powerful software tool in such a phase is vital in order to achieve representative and accurate prototypes with a reactive crewmember involvement. This tool must also provide dynamic features in order to be able to validate critical parts of the design using a dynamic behavior of the symbology when necessary.

Furthermore, the production of this prototype is also intended to prepare the specification work. The formalism used to describe the prototype must therefore be compatible with the specification formalism.

2) The formalized specification :

Once the main features have been defined through the prototyping phase, the goal of the symbology designer engineer is to produce a specification package, describing unambiguously the functional requirements of the application.

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This formalized specification approach was introduced for the first time in the framework of Airbus program by AEROSPATIALE Division Avions (now EADS-Airbus) for the development of several aircraft subsystems such as Flight By Wire (FBW) or Electronic Instrument System (EIS) displays. Of course, the use of automatic code generation had still some lack in the formalism capabilities and, as a consequence, a lot of SW parts were also coded manually. Nevertheless, the principle and the interest of such approach had been assessed and validated on a real industrial project including embedded SW qualification problematic [2].

In the Eurocopter new approach, the formalized specification package is produced using three different computing aided design software tools, gathered and managed within a so-called Computer Aided Graphic Workshop (GAGW). Each computer aided design software tool is covering a part of the full display function requirements. This splitting of display function requirements corresponds in fact to the display chain classical splitting in three main parts used for implementation in HW computers (see figure 4):

- The input/output (I/O) part, which specifies (name, type, coding, etc…) all data entering in the display computer for symbology generation and animation or which are produced as output by the display computer to be used by another part of the system.
- The processing part, which specifies all symbology animation logic's and computation algorithms necessary on input data in order to prepare graphic output data required by the Symbol Generation (SG) specification formalism.
- The graphics part, which specifies the pure graphics generation process of the symbology (drawing shape, size, color, position, etc… of the symbols).

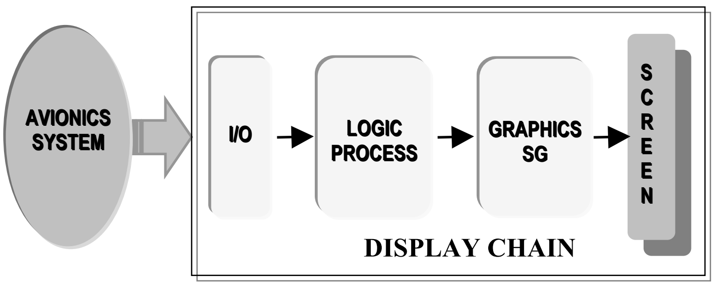

Figure 4 : Display chain splitting

Inside the CAGW, the three different specialized specification software tools remain however independent. They must therefore be encapsulated within a federating software tool in order to ensure the consistency between the different parts of the formalized specification.

This is particularly true for the management of specification evolutions during the development.

This federative software tool is particularly used :

- As CAGW primary user interface to launch the different specialized software specification tools.
- For configuration management of the different parts and formalisms of the formalized specification.
- To launch the automatic formalized specification files delivery procedure whatever the addressee of the delivery : equipment supplier, EC simulator or designer engineer for functional testing on workstation.
- To launch an automatic consistency checks procedure of the formalized specification which has been developed to check project rules within a specific formalism on the one hand (use of authorized color set in the graphic specification for example), and on the other hand, to check consistency of the data flow between the different parts of the specification.

To make easier and human feasible the configuration management activity, one important aspect has been the definition of a fine functional hierarchical structure of the application and to enter that structure within the configuration management tool in order to be able to manage small independent specification items. Each of these small independent specification items covers all the different specification formalisms (mainly processing and graphic). The hierarchical structure then produced looks like a tree, the leaves of which correspond to different specification items.

A minimum of four functional hierarchical levels have been found adequate to obtain a good level of granularity of the specification for classical symbology application. From the largest to the smallest levels, the following levels have been defined (see figure 5):

- The "function" level (the biggest one), corresponding to the main symbology function (e.g. flight, navigation or vehicle management functions).
- The "book" level, corresponding to the symbology format inside the function (e.g. Primary Flight Display (PFD) format).
- The "chapter" level, corresponding to a specific area of a symbology format (e.g. airspeed area of the PFD format).
- The "paragraph" level, corresponding to the functional elementary item inside a chapter (e.g. airspeed AFCS setting value).

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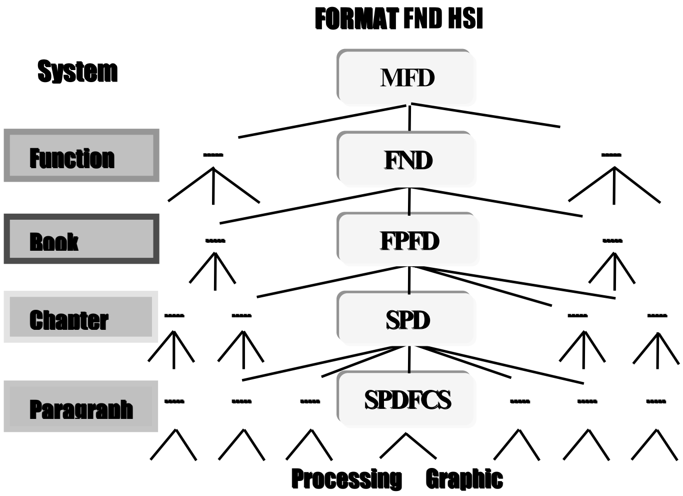

Figure 5 : Structure of the formalized specification

3) The functional validation :

When a homogenous functional part of the formalized specification (usually a paragraph) has been fully developed and verified using the automatic consistency checks procedure, this formalized specification part can be functionally validated using a requirement based testing activity according to high level system functional requirement specification (usually using classical textual formalism).

With this aim, the formalized specification part is delivered and an executable model corresponding to this part is automatically generated by ACG tools on the CAGW workstation simultaneously with a testing environment which allows to activate input data of the model.

Running this model on the CAGW workstation, as off-line simulation, allows the designer engineer to activate inputs according to functional requirements and validate the behavior of the specification by looking at the simulated symbology on the workstation screen.

4) The operational validation :

When a complete set of functionality (usually a certain number of books) has been fully developed, verified and functionally validated on workstation, an operational validation in a representative environment on real time piloted simulator can be done in order to validate that the functionality's specified in the formalised specification answer correctly to operational needs of crewmembers (see figure 6).

With this aim, the finalized formalized specification is delivered and an executable simulation model is automatically generated by ACG tools and integrated in the simulation environment (Flight mechanics, engines, sensors and Automatic Pilot models) providing a coherent production of all the presented information.

A full evaluation of the application can therefore be performed, including systems failures and degraded modes simulations, under realistic mission conditions. These evaluations can go up to Crew Workload Assessment through complete operational missions, and their conditions are getting actually very close to those of training simulations.

(image taken from a video recording realised during an engineering global evaluation)

Figure 6 : NH90 engineering simulated flight

LAST APPLICATION : EC225/725 PROGRAM

In the frame of new helicopter EC225/725 program, this new approach using last Computer Aided software tool generation has been used by Eurocopter for the development of cockpit MFD symbology.

The application was strongly derived from NH90 development work, but some specificity's had to be taken into account like the screen, AP functionality and interface, etc…

The upstream prototyping phase has been performed with VAPS™ tool, provided by Engenuity Technologies Company, which has been selected by Eurocopter to develop all graphics prototypes.

This tool is used to build quickly and accurately a symbology drawing using a large standard graphics primitive's library. Based on this pure graphics definition, the tool is also used to create a display structure of the symbology by using a range of predefined and/or customized high level objects allowing easy dynamic behavior prototyping feature and preparation of the specification work.

The formalized specification package has been produced using three following different computer aided design software tools :

- ADBS for the input/output (I/O) part.
- SCADE™ for the processing part.
- VAPS™ for the graphic part.

ADBS : Eurocopter proprietary tool devoted to the management of avionics system interface (see figure 7). Built around an ORACLE™ database, the tool allows defining and managing consistently digital data exchanges within a system during all the system life cycle.

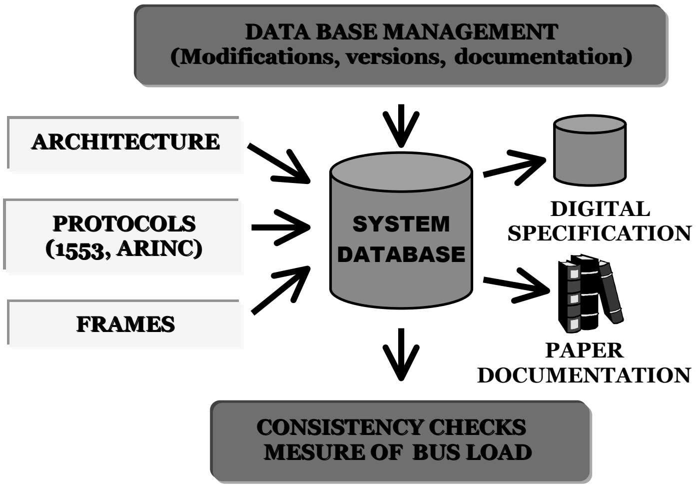

Figure 7 : ADBS tool

The tool allows data consistency and time saving thanks to the sharing of the unique data base content between all contributors of the system development such as : design office team for system design, code generators for software coding, integration rig test means, flight test installation means.

The tool is able to produce two types of outputs : Digital specification ASCII files, which can be used for ACG purposes, and equivalent classical paper documentation files.

SCADE™ : provided by ESTEREL technologies company, is the last generation tool devoted to the specification of data flow synchronous application (issued from the Aerospatiale SAO family tools). The SCADE™ formalism is based on LUSTRE language whilst introducing complementary notions in order to make easier the design of large and complex models.

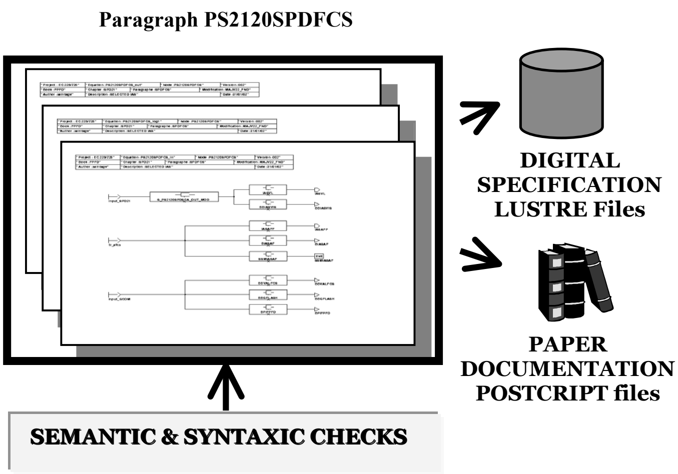

Figure 8 : SCADE™ tool

A qualified C code generator, compliant with DO178B level A requirements, is available in the tool package to transform automatically LUSTRE files produces through the editor in C code.

VAPS™ : already introduced in the upstream prototype phase, is also used for the formalized specification of graphics aspects by reusing and completing the work done during the prototyping phase.

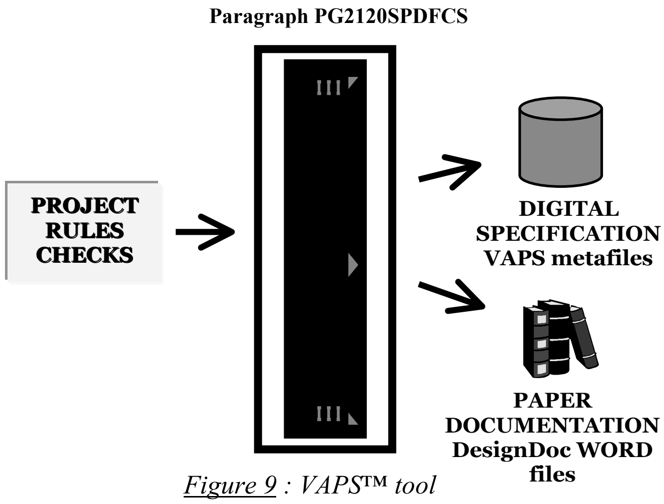

Figure 9 : VAPS™ tool

A qualified C code generator, compliant with DO178B level B requirements [3] (level A in few months), is available in the tool package to transform automatically the VAPS™ metafiles produced through the editor in C code. In addition, a paper documentation module, called DesignDoc, is also available to produce Word files according to customized templates.

BENEFITS AND EVOLUTION FOR FUTURE

This new approach applied on EC225/725 program represents a real step forward in the HMI oriented avionics development process efficiency.

Thanks to last generation of SW tools formalism capabilities, 100% of the SW application can be generated automatically, and the time necessary to produce the SW code of a new version of the application (few hours) allows very reactive iteration process during simulation phase or embedded software integration phase. Moreover, the progressive availability of various qualified code generators as part of COTS SW tools packages, gives the opportunity to reduce significantly the testing effort on embedded software. This provides also a significant cost reduction on software development, despite the necessary investment in terms of software licenses. This gain is also particularly true during the in-service phase for the management of possible evolutions during the life of the aircraft.

As a side effect, the use of ACG associated to the availability of standard COTS graphics electronic boards, improves to a large extend the portability of the developed SW application, reducing positively the HW electronics obsolescence problems.

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Finally, the opportunity to have a very representative simulation application, is also very interesting and useful, while training simulators are not yet available, for HMI training of Customer crews prior to their first flights on real rotorcrafts or in order to prepare training simulator models and equipment.

Several axes remain to be developed for the future, in order to further improve the process associated to formalized specification methods :

- New techniques of formal proof, inherent to the use of formalized specification begin to be available within some SW tool packages such as SCADE™. They are likely to bring a significant increase of efficiency to validate the specification or to elaborate test cases associated to the SW verification.
- The possibility to reuse, for formal validation, the work done when debugging the specification, and to reuse the test cases generated while validating the specification for verification of the corresponding SW are also likely to optimize the whole development process. This implies, of course, to evaluate the representativeness of the simulation used to validate the specification (use of qualified tool as embedded software and implementation in the embedded equipment such as AG code is not affected by other SW parts).
- The management of the different specification items within an object oriented data base could improve the reusability of the different developments inside and/or between programs. This assumes a tighter integration between the different specialized SW tools and their productions within a fully integrated workshop managed as a specialized object oriented database.

CONCLUSION

The development of HMI of modern complex avionics, where crew workload is the challenge, is based on a crew-centered approach which cannot afford separate and/or sequential development of the different constituents.

The methodology described in this paper addresses this problematic as a whole. The prototyping and simulation techniques which have been implemented allow to take into account in an integrated way all the constituents of the Helicopter, while keeping the pilot in the loop all along the process since the very beginning. The CAGW allows to control the inherent complexity of simultaneous iterative evolutions of the HMI and avionics systems impacting all aircraft aspects (flight control systems, avionics and vehicle systems). The increasing use of automatic code generation contributes to the cost and time cycle reduction with a single specification principle avoiding any risk of divergence.

The paper has focussed on the motivations for using this method and the benefits gained during the development. The superiority of the approach, however, is not limited to the development phase. The already mentioned advantages are complemented for the in-service phase by an easier, more reactive and less expensive management of the different possible further evolutions. It also contributes to an earlier availability of different training simulation [SW] data packages [1].

The potential future trends are mainly linked to new formalism developments such as proof techniques allowing upstream formalized specification validation, and to significant improvement of the integration of the different specialized SW tools within the graphic workshop associated to an object oriented data base management technique.

The implementation of these new features, capitalizing current experience, will allow another step forward in efficiency and will thus provide the adequate tools to meet the proposed challenge.

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