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# *NH90 FORMAL SPECIFICATION & ENGINEERING PILOTED SIMULATION*
## *"Paving the Way for a New Range of High Fidelity Training Means"*

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**Abstract**

The evolution of the avionics systems embedded in modern helicopters has followed the tremendous last decade's development of electronic computing resources. This evolution has allowed the integration of various new functions and capabilities for more complex missions, thus permanently expanding the volume of information to be managed by the crew.

In order to meet the resulting Crew Workload challenge, Eurocopter (EC) has evolved from the traditional Technology Centered design towards a new Crew Centered approach. This new methodology was first established for the NH90 design and development phase. Based on a precise contractual framework for Customer involvement in the cockpit design, it combines Computer Aided Design Workshops (using high-level specification tools based upon formal specification language and automatic code generation) with intensive use of engineering simulations. Such a methodology allows upstream pilot-in-the-loop validation, continued all along the design with a simulator progressively enriched by different software components automatically generated from the real formal specifications. The engineering simulation development is no longer parallel to the design but becomes an intrinsic part of it with only one single electronic specification avoiding any risk of divergence. It contributes to an increased reactivity and a better control of the inherent complexity of the design process. At the end of the development phase, a high fidelity engineering simulation is thus available, allowing full mission simulations.

After presenting the grounds of this approach, the paper will explain how a new multiplatform simulation environment initially developed to improve the engineering simulation flexibility has open the door to the deployment on various platforms (down to PC laptops) of simulations originally confined to heavy simulation environments. Thanks to this new simulation environment, various low cost (but high fidelity) NH90 training means can be proposed, complementary to classical Full Flight Training Simulators and available earlier.

The benefits of this new synergy between engineering and training simulations will be illustrated through a first EC225 Super Puma application already realized for Eurocopter internal needs.

**Abbreviations**

| | |
|---|---|
| CAD | Computer Aided Design |
| CLS | Control Loading System |
| EC | Eurocopter |
| FBW | Fly-By-Wire |
| FCS | Flight Control System |
| FFS | Full Flight Simulator |
| FMS | Full Mission Simulator |
| H/C | Helicopter |
| HMI | Human Machine Interface |
| LTD | Light Training Device |
| MFD | Multi Function Display |
| PC | Personal Computer |
| PTT | Part Task Trainer |
| R&D | Research and Development |
| RISE | Real time Interactive Simulation Environment. |

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## Introduction

The design of modern helicopters cockpits and Human Machine Interfaces (HMI) must cope with the permanent increase of embedded avionics complexity. The modern avionics systems provide various new capabilities for more demanding missions and cockpit designers must therefore provide the crews with an easy access to a steadily increasing amount of information. They must in the same time keep the workload as low as possible.

The crew workload becomes thus a critical issue for the cockpit design of modern military helicopters. The traditional technology-centered design process has evolved towards a crew-centered design process, where HMI becomes an intrinsic part of the complete weapon system design. As for the NH90 development, optimization loops must address the various design aspects from a global standpoint with a permanent user's involvement.

The key point for the success of such approaches is the management the convergence of this process. It relies on two aspects: the ability to start collecting the user's recommendations as upstream as possible and the ability to provide adequate technical reactivity.

The paper will show how the combined use of computer aided formal specification workshops and intensive engineering simulation meets this challenge.

It will then focus on the recent availability of a new Eurocopter Real-time Interactive Simulation Environment (RISE) which bridges the gap between engineering and training. It will show how RISE applications capitalize on the sophisticated engineering simulation resulting from the above mentioned technical choices, and opens the door to an early availability of various high fidelity low-cost training means.

## Cockpit Design and Formal Specification Workshops

The design of modern helicopters cannot afford separate and/or sequential development of the different constituents, nor a one shot pass-or-fail evaluation at the end of the process. A Crew-Centered approach has thus been implemented [1], based on interrelated analysis, design, and evaluation activities where the user must be permanently involved

The development of user interfaces obviously applies all lessons learned from previous designs. However, the understanding and knowledge of human capabilities is still limited. Therefore, new designs must be based on detailed analysis of the requirements and, fundamentally, iterative evaluation by the users of the proposed design. The results of these evaluations are then used in subsequent analysis and design steps, which reflect increasing inputs from analysis and evaluation.

Such processes need a strict engineering control in order to ensure design convergence. Human Factors evaluations start in the early phases with paper, mock-up and work station concept prototyping, and continue downstream to full dynamic piloted simulation of representative tasks and missions.

Thanks to the increasing availability of powerful computing resources, engineering simulation provides the adequate tools for evaluation concern.

Eurocopter has invested in engineering simulation for more than ten years [2]. The R&D simulation was originally implemented for handling qualities studies and became rapidly a key engineering tool for avionics & cockpit design, from simple off-line simulation on work stations to full real-time piloted simulation with dome immersion (see figure 1).

Fly-By-Wire systems and modern auto-pilots developments have induced a high fidelity modeling of helicopter flight mechanics, under the control of the design engineers who have the best knowledge of and direct access to the helicopter data.

The need in communality of functions and the increasing use of Computer Aided Design (CAD) workshops have led to the constitution and reuse of functions databases (HMI, FCS, architectures...) directly available for simulation with better reactivity.

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*Fig. 1 - Eurocoper Engineering Dome Simulator (SPHERE)*

In order to ensure the coherence of the whole development process, the different engineering phases use thus common tools and procedures, with the ability to reuse as much as possible the work done for each phase in the next ones, taking benefits of new process automation capabilities provided by the software engineering tools.

As the evaluation process involves the users through various iterations and adjustments, modern industrial constraints and contractual deadlines impose a high reactivity with a strict engineering configuration control. Structured design methodologies have therefore been implemented, based on the use of CAD software tools, initiated in the framework of Airbus program by Aerospatiale Division Avions (now EADS-Airbus) for the development of various aircraft subsystems such as Flight-By-Wire (FBW) or Electronic Instrument System (EIS) displays [3].

These tools provide high level formalism associated with automatic code generation features. They allow unambiguous description of the processing associated to the functional requirements of the desired application.

In this approach, the specification package is no longer a simple documentation, but already high level formal language software. A **single electronic specification** principle is thus implemented, where this single deliverable specification is applicable (through automatic code generation) to both simulation and real equipment application software (see figure 2),

The following advantages result from this method:

- Intensive use of simulation techniques for earlier validation of the requirements,
- Better tests coverage,
- Lower simulation effort (no parallel simulation software development),
- Elimination of the risk of inconsistency between simulation validation and real equipment.

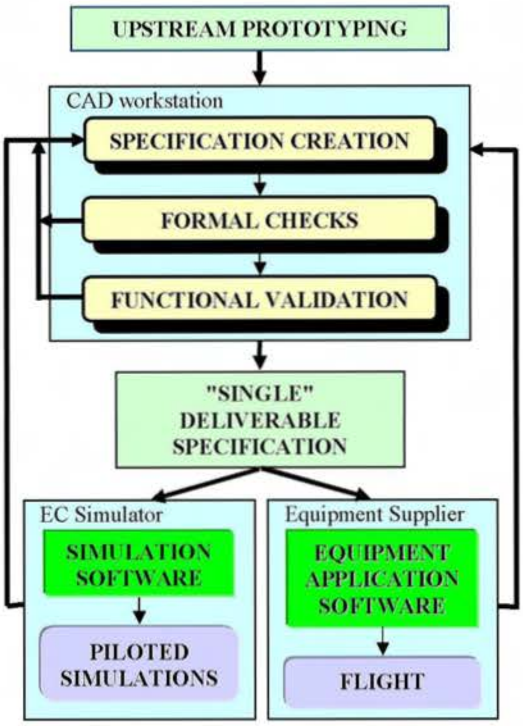


*Fig. 2 - Definition /Specification/Evaluation Process (Single Electronic Specification)*

This philosophy is applied to most critical components of the avionics & cockpit, and the use of the simulator for engineering purpose is now a standard approach for new developments. When a complete set of functionality has been developed and functionally validated on workstation, the specification is automatically translated for the simulator targets and the result is embedded in a real time simulation environment reproducing the concerned system architecture and data flows. An operational validation is then conducted through piloted simulation sessions

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The possibly requested modifications are not implemented in the simulation code but on the "single" specification, and the loops are re-iterated until adequate maturity is reached.

When a specification version is delivered to the supplier, it is therefore already mature and largely validated, thus optimizing the further flight test phases.

The simulator being used along the complete design process, it is progressively enriched by the different components. At the end of the development phase, a highly representative engineering simulation is available, allowing full mission simulation.

In the case of the NH90 program, this approach has been particularly elaborated [5] and the level of realism and coherence at the end of the

not the case for all the components of the simulation.

For EC simulation, the challenge consisted in being able to deal with two opposite constraints: On the one hand a full representative and updated simulation was required to match the functional specification to be evaluated, and on the other hand the time delay to integrate a new delivery had to be reduced to a minimum. Moreover, it was necessary to perform the integration process while maintaining the existing simulation available for evaluations. EC simulation department had thus to adapt its own tools methodology and concepts to reach these goals.

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level of realism and coherence at the end of the development is extremely high. These simulations have allowed in-depth testing and tuning much before the first flight tests and were pursued down to Crew Workload Assessment through complete operational missions including threats, failures and adverse weather conditions (see figure 3).

*Photo Eurocopter -*

*Fig. 3 - Crew Workload Assessment Simulation*

**Real Time Interactive Simulation Environment (RISE)**

Various H/C simulation components such as Flight-By-Wire or Electronic Instrument System are directly obtained from the previously described design methodologies. However, it is become a powerful and complementary tool to the original simulation means.

The initial motivations for RISE development came from EC simulation environment characteristics. One fully representative cockpit (see figure 4) is controlled from a dedicated simulation room. The cockpit is installed inside a dome for visual immersion (see figure 1). Depending on the simulation objectives, an audio generation system, a control loading system and various panels and displays can be coupled to the simulation.

The main real time proprietary VME/VxWorks computer framework (called ARTIST) is used to execute and to control the real time simulation, thus ensuring the modeling of the environment and of the helicopter itself and its equipments. The components issued from the design process are a part of that simulation.

Two simulation cockpits are permanently available (one is dedicated to NH90 activities and the other to HMI and to handling qualities R&D).

These costly resources need to be shared and were not sufficient to provide as many slots as required for parallel integration and for new activities such as training media development.

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RISE, originally created within EC simulation department for training media development, turned out to be particularly adapted to meet the needs of user showing different cultures and expressing various constraints. These constraints are presented below, as well as the solutions proposed by RISE in return:

**1)** RISE initial mission consisted in providing means for the validation on various Unix based platforms (Sun, SGI, Linux) of models intended to be integrated into Full Flight simulators. This type of environment implies in particular to be to be able to assess the Real Time behavior of models in the most stringent and varied phases of simulation.

RISE was therefore developed as a generic framework, allowing integration of various types of simulation models, in order to control them into different phases (e.g: Loading the interface, snapshoting a situation, positioning on new init, real time running, accelerate time running), as required in modern trainer environments. For each model, a periodical scheduling is managed in a global approach using the best possibility of the Hardware,

The different phases can optionally by used, and an automatic makefile is generated to take into account de dependencies and to build the corresponding dynamic library,

*Fig. 4 - Fully representative NH90 cockpit*

These phases are controlled via a scheduler in charge of calling the processes involved in the simulation. For each of these processes, the users can freely define the time period, the task identifier, the sequence in the task and the name to be displayed in the monitoring interfaces.

Depending on the type of hardware platform, the scheduling of the run time phase is based either on standard Unix operating system signals, or on a specific library ensuring the accuracy and the real-time response determinism.

**2)** RISE use had to be rapidly extended to the validation of these models with a pilot-in-the-loop, implying a capability to evaluate the results of current developments in connection with a complete simulation environment.

In the same time, EC had to share with a simulator manufacturer the development of a Flight Training Device:

- The simulator manufacturer was building the replica of a specific helicopter and its environment, consisting in a helicopter flight deck including instruments, equipment, panels and controls.
- EC had then to provide to this manufacturer, enclosed in a PC, pre-integrated software components necessary to represent the helicopter.

These two requests happened to be very close one to the other. Indeed, in both cases, the challenge consisted in adapting RISE to provide a multi platform coupling capability.

Once more, this configuration is controlled via RISE generic management, allowing switching from "master mode" to "slave mode", and then being able to wait for external simulation control command and to exchange the simulation interface with any external host computer. This communication is ensured via Ethernet media.

In such a use, RISE can be considered as an independent real time component, giving an interesting solution either to run inside ARTIST environment using one of its available computers or to optimize any FTD development and to deliver software data package through a low cost "black box" component. This approach minimizes the classical integration problems and

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ensures EC software integrity and confidentiality

.

These concerns explain why RISE is now available on four Unix/Linux platforms: SunOS, SGI, standard Linux and dedicated Linux computer (RedHawk Concurrent computer) ensuring, when needed, real time accuracy.

**3)** Due to its flexibility and the performance measured in multiplatform use, RISE has rapidly been required to be able to substitute EC simulator during integration, prototyping, development, tuning and pre-validation phase, while maintaining ARTIST compatibility.

An "ARTIST/RISE gateway" has also been developed to be compatible with EC original simulation environment, so that any source code model initially expected to run on ARTIST platform, remains fully compatible with RISE and vice versa, thus minimizing the portability constraints.

Thanks to this compatibility, any EC simulation running on the large simulation facilities, (dome immersion with CLS, Visual data base, audio generation…), can also be adapted to run on standard low cost computers (e.g. PC or laptop), thus bringing additional flexibility for development and tuning phases.

To keep on considering the simulation in the global design office process, RISE is now able to be substituted to the full means at any development stage. This performance is obtained with a very high compatibility level, authorizing to share a centralized source code database, and giving a permanently synchronized status between ARTIST or RISE targets. This feature is particularly useful to ensure a permanently fully representative and up-to-date simulation in both environments.

The consequence of this gateway is that any component issued from formal specification and Engineering Process of the design becomes automatically available to be integrated into a RISE simulation, allowing a strong reactivity while ensuring high fidelity.

**4)** All the previously described uses start with a development stage of implying that interfaces between models might evolve. These interfaces must remain easily and quickly accessible for modification without generating heavy dependencies.

Fulfilling this constraint is possible thanks to RISE architecture and philosophy, which can be summarized, in the following main rules:

> **a/** The simulation interface (e.g., the functional information data flow between the models contained in the simulation) is considered as a very important component of the simulation, and must be easily described and modified by the user. This interface is transparently (via RISE generic services) managed in a shared memory.
>
> **b/** RISE generic services have been developed to check automatically this shared memory interface and to provide various tools, without any efforts or constraints for the developers. The automatic shared memory management takes care of allocation, attachment, access and destruction,
>
> **c/** RISE makes intensive use, via RISE API, of C++ language properties (polymorphism, addressing mechanism…) to access the interface.

**5)** Whatever the scope, RISE users are aeronautical experts able to easily build their simulation, without worrying about the instrumentation.

For each simulation build in RISE environment, RISE generic management and services have been developed to be used, without any constraint for the user:

- The dumper, which consists in a real time and non intrusive shared memory investigation tool, giving the possibility to retrieve any information contained in the shared memory interface with its symbolic name, and then either to display it,

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to plot it or to modify its value during any simulation phase (see figure 5).

Fig. 5 – Generic RISE Dumper

- The recorder, which can be used to write in a formatted file any information of the simulation. The content of this file can be dynamically described from the complete shared memory interface list using the same principle as the dumper (see figure 6). The user can then easily monitor and record any information of the simulation, during any phases, and without any preparation.

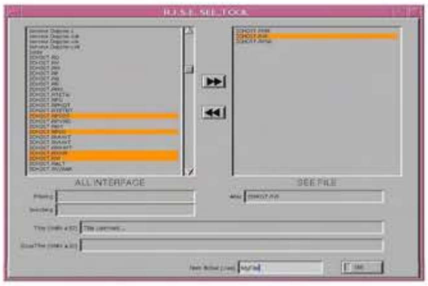

*Fig. 6 – Generic RISE Recorder*

The dashboards capability allows to design and to configure the simulation depending on a specific user context. To manage this function, a dashboard designer feature gives the possibility to create a specific context to monitor the interface (see figure 7). These dashboards can be exchanged between various RISE simulations. This tool can be considered as a middle way between the generic services and a customization.

Since it was developed to be able to take over from full simulation means, RISE is "Helicopter oriented" and provides a generic and "plug and play" piloting interface required for most evaluations:

- A flight control command interfacing most commercial joysticks, or using virtual piloting interface (see figure 8),

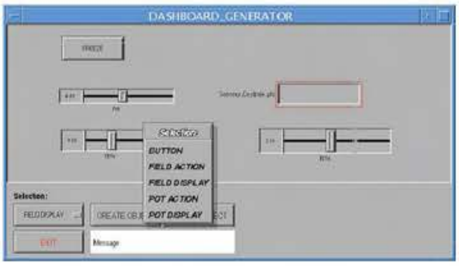


*Fig. 7 – RISE Dashboard generator*

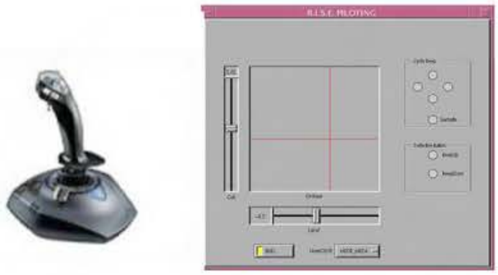

*Fig. 8 – RISE compatible joystick and virtual piloting interface*

- A generic flight display (figure 9)

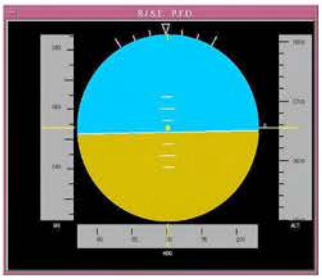

*Fig. 9 – RISE generic PFD*

**6)** In order to answer internal training requirements, consisting in a "simulation on the desk" having to be also representative regarding the aspect of Control Panels to be represented, RISE dynamic library had to be developed to integrate customized application, thus providing both a flexible and extensible Simulation Environment.

RISE shared memory is also accessible from any customized application using RISE API. Therefore, the simulation environment is fully open, giving easily the facilities:

- To design any graphical application, without worrying about RISE shared memory communication and allowing users to introduce their own specific components (hereafter an application with a virtual panel interface based on real image animation),


*Fig. 10 – EC155 virtual Auto Pilot Panel*

- To connect to any RISE simulation interface any existing customized application, allowing the optimization of the development resources. (RISE API maintains the binary compatibility, using hidden addressing mechanism allowing the user to define which information of his shared memory is expected to be plugged to inter act with the application) Due to this specificity any RISE customization can be considered as a new component available to be directly reused for a further development.

**Light Training Devices**

As described above, RISE has been designed and is intensively being used in the engineering simulation environment. It has proven to be a very efficient solution to integrate High Fidelity components issued from formal specification and Engineering Process on various platforms down to conventional PC's with excellent performance.

Allowing building a high fidelity simulation, on standard PC, RISE opens the door to a new concept of Light Training Devices (LTD).

These LTD's use the previously described process to produce an important part of their simulation software and they capitalize on the engineering know how. The physical instruments, equipments, panels and controls are not installed in a cockpit replica, but are represented in a completely virtual and interactive form displayed on the PC screen. This approach leads to the availability of low cost but high fidelity "desktop simulators".

These trainers are thus very useful for initial training on complex avionics. They allow easy in depth familiarization with normal and degraded avionics controls and modings in a real time interactive environment. They are complementary with conventional training simulators and contribute to optimize the whole training process.

In this LTD application, most of RISE functionalities, devices and tools are directly used:

- A complete simulation (including aerodynamic, engine, automatic pilot, navigation system…) is built and tuned using RISE management and tools.
- ARTIST/RISE gateway is used to import high fidelity models from software engineering process.
- RISE customization API is used to build the virtual/interactive panels and control commands.

**Example of an Engineering→Training Synergy with an EC225 Super Puma Application**

An example of LTD application is described hereafter and illustrates this new concept. In this application, the purpose consists in providing the means, for EC instructors, to

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present EC225 avionics and HMI in normal and degraded situations.

To achieve this goal, the RISE simulation includes:

- A representative aerodynamic and engine modeling,
- An atmospheric modeling,
- A radio navigation environment and the corresponding helicopter system,
- A fully representative flight control system heavily involved in the new avionic,
- The virtual panels, indicators and the equipments required to control the helicopter modes and configuration.
- An instructor interface to configure the environment and the helicopter status,
- EC225 Multi Function Display issued from CAD workshops, and making it completely representative of the real aircraft.
- A virtual terrain representation providing a background flight deck view coherent with the helicopter situation and adding realistic feeling.

All these components are computed in a standard PC under LINUX OS, and the flight loop delay (from a control command via the piloting interface until the effect in the MFD) is easily kept below 80 milliseconds, which is compatible with FTD qualification requirements.

An image of the result is presented hereafter (see figure 11).

*Fig. 11 - Snapshot of the EC225 LTD PC screen.*

**NH90 Training Means**

The first serial NH90 helicopters will soon be delivered, and the corresponding crews need thus to be trained to this brand new helicopter.

*Fig. 12 - Pictorial view of a NH90 PTT*

There is a technical dependency between avionics development achievement and inputs needed for conventional training simulators development. This dependency leads to a classical time lag between the delivery of the first H/C and the availability of the first Full Flight or Full Mission training Simulators (FFS/FMS).

However, in the case of the NH90, as explained in the above introduction, the avionics development has made an unprecedented use of formal specification workshops with automated code generation and the level and realism of the engineering simulation in this multinational program has been particularly high [5].

This situation is therefore be very beneficial to the training of the first crews. Indeed, the use of the engineering simulator for training purposes (within its limitations compared to an FFS/FMS) is an efficient interim solution already implemented to fill this gap.

Moreover, the availability of the RISE versatile simulation environment allows proposing also various types of light training devices based to a large extent on this existing engineering

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simulation. These devices can be developed rapidly and will constitute a valuable complement to conventional simulation.

They can consist of Part Task Trainers (PTT) featuring an almost complete helicopter desktop simulation (see figure 12) or specific LTD's focusing on particular HMI aspects for aircrew familiarization, such as Multi-Function Displays (MFD) or Automatic Flight Control System (AFCS) controls and modings (see figure 13).

*Fig. 13 - Pictorial views of NH90 (MFD) LTD and NH90 (AFCS) LTD*

## Conclusion

The impressive evolution of electronic resources has allowed the integration on modern Helicopters of various new avionics capabilities allowing facing increasing mission complexity. As a consequence, the training needs also increase and can no longer be envisaged without the support of interactive simulation tools.

Fortunately, this electronic resources evolution has also allowed a significant improvement of simulation performance. Moreover, when formal specification language and automatic code generation are used in the avionics development process, the fidelity of the simulation can be ensured more easily.

In parallel with the Helicopter FFS/FMS development increase, recent technology advances also allow to propose low cost desktop simulators.

Due to the intensive use of CAD specification Workshops in its development, the NH90 program is an ideal candidate for this approach. Thanks to the already existing engineering simulation, a short term implementation of such solutions capitalizing the design office know-how will help filling the gap before FFS/FMS availability.

In the long term, these Light Training Devices will still remain particularly efficient for avionics HMI familiarization and they will provide complementary means to conventional simulators, contributing to the optimization of the whole training process.

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