A Concept of Flight Execution Monitor (FEM) for Helicopter Pilot Assistance

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ABSTRACT

PAVE ("Pilot Assistant in the Vicinity of hElipads") is a global research project conducted under the ONERA-DLR common research programme.

Several new technologies are now available for helicopter on-board applications which have potentialities to support the pilot's perception and decision making. The technologies addressed in the frame of this project include an advanced flight control system, calculation of flight envelope limitations, enhanced and synthetic vision, mission in-flight planning and guidance. In order to obtain actual performance and safety benefits, integration of these technologies is one of the key issues addressed in the project.

ONERA is especially involved in the development of a particular module of the pilot assistant, called the Flight Execution Monitor (FEM).

The module is dedicated to the monitoring of the current helicopter situation and of the pilot's procedural activity. It is based on a high level Petri net description of the procedures, derived from the specifications of the flight manual and from interviews with the users.

This Petri net description is used to monitor the execution of the procedure, to graphically display the progress of the helicopter situation and also to provide the information required given the current situation, including some flight limitations which are calculated on line and displayed to support the pilot's decision. A first prototype of the module has been developed and implemented in a man-in-the-loop simulation environment.

The rationale behind the concept, the architecture of the current prototype and the possible future directions are presented. This development results from applied research on control execution software; it is also a pragmatic attempt to investigate the possible alternatives in the task allocation between the human operator and an automated system such as the modern helicopter.

ABBREVIATIONS

DLR	*Deutsches Zentrum für Luft-und Raumfahrt*
Europa	European Rotorcraft Performance Analysis code
FEM	Flight Execution Monitor
OEI	One Engine Inoperative
ONERA	*Office National d'Etudes et de Recherches Aérospatiales*

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PAVE	Pilot Assistant in the Vicinity of hElipads
PND	Petri Net Description
ProCoSA	*Programmation et Conduite de Systèmes Autonomes*

1.0 INTRODUCTION

1.1 Context of the Project

PAVE ("Pilot Assistant in the Vicinity of hElipads") is a global research project conducted under the ONERA-DLR common research programme. The project was historically initiated by DLR on the basis of previous research work for civil transport applications (Rataj, Bender & Kohrs, 2000 and 2001). ONERA joined the project in year 2000, including contribution in the flight mechanics and human factors research domains, based on the experience gained for autonomous systems applications (Barrouil & Lemaire, 1999).

Several new technologies are now available for helicopter on-board applications which have potentialities to support the pilot's perception and decision making. The technologies addressed in the frame of this project include an advanced flight control system, calculation of flight envelope limitations, enhanced and synthetic vision displays, in-flight planning and guidance, definition of low noise procedures and mission execution monitoring (Figure 1).

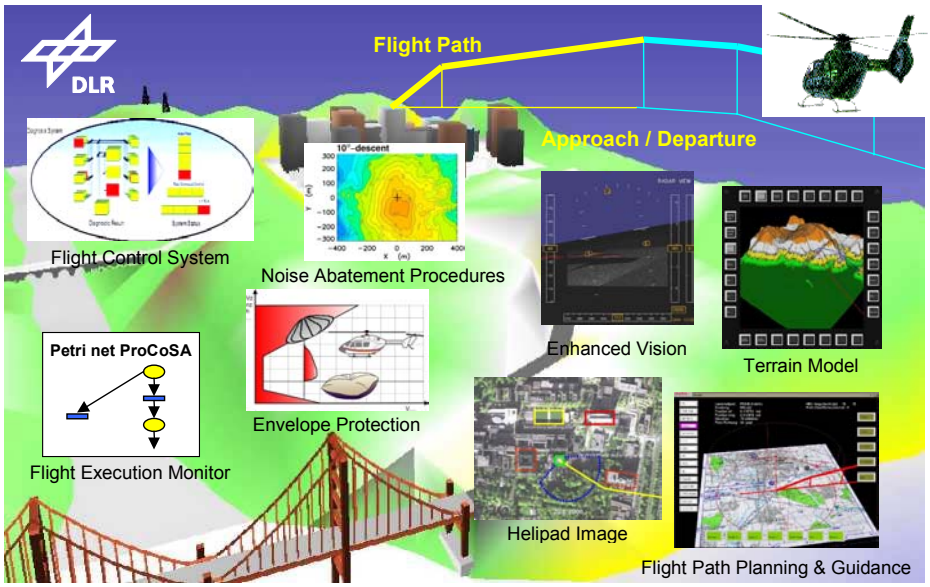

Figure 1: The Support Functions of the Assistance System (from DLR).

In order to obtain some actual performance and safety improvements, the proper integration of all these technologies to constitute the assistance system is one of the key issues addressed in the project. The system will benefit from previous assistant systems projects (see Winter & al., 1997 for a review) and it will make use of a generic architecture which has already been applied and evaluated for various applications (Walsdorf & Onken, 1998).

The approach is based on the now well established principles of human centred automation and pilot assistance. In particular, the goal-oriented interactions of the human operator are decomposed into the following generic functions of what is called a recognise-act cycle (AGARD, 1995):

- Monitoring: recognise the actual state of the world and compare it with the desired state (which corresponds to the goal of the interaction).
- Diagnosis: analyse the deviations of actual and desired state.
- Plan generation and selection: think and decide about the actions to modify the state of the world to reach the desired state.
- Plan execution: take the necessary actions to change the state of the world.

1.2 Operational Needs

A review of the helicopter safety statistics was conducted in order to identify the possible elements and directions for safety improvements which should guide the design of a generic assistant system. This review revealed a quite different profile than that of fixed wing aircraft.

The primary division in helicopter accidents statistics is between private pilots and professional pilots (Iseler & Maio, 2001). This fact is significant of the well known positive correlation between the regulation of an activity, the level of the operators' proficiency and its level of safety. The present research project is intended for generic applications, although it makes use of high technology equipment and requires the availability of shared data, which certainly won't be immediately affordable to a private pilot.

Among the professional uses of the helicopters, and due to the low altitude and versatile characteristics of their missions, it appears that the distribution of the safety events is quite uniform among the flight phases, although some phases may appear more critical when more specific missions are considered (e.g. cruise in EMS missions, maneuvers in aerial application missions, …). This fact suggests that the assistance may be worth providing during the whole flight, and not only during the approach phase.

Human error or, more precisely, judgement error is often cited as a primary cause or a contributing factor of the accidents. This error denomination remains very broad, as it includes estimation errors related to visual perception as well as representation errors or over confidence in the basic piloting skills under bad weather conditions. Nevertheless, it suggests that safety may be improved by an active support of the pilot's evaluation of the flight conditions and safety margins.

2.0 THE CONCEPT OF FLIGHT EXECUTION MONITORING

2.1 Keywords: Automation and Assistance

The new generation helicopters may be considered as automated and intelligent systems, as they are equipped with multi-modes 4-axes autopilots, elaborated navigation aids, flight management systems and electronic check list. Automation surprises similar to those of fixed wing "glass cockpit" aircraft have been reported (Harris, 1997).

The principles and general models which are used as guidelines behind the concept of the Flight Execution Monitor are summarised below.

Although automation has proved efficient to improve mission performance and safety to the current level, several possible drawbacks have been demonstrated: poor situational awareness, excessive focus of attention when reprogramming, mode confusion, difficulty of manual recovering, and impoverishment of the operator's knowledge and expertise, due to the lack of practice of manual procedures (Amalberti, 1998).

The principles of human centred automation have been established in order to help avoid these drawbacks. In particular, these principles include the respect of human authority and of human ecology, which should preclude to the design of an assistant system.

The ecological safety model of pilot's cognition describes the dynamic regulation of the operator's activity, tuning a compromise between reaching the assigned goals with the required objective performance and using the minimum resources. Three main solutions are identified, which are used by the human pilot to bypass his/her limitations and to keep the situation under control: mental representation, planning and anticipation, skills and behavioral automation. For instance, it has been shown that the experienced pilots tend to invest in long term anticipation as long as the situation is normal, although this is sometimes done to the detriment of short term monitoring.

In the design of an assistance system, three different paradigms for human machine coupling have been described (Amalberti & Deblon, 1992): the system working as a consultant on user request, as a partner of a cognitive team, or as a permanent critic of the operator's decision. The last is thought to be the most promising for rapid process control. In order to favour the operator's acceptance and trust, the system should provide assistance during normal conditions, not only during incidents, and it should be based on deep knowledge, such as the physical laws governing the evolution of the process. Also, as such a system is necessarily imperfect, solutions should be proposed rather than executed.

2.2 Application to the Concept of a Flight Execution Monitor

The primary task of the human operator, according to the recognise-act cycle, and an essential task for the flight crew of the recent automated helicopter is to monitor the ongoing flight progress. For instance, inadvertent exceedances of the flight limitations or deviations from the planned trajectory should be detected and recognised immediately.

Given the existing equipment, several developments have been made to provide the pilot with the appropriate navigation aids and warnings (for instance Gollnick, 2001), and so to effectively participate to the short term monitoring . However, these developments are generally based on calculation algorithms of the trajectory, rather than on an actual description of the flight activity.

The principles of human cognition summarised above also suggest that the assistant system should primarily focus on the short term monitoring of the system and, indirectly, of the pilot's actions, and that the system should try to implement and favour the human skill-based behaviour, rather than the more costly rule- or knowledge-based behaviours.

A concept to satisfy these requirements is to provide the pilot with an overview of the current status of the helicopter within the assigned current procedure, using a representation familiar to the pilot and including the safety limitations. As such, the concept should participate to the pilot's situation assessment and awareness, rather than replacing him/her.

Within this concept, a module called the Flight Execution Monitor (FEM) has been integrated in the PAVE project (Figure 2). This module is built around a goal-based description of the flight activity, using the formalism of Petri nets, because of their ability to mimic the skill-based behaviour of a human operator. The module is intended to work as an independent process, calling the available helicopter information sources as required for monitoring, and making use of complementary servers for the necessary calculation and display of the results.

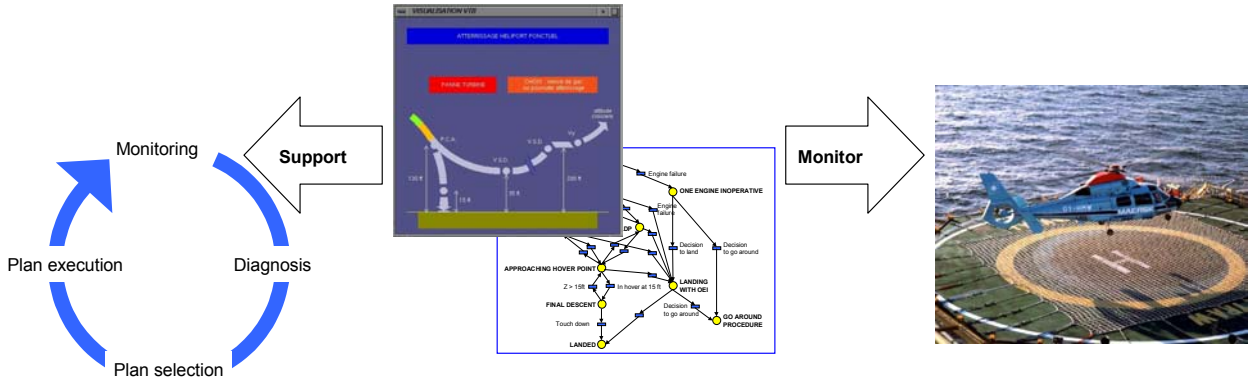

Figure 2: The FEM as a Support of the Pilot's Short Term Monitoring.

3.0 DESCRIPTION OF THE FEM MODULE

3.1 Petri Net Description of the Activity

The formalism of Petri nets was chosen to model the pilot's activity because of their ability to mimic the skill-based behaviour of a human operator. They are especially adapted to represent the dynamic behaviour of discrete systems – such as a piloting procedure- and to express the parallelism and the synchronisation of the shared resources. Their simple graphical representation makes them easy to understand by domain experts, providing that the wording and the mission decomposition are based on their own description of the activity. Last but not least, the Petri net theory provides the possibility for formal validation of the Petri nets, which appears to be a desirable feature of any software candidate to certification.

Petri nets have already been used to model the production rules typical of a pilot's behaviour in other applications (e.g. Onken, 1995).

The Petri nets description (PND) of the pilot's activity during a generic mission have been generated on the basis on the information provided by the flight manual of the two engines Dauphin helicopter. The generic mission is classically decomposed under phases and sub phases, from the preliminary ground verification to the engine shut down. Some of the main take-off and landing procedures have been described, including the procedures on confined areas and with one engine inoperative (OEI). This mission decomposition was further refined by means of interviews of a flight test pilot, and was formalised into a hierarchical structure of Petri nets as shown on Figure 3.

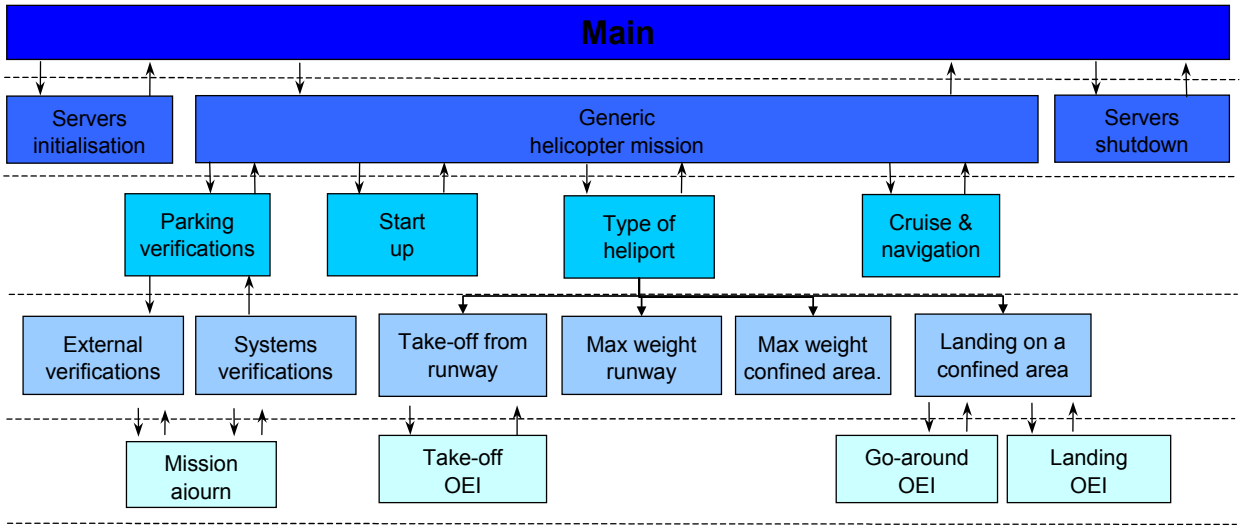

Figure 3: The Structure of Petri Nets Describing a Generic Mission.

Once the decomposition of the mission as a structure of Petri nets has been achieved, each mission phase is translated as a Petri net, down to the elementary parameter values used for monitoring. The Petri net description of the landing procedure is given as an example on Figure 4. The places named in italics correspond to a sub Petri net.

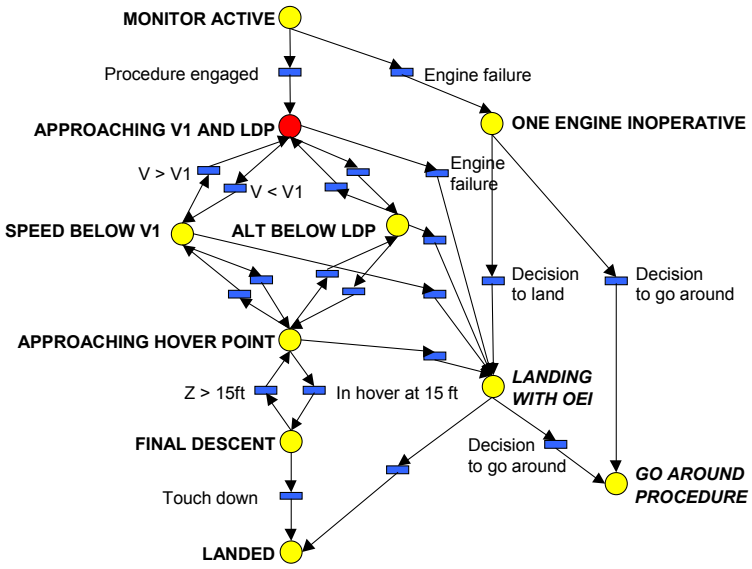

Figure 4: The Petri Net Description of a Landing Procedure.

Behind this Petri net graph, the events required for firing and the actions attached to each transition have to be specified. The actions may be directed either to a server or to a sub net and they may include some arguments.

3.2 Tools and Architecture

The first prototype of the FEM module has been developed, making use of a software called ProCoSA which is developed at ONERA. This software has already been applied to the execution control of

autonomous vehicles; it allows an easy design of the Petri nets and their implementation for real time on board applications.

ProCoSA is in fact composed of the three following tools:

- EdiPet is an interactive Petri net editor (Figure 5), which is used off-line in order to graphically design the places, transitions and arrows which constitute the Petri nets, together with their corresponding actions, events and related servers;

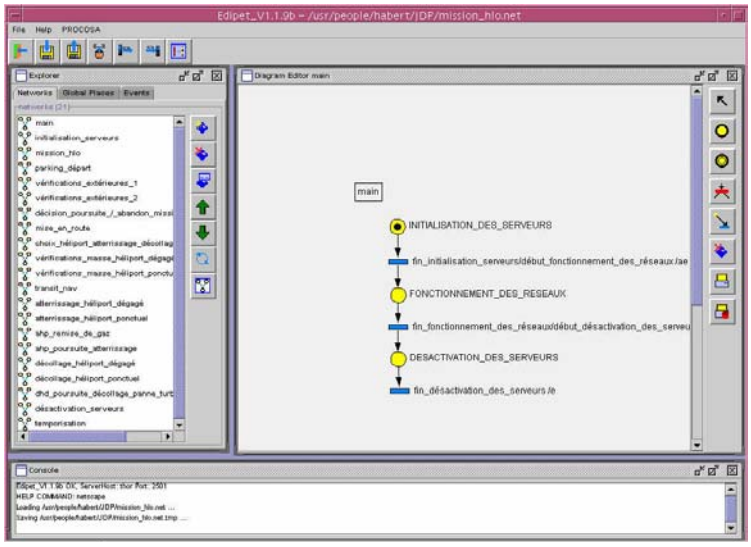

Figure 5: The Interactive Petri Net Editor 'EdiPet'.

- The Petri net player is an independent software which actually interprets and controls the behaviour of the Petri nets in their real time environment; it also enables interactive transition firing for the purpose of the Petri net debugging.
- VisuPet is the interface software behind EdiPet which allows the visualisation of the Petri nets behaviour (places marking) when they are activated.

The global architecture of the FEM module within the simulation environment is described on Figure 6.

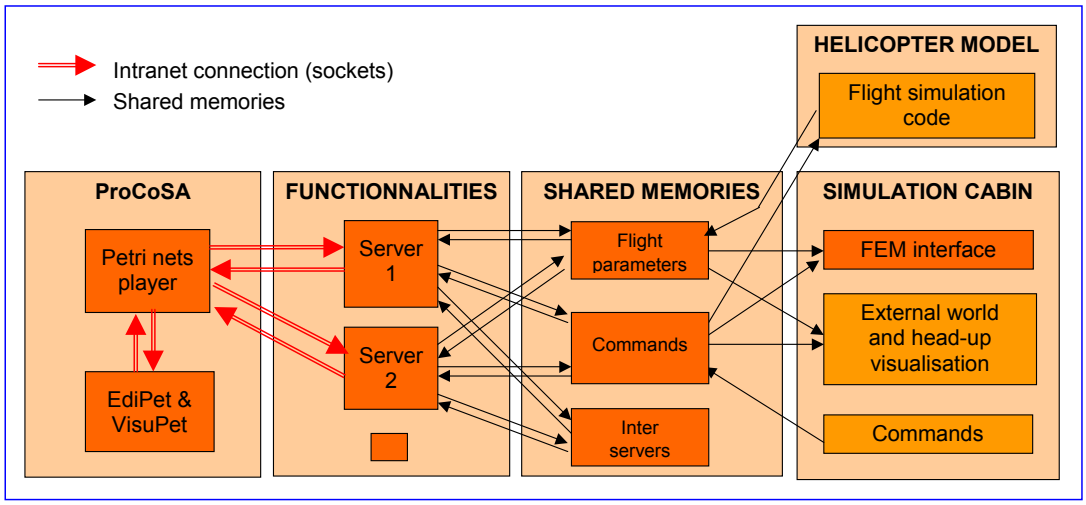

Figure 6: The Global FEM Module and Simulation Architecture.

The core of the FEM module is composed of the hierarchical structure of Petri nets implemented under ProCoSA, which is working as an independent process. ProCoSA communicates with different servers by the way of an intranet. Each server is also an independent process, written in the C language, which has access to common information via shared memories.

One server is dedicated to the collection of system information as required for monitoring, one is used to control the FEM interface as commanded by ProCoSA, and other servers are used for on-line calculations which cannot be easily implemented as Petri nets, such as the calculation of the maximum landing weight as a function of the actual landing conditions.

3.3 The User Interface

When the FEM module is running, the Petri net graph allows a direct understanding of the current helicopter situation, by following the marked places (coloured in red on Figure 4). This presentation of the current situation is useful for the Petri net designer in order to check the correct functioning of the system. However, the Petri net marking is discrete by nature, which makes it of small benefit for the use of the pilot: the evolution of the procedure may be either too fast for the markings to be displayed, or on the opposite, it may be too slow and the display may remain static and non informative.

This is the reason why a specific graphical interface has been developed. This interface is controlled by the way of actions sent by the Petri net and have also access to the shared flight data. It may receive the pilot's input for choices and confirmations. Different pages related to the different possible mission phases are available, including checklist pages and procedures descriptions similar to those of the flight manual: the page related to the landing procedure is presented on Figure 7.

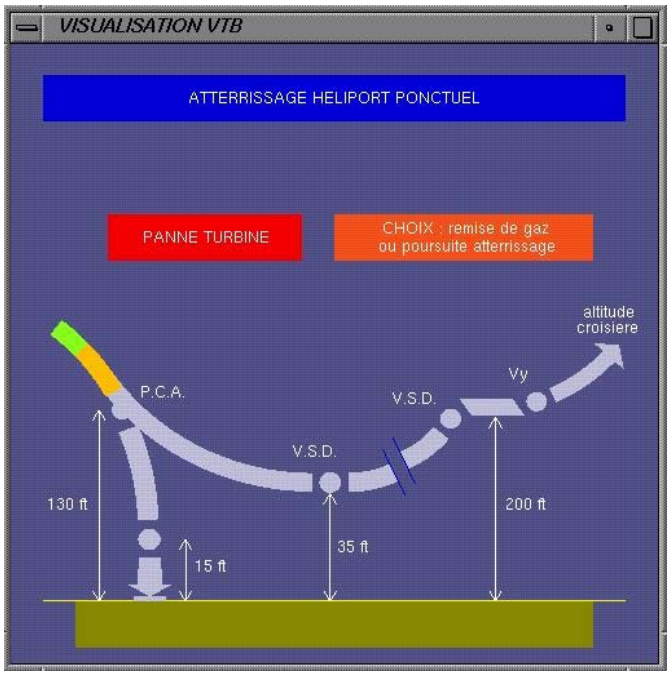

Figure 7: An Example Page of the Interface Controlled by the Petri Net Player.

This type of adaptive interface is a first prototype, trying to take advantage of the specific features of the Petri net graphs: it requires extra test and validation before being considered for introduction in the cockpit. In particular, the appropriate necessary inputs from the pilot and the warning or caution signals have to be determined, taking into account the existing cockpit design.

4.0 CONCLUSION

A preliminary development of a Flight Execution Monitor has been conducted as part of an assistance system for the helicopter pilot. This development based on the formalism of Petri nets using a tool already validated for real-time on-board applications appears to be a promising concept, as it provides an evolutive description of the mission similar to the pilots' usual representation of their mission.

Further work is necessary to validate the Petri net descriptions using both formal analysis methods and piloted simulation and to integrate the FEM module with the other components and available information sources in the frame of the PAVE project, based on a design philosophy respecting the principles of human cognition.

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