PILOT ASSISTANCE FOR ROTORCRAFT

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Abstract

Based on Eurocopter's experience on all-weather capability for helicopter gathered in the research projects AWRH (all-weather rescue helicopter) and HTT (helicoptère tout temps) Eurocopter decided to make more detailed investigations on assistance systems for pilots. The project was called PILAS (Pilot Assistance System). It was funded by the German Ministry of Economics and Technology, started in 2003 and ended 2008. Main target of this research project was the development of a pilot assistance system, which helps pilots in critical situations and supports them in the handling of the helicopter and the fulfillment of the mission. The assistance system was successfully tested in a cockpit simulator and tested inflight on the research helicopter EC145.

1. ACCIDENT STATISTICS – THE MOTIVATION

The special advantage of helicopters is to be able to fly in low altitudes and land in unprepared areas. Helicopter operators use these properties daily. Flying close to the earth and in airspaces which are not covered by radar surveillance and doing that in bad-weather conditions is bearing a high safety risk. That has already led to several fatal accidents, as the statistics are showing us. Especially for Helicopter Emergency Medical Services (HEMS) flights, the NTSB (National Transportation Safety Board) has stated recently in an official release note (see references), "that a concerted effort must be made to improve the safety of emergency medical services flights". And Robert Sumwalt, chairman of a NTSB hearing on HEMS operation in the US added: "We have seen an alarming rise in the numbers of EMS accidents and the Safety Board believes some of these accidents could have been prevented if our recommendations were implemented."

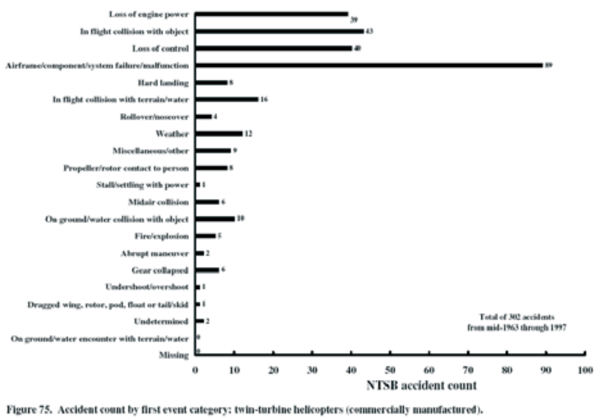

Figure 1: NASA accident statistics

At the same time the helicopter operators want to extend their operation time in order to perform also flights in bad-weather conditions and during night. Both factors, the need for an increase of flight safety and the extension of operation time require assistance for the pilot from system side.

2. OBJECTIVES OF PILAS RESEARCH PROJECT

In 2003 Eurocopter Deutschland GmbH started a research project under the name "PILAS" – PILot Assistance System.

Figure 2: PILAS flying research test bed – an EC145

The project was funded by the German Ministry of Economics and Technology and was finished end of 2008. Several partners from the German aerospace industry, research institutes and universities contributed with their special knowledge. The goal of this research project was the development and the test of a pilot assistant system, especially to provide:

- A better situation awareness of the pilot and a higher flight safety,
- a simpler handling of the aircraft,
- a higher economy of rotorcrafts,
- an extended scope of application in context with future air-traffic control (ATC)

procedures.

The research project was subdivided into several work-packages: the development of the core assistance system, the development of an adaptive and central database, the improvement of the human machine interface, the development of a 4-axes autopilot with guidance functionality, research on pilot state interpretation and the integration of all subsystems into a helicopter including flight testing.

3. AN AVIONIC SYSTEM BASED ON COGNITIVE ASSISTANCE

Increased pilot workloads, loss of situation awareness or pilot out of the loop are the main indications of the inherent borders of conventional automation today.

Inside PILAS, investigations were performed on the approach of a cognitive assistance system with cooperative automation.

The main objectives of a pilot assistance system including the cognitive approach and cooperative automation are:

- support and increase of the awareness of the pilot for the current situation and the projection of the situation into the future,
- direct the attention of the pilot on the most urgent task,
- develop transparent and comprehensible action proposals

Cognitive system architecture was selected in PILAS in order to handle the difficulties with conventional automation today. This concerns a goal and knowledge-based system, which is comparable in its processing levels to the human behaviour process.

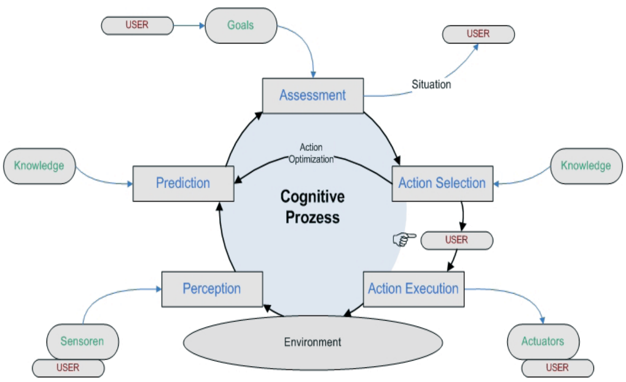

Figure 3: The Cognitive Process

Figure 3 indicates the substantial processes of cognitive architecture applied here. The different steps of the cognitive process are described hereafter in detail.

The first processing level deals with the **perception** of the environment (and of course of the own system state). By means of sensors the own system states and the state of the relevant environment are noticed like „the state of world“. This image of the world results in a mental depiction inside the system. It is the basis, on which a later assessment and a meaningful decision making is possible.

The cognitive process shall take care to avoid critical situations. Already the approach of critical situations shall be detected and avoided. The **prediction** is concerned with the question “how the own system and the outer world will develop in the very near future”.

The following step is an **assessment** of the situation based on the current and the predicted states of the own system and the environment. The assessment is based on both, the a-priori goals as well on the current, situation-conditioned targets.

Then a search after suitable action alternatives will be started inside the **action selection** process taking into account the set of all available actions.

In the last processing level, the **action execution**, the action or action sequence is carried out. The execution can be performed by means of actuators. In PILAS the available equipments will be used as actuators as well as the pilot itself.

Independently, whether the required action is performed by the pilot or by equipment, the **decision sovereignty is always with the pilot**. For each upcoming action the pilot is the decisive instance, no matter, which the performing actuator is.

4. A BRIEF TECHNICAL VIEW ON PILAS

The technical implementation of PILAS is based on a knowledge-based assistance system in line with the approach of the cognitive process. Functional and system architecture and the system design are mainly driven by this approach.

PILAS is integrated into a helicopter system which contains sensors, displays, communication and navigation means and actuators. The Figure 4 shows the external interfaces of PILAS.

Figure 4: PILAS external interfaces

The following part provides a view on the PILAS processing units. The processing units contain the PILAS software modules and additional functionality for interprocess-communication.

In accordance with the cognitive system architecture the functional architecture (see Figure 5) of PILAS is divided into the following parts:

- dynamic situation knowledge
- database system
- perception (information gathering and feature extraction)
- prediction (situation interpretation)
- assessment and action selection
- action planning
- action execution

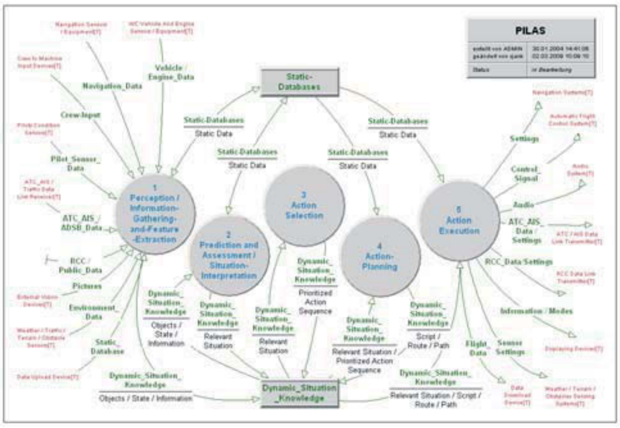

Figure 5: PILAS functional architecture / level 1

The **dynamic situation knowledge**, technically based on a middleware, contains the current status of the variables defined for the description of the pilot's state, the helicopter and its environment. The variables are stored according to the values gathered from the different sensors, data links and processing units. Each module inside the PILAS processing units may access the variables inside the dynamic situation knowledge.

PILAS generates a synthetic representation of the external world inside the dynamic situation knowledge by using additional information from the central **database system** (DBS).

The central database system contains static, non-volatile information about the helicopter state and the environment. The following data categories are contained in the database system:

- terrain data
- obstacle data
- topographic data
- aerodrome data
- airspace data
- navigation data
- weather data
- helicopter performance data

All data received from the aircraft systems, pilot controls & sensors and external databases will be stored and pre-processed. Therefore **perception** (information gathering and feature extraction) modules use these information in order to generate objects and information which can be interpreted by the situation interpretation modules.

The objective of the situation interpretation modules is to use information inside the dynamic situation knowledge as well information from the static databases to detect impacts on the current mission.

An extrapolation of the current situation into the future (**prediction**) is performed in order to detect these impacts early enough, offering sufficient time for adequate reaction.

Based on this pre-processed information the **assessment** generates relevant situation elements. These relevant situation elements are assessed concerning their impact on the mission and flight safety.

The processes for **action selection** apply rules to the relevant objects in the dynamic situation knowledge. If a rule matches, the operation required by the rule is executed. This may be the activation of a goal or the execution of a task. There may be more than one matching rule available at the same time. Therefore conflict resolution is used to determine the rule to be used. The conflict resolution is based on prioritization in a first step. PILAS has to take into account the timeliness of impacts If no conflict appears, no explicit goal needs to be determined. This does not mean that during these conflict-free phases no goals are active. Implicit goals are always followed. Implicit goals are for example to survive or to perform a safe flight.

If a conflict appears and the time to impact decreases, there may be a need to modify the selected actions for a determined goal. Therefore a check of the relevant actions is done. If an action is executed and the expected result is not obtained after a defined time, the situation is re-evaluated and another action (e.g. information of the pilot) is selected.

An expert system was used for the development of the **action selection** modules Expert systems provide mechanisms more adapted to rule interpretation than programming languages. Rules are easily modifiable and new rules can be more easily added (and old ones deleted).

Action planning and execution modules transform the selected actions into plans, procedures and commands for the helicopter system or proposals for the pilot. These modules take the current situation into account to provide adequate solutions for the detected conflicts. Huge amount of data from the database system and up to date information from the dynamic situation knowledge are needed.

Driven by the functional architecture and the system design, a common architecture for simulator and demonstrator was developed for PILAS. Simulator and demonstrator offer unique and modular system architecture with a maximum of flexibility for the localization of the modules, for the distribution of system resources and for the extension of system functionalities.

The simulator and demonstrator architecture contain the advantages of a modern, distributed system and the appropriate communication mechanisms.

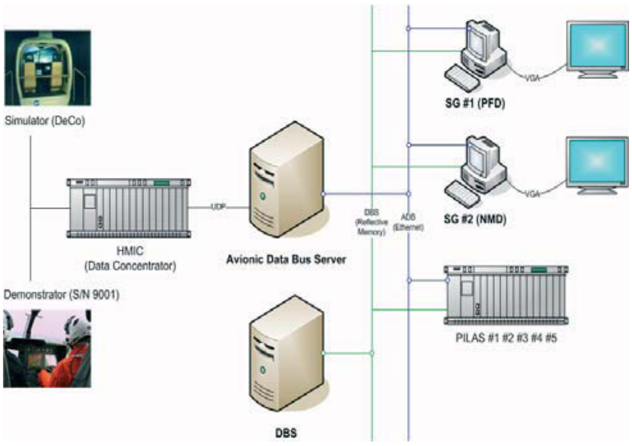

Figure 6: PILAS simulator and demonstrator architecture

Simulator and demonstrator are based on a common concept of similar system architecture (see Figure 6) after a central interface computer.

5. THE PILAS HUMAN MACHINE INTERFACE

In contrary to older cockpit instrument panels where each instrument provides just one type of information PILAS tried to combine and fuse necessary information as much as possible. It was decided to concentrate the information in two color displays of the same size. The displays are orientated in landscape format as human beings better understand this format especially when presenting synthetic vision images (see Figure 7). Due to the display-size of 8' x 6' it was necessary, to enlarge the standard instrument panel of EC145 at the right hand side. This is a compromise between an undisturbed view on the landing site and large display size providing clear information. The safety instrumentation was re-allocated above these two displays.

Figure 7: Special instrument panel of EC145 test bed.

The main target of the PILAS Human Machine Interface (HMI) was to provide comprehensive and unambiguous situation awareness (SA).

5.1. Two displays: Primary Flight and Navigation Management Display

The distribution of information between the left and the right display was defined clearly: primary flight information has to be presented in the right display, which is located in front of the pilot, while navigation and mission related information will be shown in the left display. Therefore the right display is named PFD (Primary Flight Display) and the left display is called NMD (Navigation Management Display).

Around each of the two PILAS displays there is a bezel with line selectable (LSK) and mode respectively fixed function keys (FFK). The FFKs are providing functions like decision height, barometric altitude, course and navigation source where the pilot can adjust these values after pressing the respective button and turning one of the rotary knops.

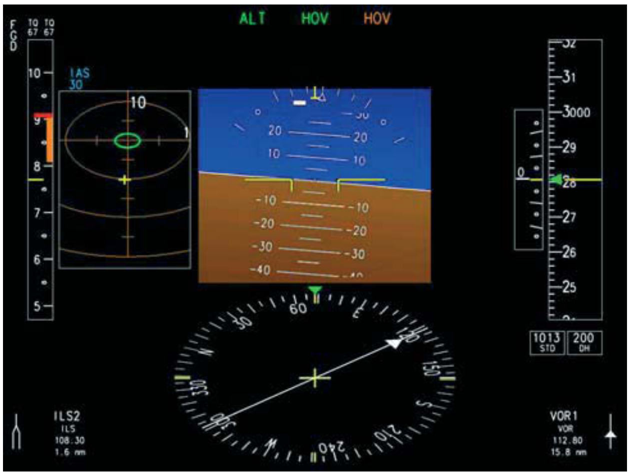

Figure 8: Conventional flight navigation display.

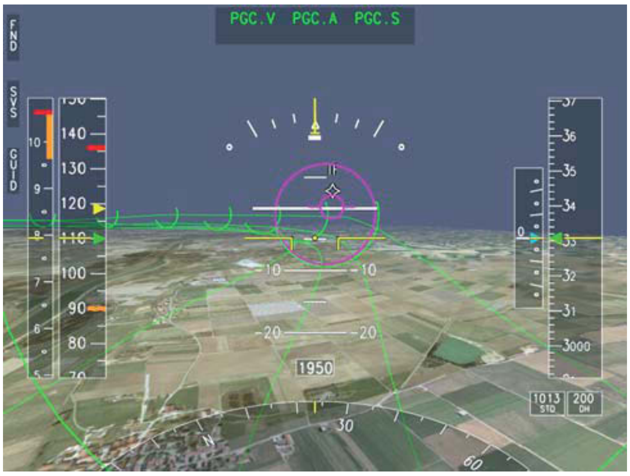

Figure 9: Helicopter specific tunnel symbology.

On the PFD the pilot can choose between a conventional flight navigation display (FND; see Figure 8) and synthetic vision system (SVS) display. The SVS is a special flight guidance display. It comprises flight guidance symbology overlaid onto a synthetic vision image. The synthetic vision is produced by a PILAS symbol generator using digital elevation data of a quality like DTED Level 2 with aerial photos superimposed. These digital elevation data of the test area around Donauwörth (Germany) had been taken from a dedicated PILAS flight campaign with a fixed wing aircraft and were pre-processed for PILAS. The overlaid flight symbology provides all essential information using transparent areas for contrast enhancement. The whole centre area is reserved for own aircraft symbol, horizon, pitch ladder and roll indicator. There are two reasons to keep the centre area free of clutters: 1) the pilot shall have an unobstructed view into the landscape in front of the helicopter and 2) the area might be used for a special flight guidance symbology – the tunnel symbology (see Figure 9).

5.2. Flight Guidance with Tunnel Symbology

The tunnel symbology is calculated by the route planer inside the PILAS assistance system. The tunnel is the safe gateway to the destination. The assistance system has taken into account all possible hazards on the way to destination and has planned accordingly. The diameter of the tunnel is 100 meter. The tunnel symbology is of round shape, which – after experience with different rectangular symbology – gave the pilots the best feeling about their position inside the tunnel (patent pending).

The small triangles at the end of each half circle would turn red, if the pilot is flying the tunnel in the wrong direction. In front of the actual position inside the tunnel there is a magenta circle moving through the tunnel as 3 second-prediction. As the tunnel is calculated in four dimensions (4D), the speed at each position is predefined and symbolized as yellow bug in the speed bar. If the pilot flies too slowly, chevrons at the bottom of the tunnel are moving in flight direction remembering the pilot to speed up. If the pilot flies too slowly, the chevrons are moving towards the own position. The selectable magenta flight predictor (see Figure 9 inside the magenta circle) shows the pre-calculated position of the helicopter with respect to the magenta circle. When flying manually it is an excellent mean to intercept the tunnel and keep the helicopter inside the tunnel. With the help of the 4-axes autopilot and the guidance module (see AHS 2009 paper: “4D Automatic Flight Path Control in Pilot Assistance System”) it is also possible to let the helicopter automatically follow the 4D tunnel trajectory. If the autopilot is coupled on the 4D trajectory the tunnel symbology turns green while it is cyan without coupling. The autopilot mode is also depicted in the autopilot symbol area at the upper center of the PFD.

During starting and landing with speeds below 25 KIAS the SVS provides as special feature an adaptive speed indication. In the case of low speeds the speed bar turns to a rectangular area which indicate the speed and the direction in a polar diagram.

5.3. NMD for Situation Overview

While the SVS provides a perspective view on the landscape in front of the helicopter the NMD gives an overview on the situation using a moving map system as basis. The data for the moving map system and the SVS originate from the same PILAS data base system in order to guarantee absolute consistency between NMD and SVS. The NMD map is continuously zoomable. It displays the route, waypoints, NAV points and more.

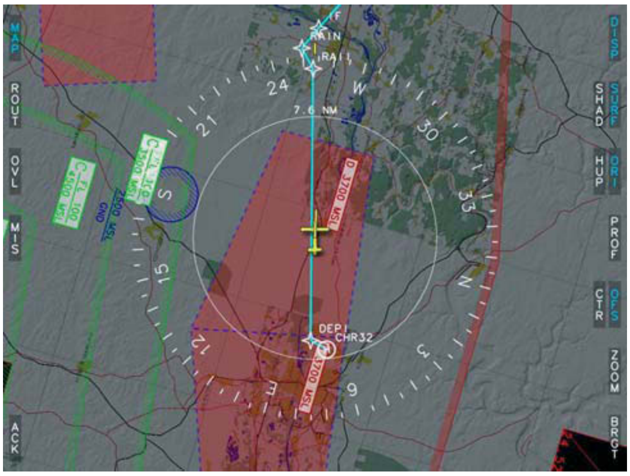

Figure 10: NMD with activated planned route (cyan) and airspaces overlay.

The means to plan and monitor routes and missions inside PILAS is the NMD. There is no control and display unit (CDU) foreseen in the PILAS concept. There might only be a keyboard for typing in frequencies and other numbers or names. The usual cursor control unit (rocker switch) of a CDU is replaced by a joystick in the interseat console. With the joystick the pilot can set or modify waypoints. He can select pull down menus and click for activation of his selection (comparable to right mouse click at a personal computer). The pull down menus contain for example departure routes and approach procedures. So the pilot is able to plan routes. Modification of planned routes can be done by clicking on waypoints or legs and moving it around. Nevertheless one of the main highlights of PILAS is the automatic route planning, which is described in the chapter "Planning a mission with PILAS: Example" (see below).

5.4. Advanced PILAS HMI features: Terrain, Weather, Airspaces, Obstacles

The PILAS NMD is not a pure moving map and route planning tool. It provides far more information for the pilot. On basis of the PILAS data base the NMD displays alerting and warning features. And at the same time coherent alerting and warning symbology is displayed in the SVS.

5.4.1. Terrain Warning Function

Terrain warnings in the NMD are displayed in the well known color scheme starting from yellowish and reaching red, where the terrain is higher than the own aircraft (see Figure 11). A safety margin is considered. This terrain warning functionality like in a TAWS is available even without any planned route. If a route is planned, the crew can additionally chose a profile window on top of the map (see Figure 11). It shows the route altitude profile with respect to the terrain altitude. The terrain is colored accordingly. When planning or re-planning a route, that profile can be used, to adjust the altitude of waypoints. Also the PFD provides this terrain warning functionality using the same color scheme for coloring 3D elevations in the perspective view.

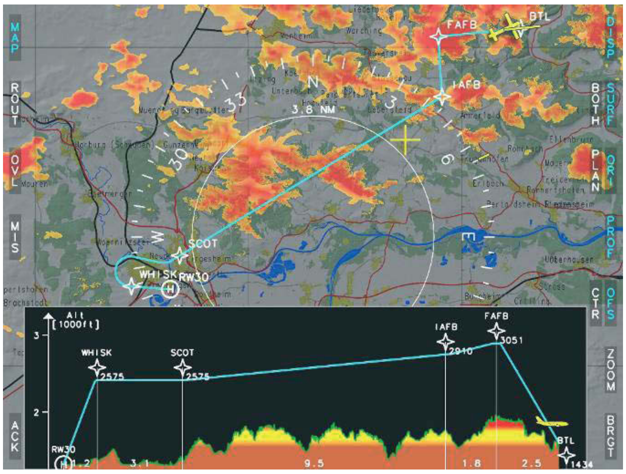

Figure 11: NMD with terrain coloring and profile view

5.4.2. Airspace Information

The pilot can chose to display airspace information on the NMD as an overlay. As most of the airspaces are limited not only in lateral extensions PILAS displays the airspaces in 3D as "flying boxes" in the SVS. These "flying boxes" with transparent walls are colored according to the type of airspace. The perspective and 3D view let the pilot easily find his way around each prohibited airspace.

5.4.3. Weather Information

An important feature of PILAS is the presentation of weather information. The current weather information is frequently updated via data link from a central data server at the met office on ground. A satellite communication data link was tested on the EC145 research for that application. The PILAS system analyses the bad weather areas with respect to an activated flight route. If the weather would endanger the helicopter on his route, the bad weather area is displayed in amber while it is green in case of not endangering the route. As the data link provides 3D weather data, these data can be displayed in the SVS as polygon boxes. The polygon lines are colored according to the computed danger level (amber or green). The surfaces of the polygon boxes show bad weather clouds in order to distinguish them safely from airspaces.

5.4.4. Obstacle Warning Function

As helicopters operate a considerable time of their missions quite close to the ground, obstacles are one of the most dangerous hazards. Therefore, the

PILAS database system contains obstacle information as well. The obstacles are displayed in the NMD and SVS in amber. Vertical obstacles are depicted in the SVS as polygon boxes with safety margin around and power lines are displayed as lines (see Figure 12).

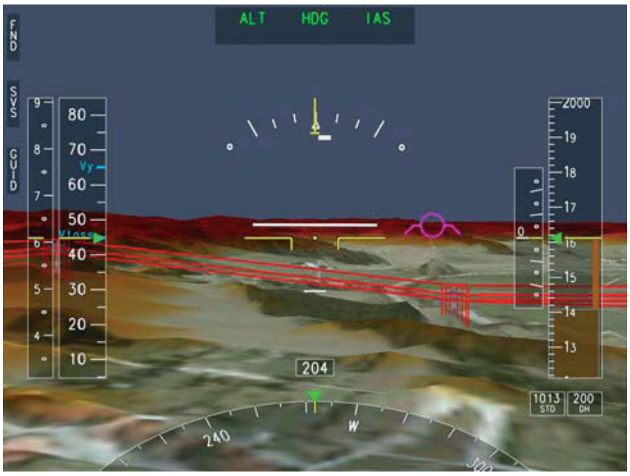

Figure 12: SVS with obstacle information

6. DEVELOPMENT AND VERIFICATION OF HMI IN A DEVELOPMENT COCKPIT

The HMI for PILAS was developed inside the **De**monstration **Co**ckpit (DeCo) which is a flight simulator cockpit with outside scene simulation (see Figure 13). This DeCo comprises the same displays as in the research helicopter. Furthermore, the system architecture and the computer platforms are identical to the helicopter platform. Therefore software developed on the DeCo can be transferred to the helicopter easily.

Figure 13: Demonstration Cockpit DeCo

7. HIGH SOPHISTCATED PLANNING SUPPORT

Route management as described above is part of the flight management system (FMS) functionality PILAS provides to the crew. But PILAS with its different assistance functionalities may contribute more. The central PILAS database system contains data on terrain, weather, obstacles, traffic, airspaces and helicopter performance data. These data are regularly updated via data link. PILAS uses these data and analyses it with respect to the route – during the planning phase and also during flight.

7.1. Planning a Route: Example

As basic scenario to verify the PILAS functionality a typical HEMS mission was selected. After an emergency call to the rescue coordination centre (RCC) a helicopter operation might be necessary. Before, the RCC sends via data link a mission order including destination and hospital coordinates directly to the helicopter. PILAS immediately displays the mission order on the NMD in magenta color. PILAS starts to analyze the actual situation. The analysis takes into account starting and landing procedures, the helicopter performance for climbing and descending, terrain, air spaces, bad weather areas, obstacles and other air traffic. During route planning, PILAS informs the pilot in a green transparent box at the bottom of the NMD that "route planning (is) in progress". After a few seconds of calculating, PILAS proposes a safe route for the first leg of the mission order. The route proposal is displayed on the NMD in yellow color and the pilot is asked to "activate (the) route" by pressing just one button – the acknowledge button. The acknowledgement of the route gives the pilot the decisive instance to decide on the route. But he could also choose to program his own route by using the joystick.

Once the route is activated its color turns to cyan. Waypoints like IAF and FAF are inserted automatically by the system. As the route is not only calculated in LAT and LON coordinates but also includes altitude information and speed respectively time PILAS displays the route as 4D tunnel in the SVS. The tunnel is displayed in the SVS as the route in the NMD in cyan. Now the pilot can take off and follow the tunnel. He can also decide to couple the 4-axes autopilot to the 4D trajectory of the route. When the autopilot is coupled the color of the route and of the tunnel symbology turns to green and the AFCS symbology area at the top of the PFD displays the AFCS mode "PGC" (PILAS Guidance Control).

7.2. Route Monitoring and Re-Planning

During the flight on the route, the system always monitors the situation with respect to upcoming threats. Let's assume that the last weather update, which was transmitted to the helicopter via SATCOM, showed a bad weather area moving into the route of the helicopter. PILAS immediately recognizes this threat, displays the weather area in amber and plans an alternate route at the backside of the bad weather area. This alternate is proposed to the pilot on the NMD in yellow color while the actual route in cyan or green is still the active one (see Figure 14). It is the decision of the pilot, to confirm the alternate route. If done, the new route is displayed in cyan. The autopilot-coupling would be terminated automatically and the pilot has to couple the AFCS onto the new route intentionally.

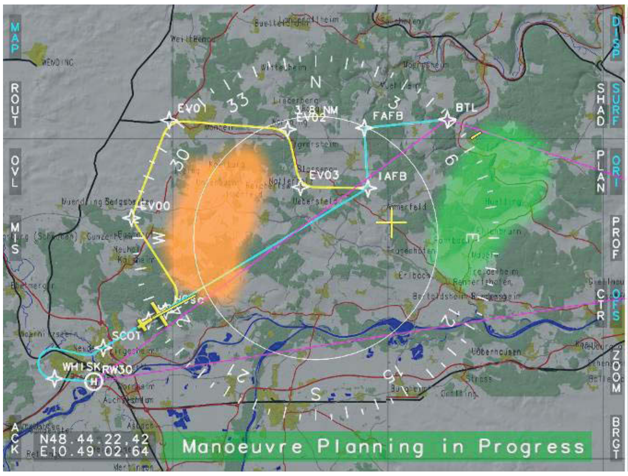

Figure 14: NMD with re-planned route (yellow)

Another threat, which cannot be planned initially during the first route planning, is other air traffic crossing the route. In such a case PILAS recognizes the threat and proposes a safe alternate route. The pilot – alerted by an aural warning – looks into his NMD and decides, to select and accept the alternate route. Finally the tunnel symbology brings the pilot to his first destination of his mission. At the moment PILAS with its AFCS capability is able, to safely guide the helicopter down to a height of 200 ft. The last 200 ft have to be flown manually. After landing PILAS calculates the next leg of the mission order or receives possibly a new mission order e.g. concerning the selection of the hospital where the patient needs to be flown to.

8. THE PILAS HELICOPTER TEST BED EC145

The PILAS project had its own flying test bed which was an EC145 (see Figure 2) with specialized equipment. The advantage of the EC145 is the large sized cargo room. The helicopter was painted in a very special research design featuring hand-written formulas on top of a color transition from purple-red to crème-yellow. The formulas shall visualize a scratchboard of a scientist. Before using this helicopter for the PILAS flight tests the instrument panel was rebuilt in a way to provide enough space for the two 6' x 8' landscape format color displays on the pilot side. The left hand side of the instrument panel including the engine and caution displays has been left untouched for safety reasons. The helicopter provides flight controls also at the left hand side. So a fully authorized safety pilot can fly the helicopter from this position.

Behind the cockpit there are two operator places. The operator place behind the pilot seat provides a keyboard with integrated pointer device to control the PILAS computers. In a large display the operator can open windows to access the PILAS software and monitor or interrupt it. When starting for a flight trial the PILAS is starting autonomously triggered by the operator. Below the large operator screen there is a second display in the size of the cockpit displays. Here the operator can select between the PFD and the NMD presentation in order to understand comments and questions from the pilot referring to the presentation.

Figure 15: The two operator places in the research helicopter.

During flight the system records all data which are used by PILAS. The recorded data can be replayed in the helicopter on ground or even in the simulator. So the whole development team can see the results of the flight test and can better understand the test-pilot's comments. Additionally there are two small cameras installed over the shoulder of the pilot which are recording the PILAS displays and a third camera, which can be moved and used for different views inside the helicopter.

The second operator place at the left side is dedicated to the experimental AFCS system. This AFCS can be monitored and adjusted (even during flight) through a notebook available at that operator place.

In order to be as flexible as possible for exchange of computers and other test equipment the whole PILAS equipment was installed into two 19-inch racks, which are installed in the cargo room at the right hand side (see Figure 16). As this helicopter is qualified as research test bed it requires a independent flight test instrumentation (FTI). This FTI records a defined set of data including the three videos delivered by the cockpit cameras. The flight test crew can set markers (TOPs) in the recordings of the FTI in order to identify special events during a flight test.

Figure 16: PILAS computer racks in the cargo room.

9. PILAS RESULTS AND CONCLUSIONS

The assessment of the PILAS HMI was one of the major measurable results of this research project. Already during the development of PILAS several simulator assessments had been performed. The pilots had to assess the crew interface and the functionality of PILAS. It showed up, that the acceptance of the system is dependent of the experience in synthetic vision systems. Those pilots with longer experience in SVS and PILAS were fully satisfied. They highlighted the need to monitor both the PFD SVS and the NMD to reach the optimal situational awareness (SA).

The PILAS assistance system was a first approach for a cognitive system inside a helicopter cockpit. It was developed as a prototyping system and assessed in simulator and demonstrator. The project showed the feasibility of such an approach for an avionic system in a rotorcraft. Further studies has do be done to identify the possible changes on existing avionic equipment as well to clarify the certification aspects, especially for expert systems.

For the flight tests, different missions were defined and flown. During such missions a set of predefined data was used in the helicopter to simulate threats. The scenarios included moving bad weather areas, interfering other aircraft, real airspaces and real obstacles like power lines. A typical flight test for the complete PILAS started with the reception of a mission order – like described in the example scenario above. Special missions had been defined to test the 4-axes autopilot and its PILAS guidance functionality. Those missions comprised more difficult flight maneuvers like sharp turns, steep climbs and descends and more. PILAS was also successfully used to analyze steep approaches up to 9° and curved approaches with and without AFCS guidance.

As a conclusion it can to be stated that the results of PILAS have been very satisfying. Interesting ideas and concepts could be shown and proved in flight. Since PILAS was a research project, the software and the equipments were not certified to hardware and software levels which would be required for a serial system. Therefore the next step, which is already in work, will be to analyze these requirements and define the steps needed to realize those ideas in a serial helicopter. Also there is a strong need of new procedures and flight rules especially for helicopters in the low air spaces and aerodrome areas before systems like PILAS can play their full role.

10. ABBREVIATIONS

2/3/4 D	2/3/4 dimensional
AFCS	Automatic Flight Control System
ATC	Air Traffic Control
C-API	Client Application Programming Interface
CDU	Control and Display Unit
CORBA	Common Object Request Broker Architecture
DBS	Data Base System
DeCo	Demonstration Cockpit
DTED	Digital terrain elevation data
EMS	Emergency Medical Services
FAF	Final Approach Fix
FFK	Fixed Function Keys
FMS	Flight Management System
FND	Flight Navigation Display
FTI	Flight Test Instrumentation
HEMS	Helicopter Emergency Medical Service
HMI	Human Machine Interface
HMIC	HMI Computer
IAF	Initial Approach Fix
KIAS	Knots Indicated Air Speed
LAT	Latitude
LON	Longitude
LSK	Line selectable key
NAV	Navigation
NMD	Navigation Management Display
NTSB	National Transportation Safety Board
PFD	Primary Flight Display
PGC	PILAS guidance control
PILAS	Pilot Assistance System
RCC	Rescue Coordination Centre
SA	Situation Awareness
SATCOM	Satellite communication
SVS	Synthetic Vision System
TAWS	Terrain Awareness and Warning System

11. ACKNOWLEDGMENTS

We would like to forward many thanks to the highly engaged PILAS project team, which put a lot of effort in this project and which invented all the detailed solutions to make the whole project running. We would also like to thank all partners involved in that research project and the German Federal Ministry of Economics and Technology represented by the DLR for funding.

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