

# PILOT ASSISTANT FOR APPROACH AND DEPARTURE

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## Abstract

Contained within the goal to extend and to utilise human capabilities in a work system, which consists of an operator, the work object and tools, is a key requirement for the tools called Man-Machine-Systems (MMS). Therefore MMS have to deal with and influence human behaviour in addition to the challenges concerned with the technical considerations of capability extensions. If only the human have to deal with and influence the behaviour of a system, based only on technical issues, the intention of extend and utilise the human capabilities and there of the work system results mostly in reduce and obstruct.

The following article describes our approach to extend and to utilise the capabilities of a helicopter pilot during approach and departure using an assistant system design based on a human behaviour model. To utilise the capabilities, the pilot will be relieved, on demand, from routine tasks like flying, searching information or monitoring states and limits. Further an intuitive usable Man-Machine-Interface (MMI) provides him a holistic, mission dependent overview of the situation. An extension of the capabilities can be performed, physical, sensory and cognitive. On the sensory level fused imaging sensors with different wave lengths enable the detection of obstacles under adverse weather conditions. Applying sensor and information fusion as well as knowledge based planning extends the pilots cognitive capabilities.

For the assignment of mission tasks to a machine two criteria were considered. First, a special machine capability have to be available to solve this task and second the assignment to the machine fits into our considerations of the human behaviour and thinking. This requires an appropriate picture of the actual situation and the knowledge of the goals of the pilot by the assistant system in order to help the pilot to find out the most important and most urgent action as well as a suitable way to support him during action planning and execution.

## 1 Introduction

Approach and landing as well as take off and departure are accident prone flight phases in helicopter missions. "Human failure" is the predominant cause of these types of accidents. The main reasons for the accidents during these flight phases are a false assessment of the landing site and the potential approach and departure trajectory as well as the high workload of helicopter handling in low altitudes in the proximity to obstacles.

The new CNS-Technologies enable, amongst other things, the use of waypoints independent from ground infrastructure to build up routes. These can be applied to define new kinds of trajectories, regarding the specific capabilities of the helicopter for takeoff and landing, partly usable also under IFR conditions. This leads to a number of new potential approach and departure trajectories with various benefits. One important benefit can be a particular quiet or power efficient flight path, e.g. a low noise trajectory for a landing in a residential area or a power efficient a landing in the mountains. Using the special capabilities of helicopters, more economic takeoff and departure trajectories on airports are still possible. Direct routes to the helipads, non-interfering with other traffic, lead to a significant increase in the efficiency of the helicopter and the airport use. Furthermore, there can also be a required approach or departure flight path for a certain helipad which has to be known and followed.

To select the appropriate trajectory using the described new possibilities, a huge amount of information about the landing site and it's environment as well as sophisticated planning is necessary. This task is very demanding and in some cases not feasible for the pilot. For example, he is not able to predict the noise foot print of the helicopter on the ground or to execute a precise performance calculation. Hence, current and even more the future opportunity to optimize the mission efficiency with a necessary increase in safety can

only be achieved if the pilots are being assisted in an effective way.

Safety and economy are the driving factors for the efforts of the aviation industry concerning their research and development. These efforts are influenced by a technical point of view which is suitable for the most research areas like aerodynamics, flight mechanics and so on. But in the area of avionics, cockpit and support system design this general practice leads to a task oriented system structure. That means, one system for one task. Such a system includes the necessary sensors, information processing and indication for exactly this one task independent from other situational elements which may have an respond to this task. With such a system a decreasing accident rate, based on flight hours, but also a shift in the failure causes from technical to human factor problems occurs.

For the assistance to be truly effective, it must act in a "human like" manner, able to anticipate the pilot's needs. Due to human factor problems based on human behaviour and human performance, it is necessary to extend design guidelines taking not just the technical point of view into account.

To overcome these deficiencies a new approach to pilot assistance will be presented. This approach based on a general structure of human behavior in a guidance and control task called recognize act cycle. In this cycle the subtasks, coordination, information acquisition, situation analysis, planning, plan selection and plan execution are defined to assemble human behavior.

To solve a complex problem it is necessary to decompose the problem into simpler, decoupled subproblems which can be solved nearly independently based on the recognize act cycle structure. The dissected problem is made up of a hierarchy of subproblems such that the higher level solutions of the lower levels are combined to a near optimal complete solution of the original problem.

It is important when designing an assistant system based on this approach to maintain a balance in the complexity of the subproblems as well as in the machine support for the subtasks of the recognize act cycle.

## 2 Design Advisement

### 2.1 Global System Design

Assisting the pilot primarily means supporting him to reach his goals rather than assuming a dedicated task, he have to perform, by a machine, even if this task is exhausting but isolated in the support structure. Hence, it is reasonable to align the cockpit design, including assistance systems, following the process a human uses to reach his goals in a guidance and control task. To reach the goals a human executes the so called recognise act cycle [1]:

1. Recognise the actual state of the world and compare it with the desired, goal based.
2. Analyse the deviations of the actual and desired state of the world.
3. Think about actions to modify the actual state.
4. Decide about the action to reach the desired state.
5. Take this action to change the state of the world.

To make this generic procedure subsumable for problem solving by machines, it is necessary to decompose a complex problem into simpler, predominantly decoupled subproblems. This leads usually to a hierarchical decomposition of the complex problem into solvable subproblems on the lowest level. The solutions from the lowest level serve as input for the higher levels. On the higher levels these solutions will be combined to a near optimal solution of the more complex, original problem. Hence, not only one recognise act cycle but for every subproblem on every level a unique cycle will be executed.

An optimal solution for a complex problem can only be determined if no assumptions are made and every dependency between subproblems is taken into account. The inevitable procedure to solve a complex problem by a machine with a solution combined of simpler subproblems simplifies the original, more complex human procedure causing the loss of higher intelligent behaviour of machines. For the whole work system pilot/helicopter, higher intelligent behaviour is maintained if the solution combination of subproblems is assigned to the pilot and he is aware of what the support system and it's conditions, will do for him.

From the generic level of the recognise act cycle important design aspects can be derived. If a result of a recognise act cycle step is obtained the transition to next step is performed. On the rule- and knowledge-based level of human behaviour the transition results are conscious to the human because human performance on these levels is based on explicit know how [2]. Hence, it is reasonable to provide the system obtained results to the operator even if the next step is fully automatic, including the information transfer, with no additional information necessary. In this way the operator is able to comprehend and assess the support he gets from the system, i.e. his is adequately informed. A kind of explicit conformation of the obtained result will insure that the operator stay actively involved in the process.

Transition results are not only useful as exit points but also as entry points. Using the results as entry points the operator can influence the system support according to his perceptions of the world. Thus, appropriate input, output information can be defined.

The provided coordination functionality between the automatic support functions, relieves the pilot, as opposed a task centered design, from the error prone and exhausting task to transmit data. Miller [3] defines one of his cognitive task agents "Transmit" which means "moving something from one place to another". Such a task degrades needlessly the human information processing resource called "response precision".

To perform the tasks behind the recognize act cycle, i.e. to analyze a particular situation or to plan or act in different situations in different operation areas, an extensive, related knowledge in these areas and about the mission objective is necessary. This applies as well for the assistant system. A significant part of this knowledge will be used across the different levels of sub-tasks because it is the basic knowledge of the different areas of operation named navigation, flight control, system management and communication. So, this knowledge have to be accessible for all support functions on every level.

Some parts of this knowledge are often used by the pilot, others, seldom. Seldom used knowledge have to be trained by the pilot to be available in a short time or appropriately stored. From other parts of the knowledge, the pilot only knows where he can find the in-

formation, like a dedicated approach path to a helipad or an obstacle close to this helipad.

In this area strong machine capabilities exist. For a machine it is no problem to store a seldomly used rule base or a huge amount of detailed information, to retrieve the information in a short time and to show it in a context dependent manner. Because, the human information processing resource working memory is noticeably limited in long- and in short-term, especially for detailed information, (high demands for this resource exist), a support in this area is useful. To evade an increased load on the human information processing resources sustained, selective attention and perceptual sensitivity using a knowledge base, the stored information has to be retrieved with a minimum of input from the pilot.

## 2.2 From Goals to Support Functions

Associated with helicopter missions, there are two different goals which have to be distinguished. One goal considers the transport aspect of a helicopter mission, the other the execution. The goal which considers the execution can be termed as the goal of the pilot.

The goal of the transport aspect is the immediate or delayed transportation of persons and materials from point to point or along a specially constrained flight path. Additional, the persons and materials can either only be transported or fulfil a special task on board. The shape of the flight path depends on the current situation and on the special mission task, see [4].

The approach to achieve the goal is restricted by limiting conditions like bad weather, payload, threats etc.. To improve the approach to the goal, it is necessary to minimize the limiting conditions of the work system which is equivalent to the often used term of the extension of the mission performance (finally formulated as maximization).

The development of capability extensions of the work system is mostly technology driven because the human capabilities are more or less constant. The methods to assess the developed technologies in terms of the benefit for the work system and costs for the helicopter are considered foremost by the designers. However, costs will influence the whole work system, i.e. the helicopter and the pilot.

The costs for an improved mission capability which emerges for the pilot can not be expressed monetary. The costs are the, so called human performance costs. Improvements in the mission performance can cover a wide range of this costs. The amount of costs is related to the sum of significant modifications and extensions of the tasks behind the recognize act cycle. For example, a small impact is a change in the aerodynamics of the fuselage which will improve the helicopters drag but may have only a small impact on the control of the helicopter. If the improvement has a significant impact on the tasks there is always an increase in the human performance costs. For example, an enhanced vision system enables the pilot to fly under bad weather conditions but increases the human performance costs with additional cognitive agent tasks like "code". In the best case it is possible to minimize this costs to a small but positive amount. Without an enhanced vision system the pilot will not fly under such conditions consequently there are no additional human performance costs.

Human performance costs arise during mission execution by the tasks that have to be performed to reach the pilot's objectives. Hence, the support functions to reduce these costs have to be derived from these tasks and therefore from the objectives. A definition of the goal of the pilot is to fulfill efficiently a given mission while saving all resources like human life, equipment, workload, budget, environment and comfort. To achieve this goal the consumption of this resources have to be minimized.

Anything could happened, so the tasks derived from the goal could not be a complete set. Well, this is also not important because the non considered tasks are completely allocated to the pilot, like to kill a bee in the cockpit. Important is a defined, complete handover of tasks to and from the machine. Further the task performed by a machine should completely achieve the task's sub-goal. Thus, it is more suitable to develop a support structure from the goal of the pilot then to collect incoherent support functions from specific problems raised, e.g. at accidents, to an unstructured support cluster.

To derive a support structure, tasks have to be defined based on the consumption minimization of the resources in the specific areas of operation. The decomposition of the tasks into subtasks have to be continued

until the functions in the subtasks are clearly subsumable according to the functional elements of the recognize act cycle which consists of six broad classes of functions: Coordination, information acquisition, situation analysis, planning, plan selection and plan execution. That way in most cases an uncompleted collection of tasks will be derived. Next, the subtasks have to be split into functional tasks according to the functional elements of the recognize act cycle. Subsequently, a collection of similar functional elements and the attempt to generalize them have to be performed. At this stage a technical realization can be designed.

In more detail, the way to build up a support structure and the technical considerations will be described in the subsequent application chapters but in brief, the following example exemplifies this method. The most important requirement of the goal is to minimize the consumption of human life. Within the navigation area, the task to avoid collisions can be derived. This task further can be decomposed into the subtasks collision with ground, known and unknown man made obstacles and other airborne traffic. The decomposition into these subtasks was based on the different available knowledge and information acquisition methods. Another task, which serves the same requirement in the same operation area, is to avoid restricted areas like closed airspace or threat areas. Regarding the consumption of environment a task "avoid noise sensitive areas" can be derived. The differences between the tasks lies only in the "penalty" of not avoiding.

If these tasks now will be decomposed according to the function classes of the recognize act cycle, in the function class information acquisition, functions can be found like search for a "restricted area" close to the flight path. Restricted area in this context means a object with a position and geometric dimensions which should be avoided. In the class situation analysis the function to investigate if the flight path shows a collision with a restricted area, arise. The desired state of the world is no collision and no penetration of a restricted areas. If a deviation between the actual and desired state occur then the lateral or vertical flight path is inappropriate. In this case, a planning function has to be stated which is able to avoid the restricted areas according to an optimization criteria. In the plan execution class a function has to be stated which transfers the information how to avoid the restricted areas to the trajectory generation.

### 3 Approach and Departure Assistant

#### 3.1 Basic Architecture

To fulfil the requirement described in the chapter 2.1 a holistic system approach is necessary. A framework for such an approach is the generic assistant system architecture, developed at the Institute. This architecture allows the implementation of any support function module with full access to all available information. To implement such a module, it's not necessary to re-program the existing system software. Further a coordinated and safe data exchange is guaranteed within this architecture, for more detailed information see [5].

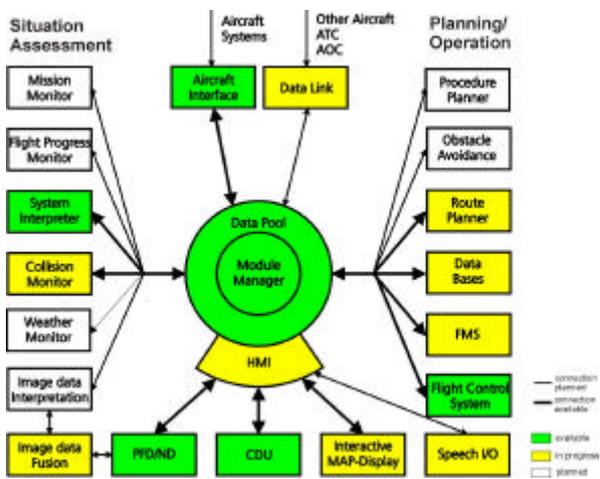


Figure 1: Generic Assistant System Architecture.

The knowledge for the assistance also has to be accessible from all support functions, so the database to store knowledge is a task independent part of the system and from that related to the generic architecture which consists of the module manager, the data pool and knowledge base.

#### 3.2 Assistant System for Approach and Departure

Developing an assistant system is a huge challenge. Therefore it is necessary to subdivide this problem into parts which are suitable to show the benefit of the new design approach. An important design guideline for the new approach is to take the work systems goal in a holistic way into account. To limit the amount of tasks derived from the goal, an appropriate subdivision is to split the system development mission specific into the two parts, approach and departure as well as en-route. The split between the two mission parts is at the top of

climb and top of descent, respectively (see fig. 2). We have started the system development with an assistant system for approach and departure which will be extended in the future with en-route support functions.

To achieve a goal, specific functions in every step of the recognise act cycle have to be performed, no matter who does it, the assistant system or the pilot. As a design guideline for the assignment of functions to the operator or the machine we defined that the necessary information transfer between both have to be minimised. This is done by introducing or omitting a specific function while maintaining the situation awareness of the pilot concerning the result of the function. So, if an added function increasing the pilot's input effort compared to that without support a modification or extension of the function is strongly recommended.

To emphasise the well balanced assistant functions a short example how to perform a transport flight from helipad to helipad out of the viewpoint of the pilot is shown below. The details of the individual functions are explained in the subsequent chapters.

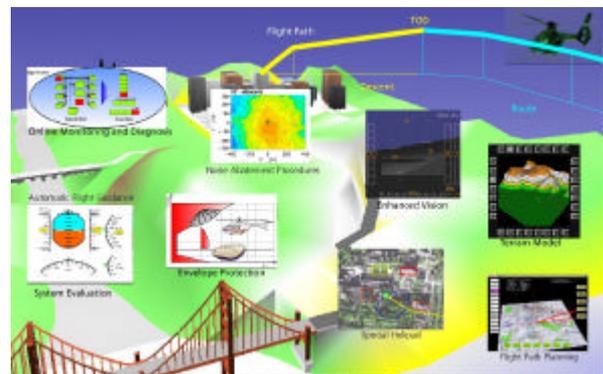


Figure 2: Support Functions of the assistant system.

The simplest way for the pilot to create a complete flight path is to enter a destination city like Berlin and optionally an attribute which specifies the kind of the trajectory, like quiet, efficient or standard. The currently available way for this input is a keypad but the planned speech recognition for such information will be more convenient. Depending on the destination city, a list of helipads in the vicinity appears on the graphical user interface (GUI) where the pilot can choose one. With this information the assistant system is able to calculate a complete flight path from the current position to the destination helipad. If the helicopter is situated on a helipad, this will be automatically taken into account by the system.

The proposed trajectory is shown to the pilot by different display layouts considering the different information requirements primarily depending on the distance to and the environment around the helipad. For example, on the helipad display different approach charts, the planned trajectory and written information are available. The presentation of the trajectory on the display is shown in, so called 2.5 D (see fig. 3). According to the pilot's perception of the situation a effective and intuitive modification of the proposed trajectory and the relevant constraints is provided by the GUI using a pointer like device on the respective map.

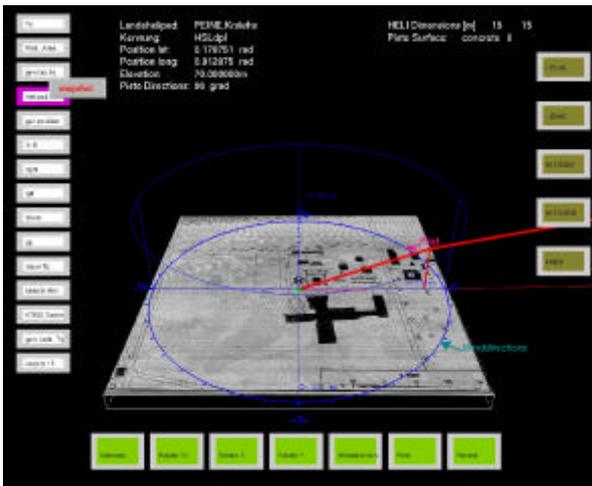


Figure 3: Helipad Display.

Considering the current traffic, the ATC sends a new way point to fly over on the way to Berlin/Schönefeld airport. The assistance includes this way point in the way point list and calculates a new flight path to the airport. On this route the helicopter crosses a noise sensitive recreation area and the government quarter. Since the attribute quiet is active, the situation analysis mark this recreation area as "restricted area". As well as the airspace over the government quarter is marked as restricted, too. These areas are sent to the avoidance planner which includes further way points to avoid the recreation area and the government quarter.

The new trajectory and the causes for the replanning, the new way point from ATC with the affected restricted areas are shown to the pilot on the map display, see fig. 6. Now he can assess the proposed trajectory. The displayed time of arrival, calculated by the trajectory generator, is too late. The pilot decides to fly across the recreation area, so he points on the regarded restricted area and deletes them. Immediately he gets a new flight path displayed on the map display and a

new time of arrival. He is always late and sends this information to the airport by pointing on the arrival time, the airport and the push button send. The airport receives the message and informs the pilot about the increasing ground fog.

That's no problem for the pilot because the helicopter is equipped with an enhanced vision system. Coming closer to the airport, the pilot flies along the predefined non-interfering route to the assigned helipad. Supported with the autopilot, the pilot uses the enhanced vision display to recognise unknown obstacles. Known obstacles are considered by the flight path planning. Shortly before touch down he is able to catch sight of the helipad and the buildings around and make the transition to a VFR landing.

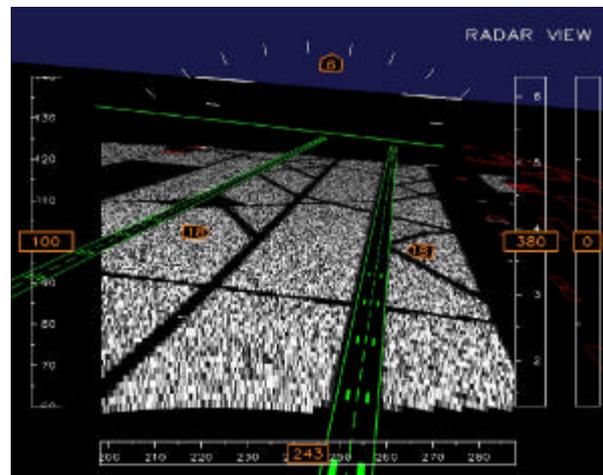


Figure 4: Enhanced Vision Display.

Using the map display for flight planning and highlighting known obstacles, restricted areas etc. on display fits to the way the pilot would normally work without this support. So the pilot is aware that unknown obstacles can occur because there is no change in his behavior compared to old fashion procedures. But tasks are supplanted like detecting, searching, filtering and transmit of information. The planning is simplified despite a higher efficiency according to direct and quiet routes. With the support of the autopilot the human resource selective attention is reduced with the added load by the EVS.

### 3.2.1 Knowledge Base of the Assistant System

The benefit of an assistant system depends considerably on the quality of the knowledge base. In the data base stored knowledge must serve high requirements

in both the volume and the quality. For a reliable situation analysis a wide palette of different information is essential. This palette includes information about the environment, information on the helicopter and his systems and information about procedures and behaviour models of pilots.

For precise planning and execution, information of a high quality is indispensable. The quality, in this case is the consistency, the completeness and the accuracy of the data.

The data base developed for the approach and departure assistant system contains different classes of information. These classes are:

- General environment information
- Terrain information
- Infrastructure information
- ATC information
- Equipment information
- Performance model of the helicopter
- Information for the flight path optimisation
- Information about procedures

The general environment information contains data like the identifier, the position, the size and the form of the helipad, the surface condition, the altitude, the illumination and approach navigation lights, a possibly available glide slope annunciator, communication frequencies, telephone numbers, secondary landing sites. These data can be found, for example, in the Aeronautical Information Publication (AIP), see fig. 3 and 5.

Terrain information consists of terrain models, aerial photos (see fig. 5) and different maps. For the terrain models two different solutions are available. At an altitude of approx. 200 ft above ground and higher the terrain model from the Shuttle Radar Topographic Mission will be used. This terrain model is characterised by the high consistency of the data and the nearly world-wide availability. The resolution of this data is 1.5 m in height at a tile size of 30 by 30 meters. This resolution is, by far, insufficient if the helicopter flies into the obstacle scenery at a helipad. In this case, other data are used, which were picked up with the digital High Resolution Stereo Camera Airborne (HRSC-A). These data provide a resolution of approx. 15 cm in the height at a tile size of 15 by 15 cm received at an altitude of 1500 m. The HRSC-A photos form the basis both for the high-resolution terrain

model and for the 3D- and simple aerial photos of the helipads (see fig. 5). This terrain model is available in a tile size of 1 by 1 km around exemplary selected helipads. The given map material is a part of a military map software consisting of the standard maps of different scales including the ICAO map of the German area (see fig. 6). The approach and helipad charts are scanned examples of several helipads from the AIP.

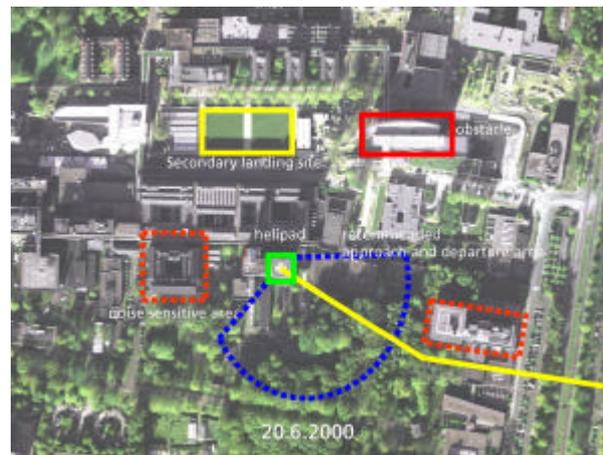


Figure 5: Augmented aerial photo of a helipad.

The infrastructure information are the places and courses of the infrastructure on the ground, i.e. the places of sport fields, noise sensitive buildings and other landmarks, the course of streets, power lines, pipelines and so on. Not only real infrastructure is available within this information, but also data of the places and courses of e.g. country's and city boundaries. This information is gathered from the so called ATKIS data base provided by the German Land Surveying Office. A special kind of infrastructure data are the aviation obstacles which are provided by the German Air Traffic Control. These data are inserted into the infrastructure data base.

The ATC relevant information refer primarily to the air space structure and the predefined approach and departure routes. The airspace information describe the site and the kind of air spaces (see fig. 7) as well as regulated procedures to enter them. The approach and departure routes are e.g., the STAR's and SID's.

Equipment information of the helicopter is necessary for the adaptation of the assistant system onto the current configuration and for the diagnosis of the systems. The information needed for the adaptation, like the in- and output parameters, can be taken from the system

descriptions. Based on this description, a failure model for the knowledge based online diagnosis is derived by an expert which refer to specific signal and structure features by a loss of a component, see also [4].

To describe the performance model of the helicopter information from the flight manual, the manufacturer and an identification of our flight test helicopter are used. The performance model contains e.g. maximum angle of climb and descent, maximum take off weight as well as the changes during a loss of a jet engine. The high quality of the performance model is a substantial prerequisite for precise flight path planning.

The information for the flight path optimisation consists of constraints in the flight envelope and the performance model concerning noise abatement, power efficiency, vortex ring state, calculation methods for the take off and landing decision point etc.. This information is mostly related to the vertical trajectory.

The source for the information about procedures are e.g. the different checklists.

### 3.2.2 Human Machine Interface

The procedure of designing a new human machine interface (HMI) for the assistant system have also been changed from a technology driven, task centered to human centered. Therefore the information to guide the helicopter have to be provided in a mission specific manner in the context of the current situation. This requires particular possibilities for the input and representation of information to the pilot concerning a specific mission or part of. From that a display distinction is made between en-route and approach and departure.

Further a clear distinction between the indication of the current states, e.g. internal, external and the currently active, planned commands as well as of the overview of the planned mission course have to be made. To achieve this segmentation and in order to comply the input requirements, two display classes are available to the pilot as HMI for the assistant system.

First, the modified Primary Flight Display (PFD). This display indicates always the current state to the pilot. For that purpose it contains the usual glass cockpit indications. Instead of the artificial horizon a virtual environment picture will be provided as background

based on the terrain model and the infrastructure information. This artificial environment picture will be overlapped with obstacles detected by the EVS which represents the current external situation. The internal state, current modes of the autopilot, as well as the required values of the controlled variables are also indicated on this display. Action proposals are integrated as symbols, tunnel in the sky and as text lines.

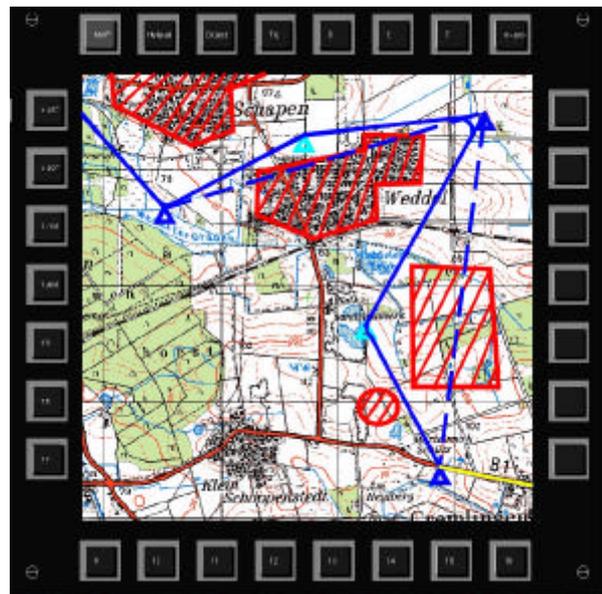


Figure 6: Interactive Map Display.

Secondly the multi-purpose display (MPD). This mission overview display has to enable a direct and intuitive modification of the planned procedures. A representation of the current situation is necessary in overview display. The information content of this indication can be considerably lower since this information is solely a marker of the current state in the course of the mission. The content of this display will be mission-dependent and interactively selectable as opposed to the PFD. The different contents of the MPD are:

- Mapdisplay
- Altitude and terrain profile display
- Air speed profile display
- Helipad and terrain model display
- System status display
- Component and component information displays

In the Mapdisplay, for en-route, four different maps are displayable. The map on the display is arbitrarily moveable. Furthermore, this display provides a graphic user interface to generate or adjust a proposed flight path or restricted area etc.. For this purpose, it is possible to enter, to delete or to move points or lines to an



During the flight in both the map or helipad display the position data of the helicopter is tracked. So the pilot can check if the planned and flown trajectories match.

The system status display shows the available redundancy of the flight control system (FCS) and the available autopilot functions. The component displays indicate which components in the FCS are intact and which are failed. The component information display represent information essential in the case of a failure in a component. Since the definition of this functionality is rather a task of industry, we inserted at this place only a picture of the failed component, see [4].

### 3.2.3 Coordination

The internal coordination takes care of the information exchange between the onboard systems and the pilot. Parts of the coordination are the module manger and data pool, the described HMI and the aircraft interface including special sensors. The external coordination takes care of the information exchange between the work system pilot/helicopter and the surrounding world. To perform this task a digital data link is necessary to provide information processing for the exchanged data. The functionality of the internal as well as the external coordination are described in the preceding chapters. Further information see [4].

### 3.2.4 Situation Analysis

By the external situation analysis a distinction between short and long term has to be made. The long term analysis predicts situations which will be encountered during a mission. The situations are caused by conditions which, compared with the mission duration have a very slow rate of change. Hence, the information for the analysis is primarily based on stored information. The uncertainty of this information increases with the level of detail and well as the analysis results.

The short term analysis estimates situations which will be encountered immediately or in within the detection scope. The conditions which cause the situation have high rates of change compared with the mission duration. Hence, the information analysis is primarily based on sensor information. The uncertainty of this information increases with the decrease of the resolution and the scope of the sensors as do the analysis results.

The transition between long and short term analysis depends on the completeness of the information. If a change in the situation is completely described by the information, like a received threat area or a way point, the problem fits to the long term analysis. Is an incomplete information with an onwardly completion available the situation can only be clarified until a certain extend which fits to the short term analysis.

The long term situation analysis for the assistant system is based on stored knowledge, like the external situation in the form of terrain models. For example, the high-resolution terrain model is used during the external situation analysis in order to examine if the planned approach or departure trajectory is free of known obstacles. The module collision monitor generates surfaces, cuboid like, along the trajectory which is used to determine slice planes between the surfaces and the terrain model. If a slice plane exists this plane will be defined as a "restricted area" which will be included in the data pool as a new situation object. The same method is applied to determine ground collisions using the SRTM terrain model.

Even if collisions with known obstacles are taken into account, good visibility conditions are necessary to fly near obstacles because there is no guarantee against the occurrence of unknown obstacles. Hence, the use of enhanced vision systems are necessary for flying in bad weather at low altitudes which comply with the short term situation analysis.

For a high performance of an EVS, different imaging sensors, supported by a terrain data base, are fused. By fusing different sensors, the pilot is informed ahead of time about a distant, but certainly in the range of the sensor, obstacle which enables him to perform precautionary measures, like reducing speed. In this case, the information about the obstacle, like the size, must onwardly be recognised by the received measurement values. So only the free spaces in the scope of the sensor can be used to describe the situation.

Information about the internal situation analysis will be found in [4].

### 3.2.5 Planning

The general consensus among aircrews exists that potential effectiveness has to be sacrificed for simplicity.

Simplicity means to easily find a plain course of actions which satisfies the goals within the bounds of applied constraints. Plain, in this context, is related to the course of actions and is independent from the method to determine it. The determination has to be easy for one who performs it.

A special machine capability is to fulfil complex calculations based on detailed information considering sophisticated quality criterion. To perform such tasks the different planners of the assistant system need defined input parameters and variables. These inputs have to be automatically provided by the situation analysis. In this case, the planners are able to determine suitable procedures, trajectory, etc., which are unsolicited suggestions to the pilot to proceed with the mission by unexpected or self-effectuated events.

The situation analysis of the approach and departure assistant system provides the necessary information concerning the attributes quiet or engine failure, restricted areas, waypoints etc. to the planning modules.

With the information about the way points, restricted areas and the quality criterion (shortest way around), the avoidance planner provides way points for the shortest way around, e.g., an obstacle. The route planner takes these way points and fuses them together with other way points e.g. from the pilot or other planners.

All plannings can be executed without any input from the pilot, so no additional workload occurs. With the proposed flight path and the obstacles shown on the map display, the pilot is able to easily assess the result of the planning. If his own perception differs from that of the system, he is able to input new way points or restricted areas as described above. This planning support enables the pilot to develop an optimized flight path, including noise abatement aspects etc., very fast and easily which he probably will not do manually.

The flight path created by the route planner contains the waypoints, flight altitudes, airspeeds and arrival times at the waypoints. This information is used to compute a precise and according to the optional attributes, optimised trajectory on the basis of the helicopter performance model, atmosphere, weather data and so on. The range of the support by the trajectory generator includes today's standards and takes into account cost, power and noise-optimized departure and ap-

proach trajectories, engine failures up to restricted trajectories and restricted airspeed or flight altitudes.

### 3.2.6 Plan execution

The calculated trajectory is used to control the helicopter in a range from fully automatic until augmented manual. For a manual flight a flight director is provided. In the case of a fully automatic flight the guidance part determines commands to follow the trajectory which are carried out by the autopilot.

In the case of automatic execution the pilot engages the guidance with few inputs according to the autopilot modes to make it clear that the helicopter now is controlled by the autopilot. To perform this support only few inputs from the pilot are necessary and these inputs are based on human behavior considerations.

For augmented manual flying the autopilot functions have to be optimized in order to fulfill the handling quality rating for level 1 including a consideration of safety limits like the vortex ring state area. The manual mode enables the application of the assistant system also to low equipped helicopters. To design the flight control system for the flight test helicopter ACT/FHS an integrated development process based on an advanced design tool has been used.

## 4 Perspective

How to derive support functions in an appropriate way are described in this article. An open question which has to be addressed in this regard is how to determine the level of automation applied to the support functions and how to adjust it during a mission. This level has to be, at any rate, adaptive, dependent on the current workload of the pilot. In the case of a low workload to avoid the loss of capabilities of the pilot to perform a certain task or in the case of a high workload to avoid an overload. For a shift of a task from the preferred performer to the alternative performer it is not important that both perform this task in the same way with the same quality criterion. It is sufficient, if the quality difference is comparable with a handling quality degradation from level 1 to 2. Bigger steps in the transition have to be avoided.

As well, an unreasonable high automation accompanied with a reduction of the operator's awareness of the

system and of certain dynamic features of the work environment. So, the reliability of the highly automated support functions have to be high, with the exception if the costs of a malfunction are low. Another problem with respect to the reliability is that failures not only occur in the case of malfunctions in the hard- or software but also if that the assumption modelled in the support functions does not met the given operational situation.

Hence, different levels of reliability have to be developed and included in the design guidelines for the proposed functions. This is also true for the transition procedures between the levels. Further, a load meter has to be developed to determine the workload of the pilot to adjust the level of automation which possibly increases during special missions to a fully autonomous execution of certain courses of action in the case the pilot is hampered. Finally, it is important to keep the pilot in an active role on board the helicopter and give him the technical means to make the flight more efficient and reliable technical means to make it safe.

## 5 Summary

In the development of the pilot assistant system special attention was paid to two aspects. One aspect deals with the question, how to specify the assistance for the pilot. The approach to clarify this question was based on the goal directed interaction of man with the surrounding world. Derived from the goal directed behavior a support structure is developed which provides a balanced and comprehensible assistance to the pilot. The individual tasks of the support structure are decomposed into functions according to the functional classes of the recognize act cycle.

To perform the functions a diversified knowledge about e.g. the areas of operation is necessary. This knowledge consists of, a data base of stored or transmitted information, measurement values and results of performed support functions. This knowledge has to be available to all support functions, so a holistic design for the basic system architecture is necessary. The developed, generic system architecture provides a task independent framework for the application modules (support functions) by supplying a common data communication, a dynamic data storage (shared memory) and a static data storage (data base).

The other aspect deals with the question, how the multiplicity of tasks and sub-tasks based on the different missions can be reduced to a few characteristic assistance functions (based on the function classes of the recognize act cycle). To determine such functions, similarly decomposed tasks are collected together and an attempt is made to find a joint technical solution for those tasks. As an example, the derivation of the function "avoid" is described in the article.

The differences between the mission parts takeoff, landing and en-route requires a split of the system development into two parts because of the different requirements according to the knowledge, the HMI and some planning features. For this reason, we now concentrate the development of support functions on the mission part approach and departure. In the article, the development of the knowledge base and the human machine interface is highlighted. However, the development is made against the background to extend the system around en-route assistance functions.

The developed assistant system will be tested in our simulation environment as well as with our new ACT/FHS research helicopter, a EC-135 with a full authority fly-by-wire control systems, to assess the functionality and the benefits in a real environment.

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