PAVE: ASSISTANCE SYSTEM TO SUPPORT PILOTS FOR IFR ROTORCRAFT AIRPORT OPERATIONS

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Abstract

To support the helicopter pilot in planning and performing flights to airports even under IFR, the German Aerospace Center (DLR) has its conducting applied research in the field of helicopter pilot assistance. A project entitled PAVE (Pilot Assistant in the Vicinity of Helipads) was launched under the management of the DLR Institute of Flight Guidance in Braunschweig. PAVE concentrates on approach and departure phase and shall enable safe takeoffs and landings even in very poor visual conditions. The project covers today's standard procedures, and emergency procedures in case of an engine failure. Research is also being done to define noise abatement procedures and time based procedures required for future Air Traffic Management applications. ONERA contributes to the PAVE project through the development of a module called Flight Execution Monitor which is dedicated to the monitoring of the current helicopter situation and of the pilot's procedural activity.

1. Introduction

The ***P****ilot* ***A****ssistant in the* ***V****icinity of h****E****lipads* (PAVE) provides the system technology to support the pilot during approach and departure by improving situational awareness and offering human centred automation to one of the complex, work intensive, and dangerous parts of helicopter missions.

Helicopter landing sites differ widely and are often located near buildings, close to terrain, or other obstacles. The helicopter pilot is dependant on visual cues during approach and landing to conduct the flight safely. Reduced visibility makes it complicated to avoid collisions or even to fly and to land the helicopter especially under difficult meteorological conditions. Helipads by their nature are situated close to populated noise sensitive places, but noise abatement procedures require a steeper approach exposing the helicopter closer to its flight envelope limits ([1],[2]). Additionally, emergency procedures in case of engine failure require very fast pilot decisions and actions. They are of vital interest especially during departure.

The Pilot Assistant addresses all these problems and takes the full complexity of the pilot work during these flight phases into account. Therefore it integrates single solutions of dedicated problems, using all available information onboard. This is a sound basis to avoid automation surprises and to design a system which can be used by the pilot without extensive training.

The objective of PAVE is

- to improve safety,
- to increase operability and
- to reduce high noise levels

by ensuring appropriate workload for the pilot and avoiding work overload.

The scope of PAVE also covers assistance in situation assessment, flight planning, flight execution, and monitoring ([7]) during approach and departure, in all weather conditions and 24 hours a day. The overall technical approach is to build, to integrate, and to test the research prototype and to evaluate it using ground simulations and flight trials. The open system architecture ensures future extensions to further missions. Flight trials are carried out using the DLR research helicopter ACT/FHS EC 135 (figure 1) and the BO 105 for noise measurement trials. The goal of the project is to evaluate pilot assistance functionalities with respect to the objectives and to present possible solutions/results to the industry.

Fig. 1: DLR research helicopter ACT/FHS (EC 135)

The project PAVE is split into two phases, a first phase (2003-2005) for the development and integration of the pilot assistant system on ground and a second phase (2006-2007) for the evaluation of the system in flight.

2. Flight Planning

With today's conventional automation inside the cockpit, it is not easy to interact with the different stand alone systems that have to be addressed. The resulting overall situation has to be combined in the head of the pilot. In dangerous situations, the interaction is not quick enough sometimes and the quality of automation is not high enough.

To propose adequate mission plans and to prioritize and present information in relation to the situation on the display, it is necessary to monitor flight execution ([7]) and to integrate information from all available sensors and systems dedicated to special problems – this is the approach of PAVE to bring a new quality of automation into the cockpit. This helps the pilot in making clear and fast decisions. If there are some deviations between the planned and the current situation, the system can inform the pilot by displaying adequate information on the display.

One of the main functions of the pilot assistant is its capability to work out an optimal plan according to the constraints set by the pilot and to predict the flight path accurately. Conflict detection with terrain is made and the assistant recommends a solution in case of conflict ([3]).

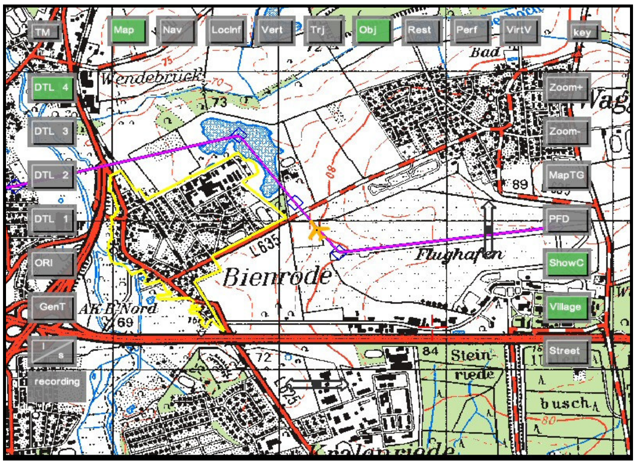

Fig. 2: Flight Planning with consideration of Noise Sensitive Areas

The place for the input of all mission parameters is not necessarily the helicopter. The pilot is able to enter the data with the use of a laptop where the same version of the pilot assistant software is installed. After saving the planned flight path on a memory stick, the data can be reloaded inside the helicopter by the pilot. The planning of a mission is accomplished as follows: In a first step the pilot can choose between predefined Standard Instrument Departures (SIDs) and/or Standard Arrival Procedures (STARs) according to Air Traffic Control constraints for a specific helipad or the pilot can select a flight path directly which he has defined before. The destination can also be defined by a WGS84-position. The result of this preplanning phase is a laterally defined flight path which is represented by discrete waypoints ([4],[5],[6]). Optionally, the planning algorithm can take into account noise sensitive areas (figure 2) to minimize the disturbing influence of the noise emission of the helicopter in urban areas.

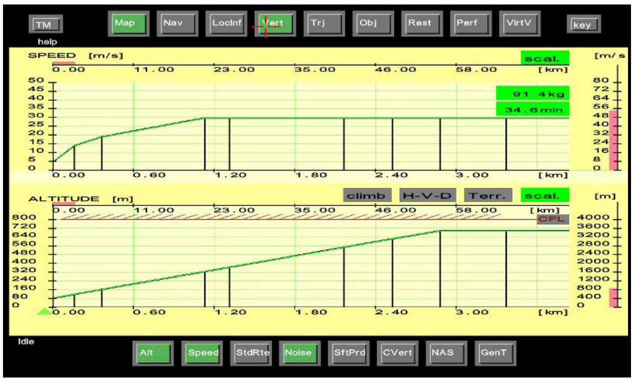

Fig. 3: Altitude and speed constraints for each waypoint defined by the helicopter pilot

After the lateral definition of the flight path, the pilot has to specify the altitude and speed constraints for each waypoint (figure 3). For a precise definition of these constraints the pilot is able to execute scaling and moving operations inside the profiles or to enter the value directly by a virtual keyboard. He is also able to select one of the following predefined kinds of approach- or departure procedures: standard, emergency or noise abatement. The flight path data for the generation of noise abatement approach/departure procedures are derived from the evaluation of recorded noise data which are acquired on the basis of multiple approaches and departures with different descent rates, airspeeds and flight path angles. The idea behind noise abatement procedures is to fly the helicopter in those regimes of the flight envelope that produce less noise than others. A number of 43 microphones are arranged on the Cochstedt airport for the acoustic data recording process. These data are synchronized with the GPS-position of the helicopter. The calculated noise model shows the connection between flight condition and noise emission and permits the regulation of noise-optimized approach and departure procedures ([1],[2]).

After the pilot has entered all necessary mission information, the trajectory generator calculates a flyable trajectory with consideration of the performance data of the helicopter. The trajectory has a high level of detail and covers typical helicopter maneuvers, e.g. backwards flight, turns, etc. An accurate flight path is a prerequisite for time based flight guidance and for conflict detection with obstacles, terrain, other aircraft, and helicopter flight envelope limits. The flight intention is reflected by the trajectory and is the core information for further assistant driven processing like operator communication, Air Traffic Control by datalink, and flight progress monitoring.

The assistant is designed to limit the necessary inputs to a minimum. Another option under investigation is Direct Voice Input (DVI) ([10]). All interface solutions have to be considered in the light of the challenging environment of the helicopter cockpit which can be noisy and have vibration and restricted space for additional devices and large size screens.

3. Situation Assessment

Aerial photos and a virtual landscape in conjunction with the planned trajectory are useful onboard the helicopter to increase the pilots situational awareness, to support the mission planning process, and to give a first impression of unknown helipads or environments. This increases the confidence in proper planning because planning mistakes are obviously visible. Inside the project PAVE two main aspects will be addressed: Providing a cockpit view along the planned trajectory and drawing the planned trajectory into the virtual landscape.

The data for the visualization were generated by a High Resolution Stereo Camera – Airborne (HRSC-A, figure 4) developed by the DLR institute of planetary exploration. This camera is a further developed airborne version of the HRSC, which was designed for the exploration of planet Mars by the international space mission MARS96 and one HRSC-A is currently flown on the European Mars Express mission. In combination with the photogrammetric processing system, HRSC-A provides image and 3D-data products with relative accuracies of about 10-15 cm and absolute accuracies of about 20-25 cm from a flight altitude of 3000m [[8],[9]].

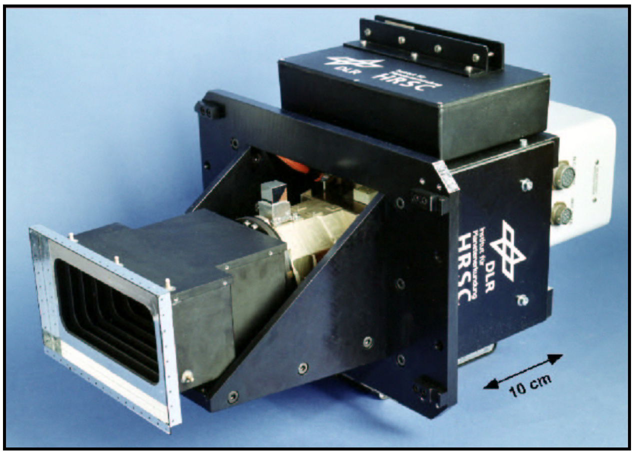

Fig. 4: HRSC-AX camera

In order to guarantee reliability regarding to the accuracy of the data, it is necessary to know the exact orientation of the sensor. For this purpose a GPS-receiver as well as a measuring sensor for the determination of the orientation of the camera are connected with the HRSC-AX, so that the proper motion of the aircraft can be reconstructed during the photographs and can be recorded to each picture simultaneously.

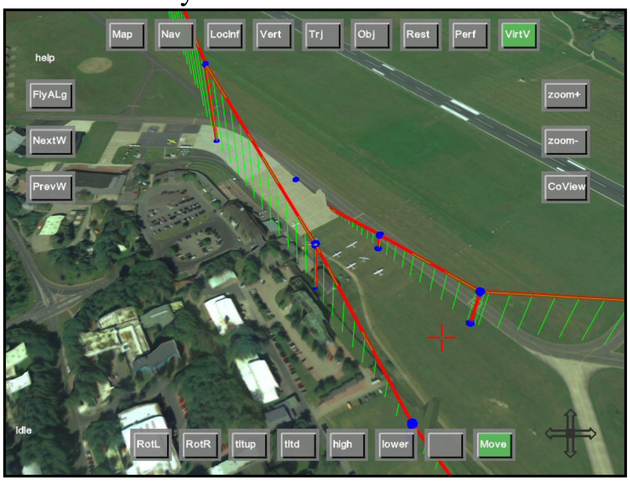

Fig. 5: Example of a HRSC-Image with an embedded preplanned trajectory

The high resolution HRSC-A data have been flown within a flight campaign for the project PAVE. The overflights aim an acquisition of highly accurate terrain data and aerial photos in the proximity of 5 helipads around Braunschweig. This is the region intended for flight tests in 2006.

Figure 5 shows an example of the virtual landscape superimposed with the planned approach/departure path. In flight it may serve to remember the pilot on important remarks given about obstacles, secondary landing places, or recommended approach sectors. This figure also shows the flight planning mode where the pilot is able to optimize the flight path by shifting the discrete waypoints (red vertical lines). Zooming, moving, and rotating functions of a virtual camera with the helicopter as the center point give the flexibility to get an idea of the current situation. Each discrete waypoint can also be moved vertically to define a new altitude constraint. Two blue markings represent the up-to-date specified value of the altitude constraint and the foot point (vertical projection to the ground).

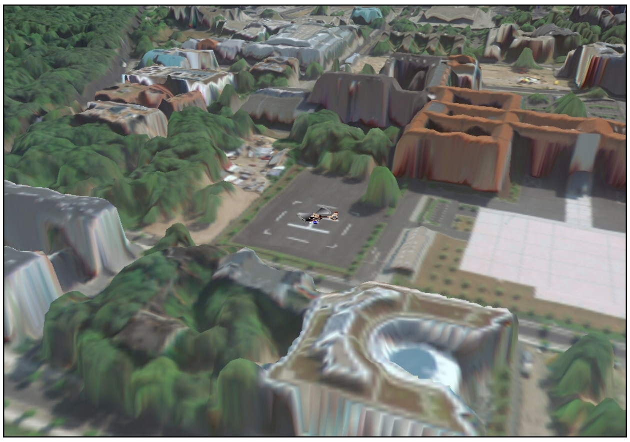

Fig. 6: HRSC-Image of a helipad surround by some buildings.

In the middle of figure 6 a helicopter on a helipad is displayed which is surrounded by some buildings. The side walls of these buildings do not correspond to nature appearance. This fact explains itself by the use of the available data, because the virtual landscape is realized by a combination of the elevation data and the corresponding orthographic photos as textures. No information about the condition of the side walls exists. Nevertheless it helps the pilot to orient in the vicinity of the helipad.

Electronic charts are also available onboard for flight preparation to increase situational awareness (figure 7). Additional information like speed or altitude constraints can be presented as a label at each discrete waypoint. In this mode it is also possible to rotate around the vertical or horizontal axis or to scale up the chart. Time-intensive looking up in the flight manual is replaced by the possibility to select the necessary charts from the database.

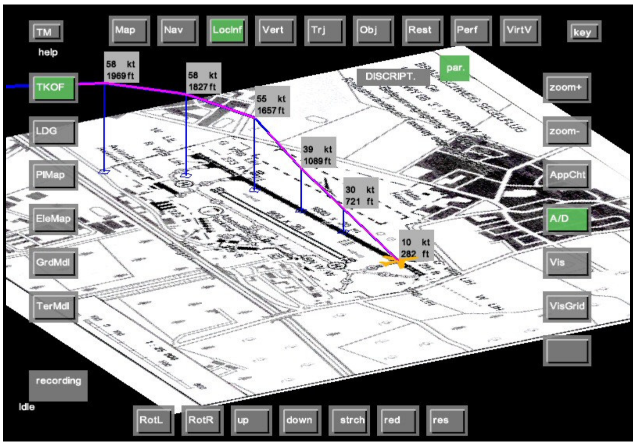

Fig. 7: Aerodrome chart of the Braunschweig airport with an embedded departure route and a description of each waypoint concerning altitude and speed constraints.

4. Flight Execution

The delegation of the complete flying task to the assistant is one objective of PAVE. The assistant guides the helicopter along a preplanned trajectory by switching autopilot modes. The Institute of Flight Systems is developing a model following control system with full authority for the FHS. The assistant enables an autonomous flight mode and provides adaptive flight control laws to improve handling qualities in degraded visual conditions for the manual flight mode. The FHS system also consists of a ground based system simulator. The simulation reproduces the flight characteristics of the EC 135, and the simulator experimental hardware is made as an exact copy of the FHS flying hardware. This ground simulator is the test platform for the intensive analysis of the complete functional range of the pilot assistant before going into real flight tests.

In order to compute the guidance parameters both for the automatic and for the manual flight mode, a comparison must sequentially be done between the current variables of state of the helicopter (position, orientation, speed, …) and the planned trajectory. The pilot assistant receives new variables of state at 30 Hz which are transmitted over a UDP connection. These parameters are written into the shared memory by the communication module.

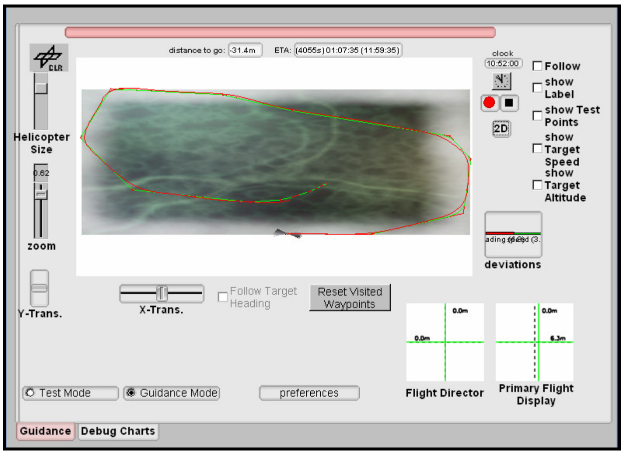

Fig. 8: Display of the guidance module which generates guidance parameter for both manual and automatic mode

The guidance module (figure 8) reads the data out of the shared memory and calculates the guidance parameters on the basis of the new data. The result is sent back to both the primary flight display for the guidance in manual flight mode and the autopilot for the automatic flight guidance. Due to safety aspects, the pilot can change at any time from automatic mode into the manual flight mode by direct intervention of his flight stick.

In co-operation with experienced helicopter pilots the display of the standard primary flight display was extended and optimized with flight director functions to present the necessary guidance parameters for following along the planned trajectory by green triangles. In manual flight mode the pilot has to follow these values constantly to remain on the flight path (figure 9). Deviations regarding speed, altitude, or heading are fast recognized by him if the green triangles move out of the range of the current variables of state.

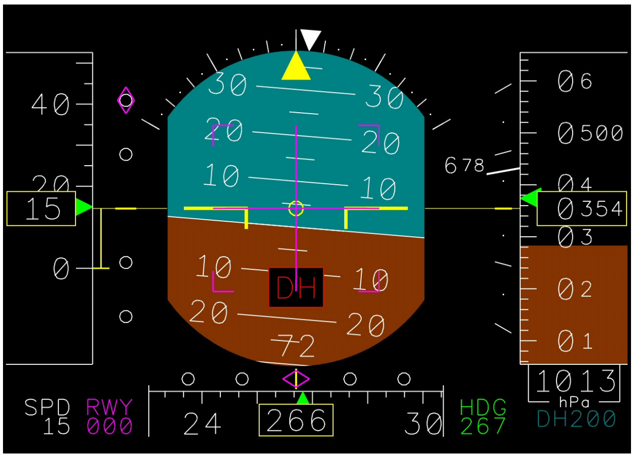

Fig. 9: Standard primary flight display (PFD) extended by green triangles for the display of guidance parameters, e.g. speed (left), heading (down) and altitude (right).

In figure 10 a combination of PFD, guidance parameters, and trajectory in plan view is displayed. With this kind of presentation the pilot can get an impression about the future process of the flight path and lateral deviations can be recognized directly.

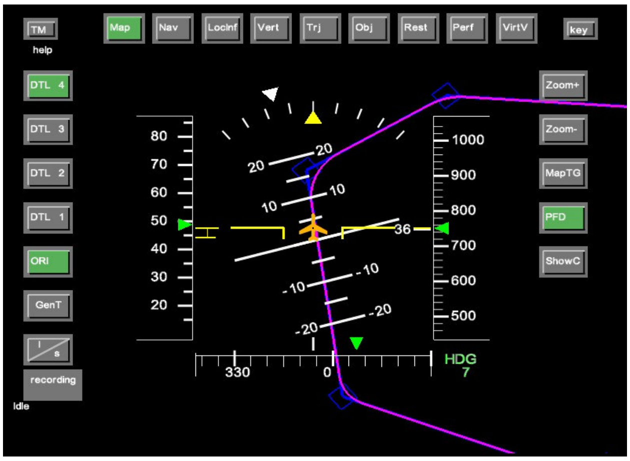

Fig. 10: Simplified PFD with additional announcement of the planned trajectory in plan view.

In the context of several simulation campaigns the different autopilot modes have been successfully tested in the ground simulator.

A flight path in terms of an aerodrome circuit has been defined to analyse both the flight path performance and the flight technical error especially for curves.

Figure 12 shows the result of both recorded tracks: the planned trajectory and the actual flight path. The curve deviations depend on the speed, the radius of the curve, and the kind of realisation of the guidance algorithm: A so called prediction length factor (PLF) multiplied by the current speed of the helicopter defines the length of a heading vector. From the current position of the helicopter the algorithm then finds a new position on the trajectory which is as far distant as the length of the heading vector computed before. The angle between this heading vector and geographically north is the new guidance parameter according to the heading. Under disregard of wind influences the

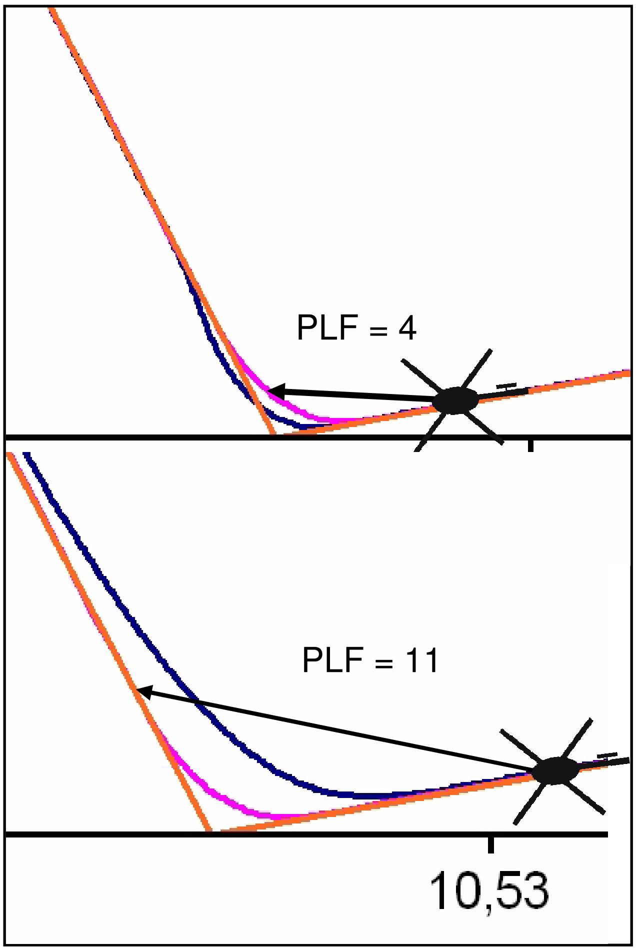

Fig. 11: The influences of different prediction length factors (PLF) on the flight technical error.

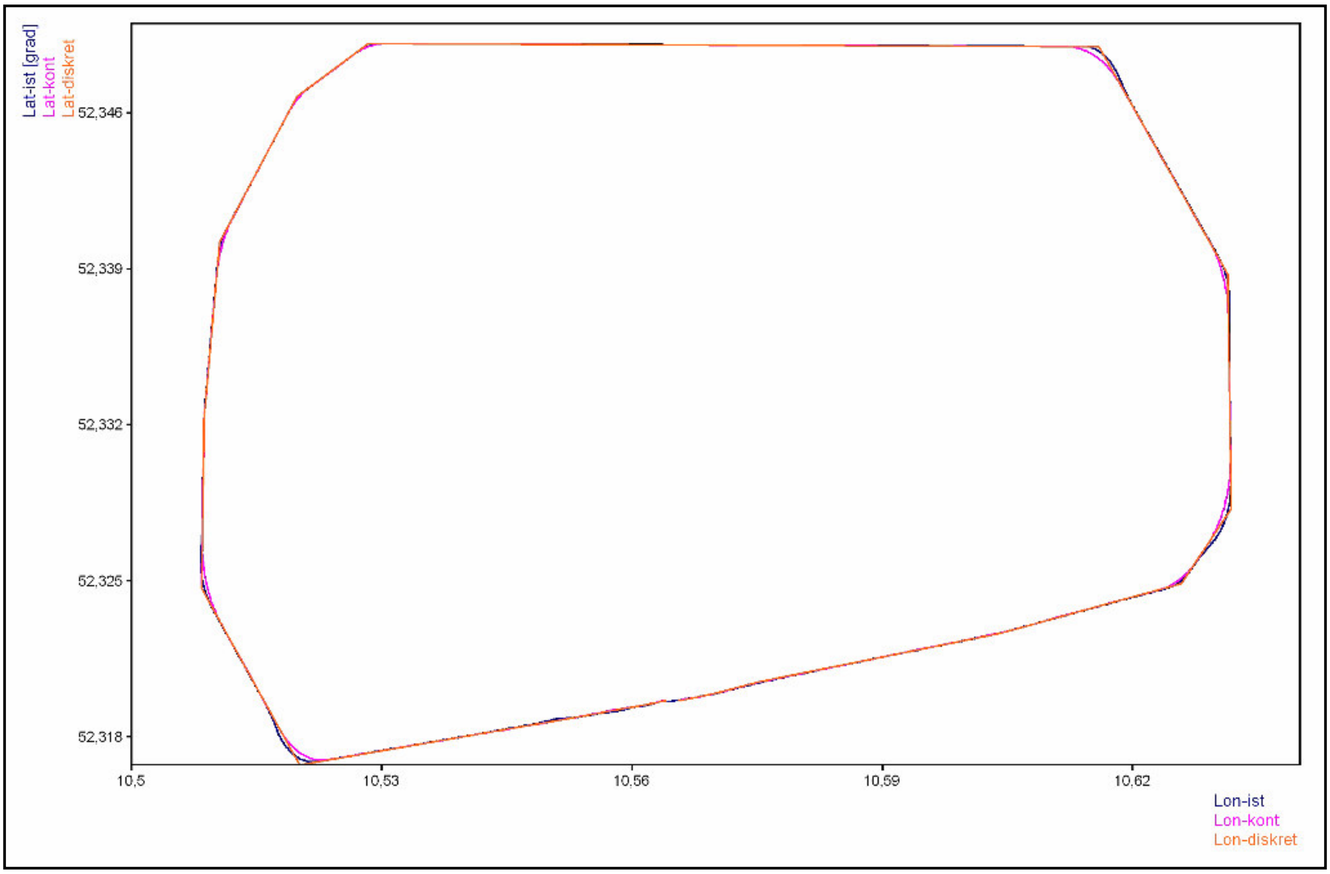

Fig. 12: Comparison between real flight path (blue) and planned trajectory (magenta) in automatic flight guidance mode flown in the ground based system simulator.

Fig. 13: As addition to fig. 12 a comparison between the variables of state (altitude, speed and heading) and the calculated guidance parameters. The last two charts represent the corresponding pitch and roll values.

helicopter should normally follow the trajectory if it flew into this direction. Curves represent a special role (figure 11): If the value of the PLF is too small (e.g. PLF = 4), the real flight path (blue) of the helicopter overshoots the planned trajectory (magenta). Otherwise, if the value is too high (e.g. PLF = 11), the real flight path cuts the curve. Figure 13 shows the comparison between the variables of state and the guidance parameters. After the system is in steady state, only very short delay times can be observed between the computation of the reference and the actual value. Especially for curves it is still investigated how to optimize this method under consideration of the latency time of the flight controller in order to get a smaller flight technical error.

In addition to the computation of the guidance command concerning the heading, the guidance module computes also the guidance parameters regarding altitude and speed. The algorithm computes the nearest intersection point between the planned trajectory and the perpendicular which intersects the current helicopter position. The altitude and speed values then are calculated by linear interpolation between supporting points of both the speed and the altitude profile.

5. Summary and Outlook

PAVE is a project for the development of a prototype of a helicopter pilot assistant system in which numerous experts in different areas are involved. The pallet extends from flight control, acoustics, aerial photograph processing, and human factors up to data processing and structure of hardware and integration. 4 institutes of the DLR and the French research establishment ONERA are involved in this project. A substantial part of the development and pre-working was accomplished, so that the system can now be tested and improved with the help of pilots. First flight tests take place in 2006 on the FHS in the environment of Braunschweig. The validation of the automatic flight guidance with the use of noise abatement procedures is one of the objectives in the context of the flight campaign.

In the European Union project OPTIMAL, the helicopter pilot assistant will also be used to accomplish time-exact approaches and will be extended functionally in this year. One of the objectives in OPTIMAL is an investigation how helicopters can be merged into the airport traffic management in the future.

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