The Crew Assistant Military Aircraft (CAMA)

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1. SUMMARY

Clumsy automation is considered to be a major reason for deficiencies concerning the interaction between cockpit crew and aircraft systems. Cockpit assistant systems are being developed in support of human-centered automation.
In this paper a general survey on the principals of cockpit assistance will be given. Demands and requirements for an appropriate automation and a functional structure of an knowledge-based assistant system will be introduced, leading to the knowledge-based assistant system CAMA (*Crew Assistant Military Aircraft*) which is presented. The realization of CAMA and its functional units – the modules – are described.

2. INTRODUCTION

In future combat transport aircraft, constraints created by low level flying in a high risk theater, the high rate of change of information and short reaction times required will produce physiological and cognitive problems for pilots. From the cognitive point of view, low level flying over rapidly changing terrain elevation coupled with complex and dynamic tactical environment will result primarily in difficulties to maintain situation awareness. It still seems impossible to ensure the pilot's situation awareness as the dominating requirement for high level mission performance and safety.
The central idea of a crew assistant is, to ensure that the crew will have all necessary and useful information and is acting under normal load condition, according to human-centered automation [1]. Design criteria, which aim at a cooperative function distribution between man and machine like that of two partners [2] have to be established.
Both man and machine are active in parallel by assessing the situation and looking for conflict solutions at the same time. In contrast with current man-machine interaction, both assist each other while heading for the same goals. Consequently Billings [1] demands: „Each element of the system must have knowledge of the others' intent. Cross monitoring (of machine by human, of human by machine and ultimately of human by human) can only be effective if the agent monitoring understands what the monitored agent is trying to accomplish, and in some cases, why.“ Hence, the level of understanding what each element of the system is doing should be as high as possible.
Therefore, Onken [3, 4] demands, that knowledge-based aiding systems should comply with two basic requirements:
(1) "Within the presentation of the full picture of the flight situation it must be ensured that the attention of the cockpit crew is guided towards the objectively most urgent task or sub-task of that situation."
(2) "If basic requirement (1) is met, and if there still comes up a situation with overcharge of the cockpit crew (in planning and execution), then this situation has to be transfered – by use of technical means – into a situation which can be handled by the crew in a normal manner."

Basic requirement (1) is to ensure situation awareness of the crew. In part, it can be transferred into the functional requirement for the assistant system as of being capable to assess the situation on its own.
Pilot's workload has become a critical issue as the mission complexity has grown. It is particularly desirable to reduce the need to compose the relevant information from numerous separately displayed data. The ability of the assistant system to detect conflicts, to initiate and to carry out on its own the conflict-solving process and to recommend and explain this solution to the pilot, gives the pilot sufficient time to cope with unanticipated events.
This appears to be a situation-dependent, flexible and cooperative share in situation assessment and conflict resolution between the electronic and the human crew member.
Automation, like recommended in the past, seems to be very attractive but it has to be handled with care not to find the pilot out of the loop of conducting the mission and flying the airplane (check „automate“ and come back in „manual“ if necessary). Automation as demanded in requirement (2) without the prerequisite of requirement (1) changes the pilot's task into automate management, merely monitoring automatic systems. Increasing workload of the crew should lead to an anticipating of future mission phases and to tasks-execution from that part of the man-machine system, that covers the more comprehensive and accurate situation comprehension for the actual task [4].

These design-criteria and requirements lead to a functional layout of a knowledge-based assistant system (KAS), which is illustrated in Figure 1.

For a comprehensive understanding of the situation, the process of *situation analysis* starts with the perception of features. More abstract objects are derived from these features and assembled to an overall situation description. This closely resembles the human way of situation analysis. On that bases the *situation diagnosis* process recognizes and predicts conflicts from observable indicators, caused by events in the domain of either aircraft, pilot or environment.

Alternatives for goals, plans, tasks and actions are generated including that one, which represents the given flightplan, and all are checked with respect to potential harmful conflicts. If conflicts are detected, only the conflict-free alternatives are passed to the conflict solver. The conflict solving process is ranking theses alternatives and selects the most favored alternative on the basis of the mission success criteria.

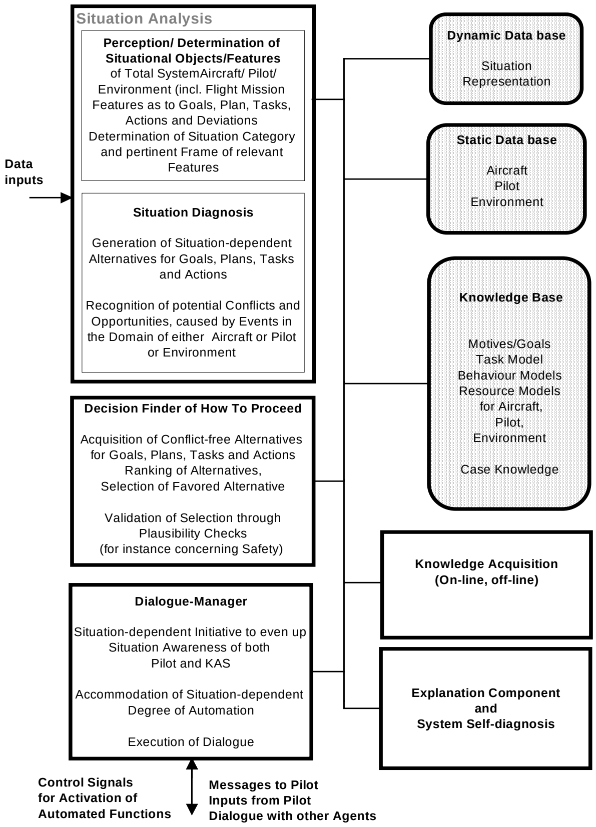

Figure 1: Functional Structure of a KAS

Dialogue management insures effective communication with the crew. This, the front-end of an assistant system is to present all necessary and useful information in a way, that is easy to comprehend. Messages to the cockpit crew should be tuned and tailored to the current situation, especially with respect to the resources of the crew. Inputs to the system should allow initialization of services and decision support without tedious or distracting input actions.

Knowledge processing needs a *dynamic object-orientated representation* of the situation-describing objects. The representation covers sensor data as well as very abstract objects like a whole flight plan or for instance the recognized intent of the crew.

Other *knowledge bases* are needed to express and enable access to domain knowledge and to permit inferencing. Models about motives and goals, task selection, execution knowledge and demand for resources as well as behavior models are important examples of this kind of knowledge, executed by additional information about the crew member.

Static data bases for navigation purposes or threat data bases can already be considered as standard.

The expert knowledge embodied in the system has to be obtained in a systematic way.

Knowledge acquisition appears as the bottle neck during development of the knowledge-based assistant system. Well-defined and efficient algorithms and methods have to be used to cope with the ill-structured and uncertain real world.

In order to increase user acceptance, it is desirable that the system contains a justification or *explanation component*. First of all the user should be conscious of the rules that are applied in the algorithm to obtain a solution or system state to gain confidence to the system.

System *self-diagnosis* makes sure that the hints and services to the crew will be really useful. The system must be able to realize, if information concerning the actual situation might be insufficient to assist the crew, or that the system itself is not working all right and needs to be corrected.

3. CAMA - CREW ASSISTANT MILITARY AIRCRAFT

3.1 Overview

CAMA (*Crew Assistant Military Aircraft*) is a knowledge based cockpit-assistant-system for military transport aircraft. It is being developed and tested in close cooperation between the DASA (Daimler-Benz Aerospace AG), DLR (German Aerospace Research Establishment), ESG (Elektronik- und Logistiksysteme GmbH) and the University of the German Armed Forces, Munich. The main challenge of the tactical transport mission are the complexity and dynamic of the tactical situation, the problems yielded by the necessity for a low altitude flight in compliance with a minimal risk routing, terrain collision avoidance, etc., management of fuel and time constraints, e.g. TOT (time over target), and the missing or insufficient establishments of approach aids. CAMA is designed under regard to the requirements, introduced in chapter 1. The realization of the crew assistant will be described in the following chapters.

3.2 System Architecture

The system is divided in several functional units, the modules (Figure 2). Each module is responsible for specific tasks. Communication between them is realized via the *centralized situation representation* (CSR). The CSR manages and provides static data and situational information, processed by the modules.

3.3 Situation Interpretation

3.3.1 Environment Interpreter

The *environment interpreter* (EI) evaluates the situation concerning weather, navigational aids, air-traffic and flying objects (e.g. SAM). When certain weather events like thunderstorms or clear air turbulences have occured,

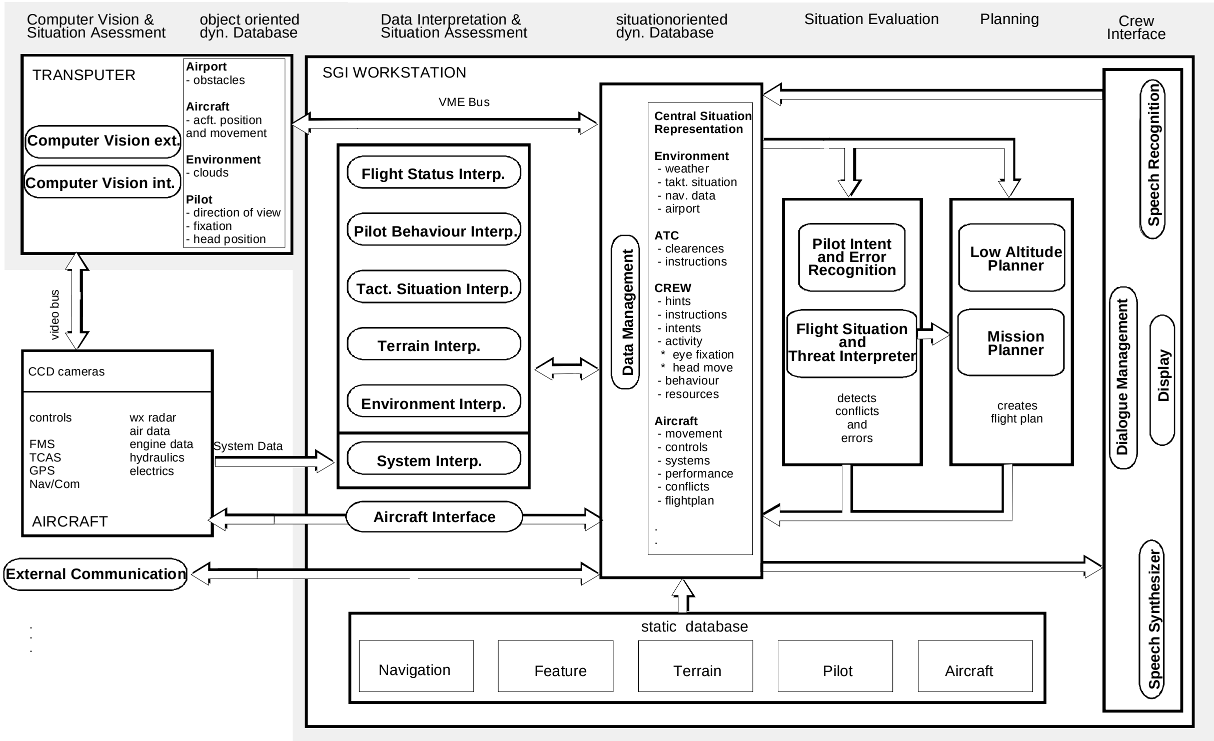

Figure 2. Structure of the Crew Assistant Military Aircraft (CAMA)

it is used as data source for the module *flight situation and threat interpreter* and the module *mission planner*.

3.3.2 Terrain Interpreter

Basing upon the present position and course, the *terrain interpreter* (TI) predicts the trajectory of the aircraft, generates a hyperplane of possible flight trajectories achievable by full exploitation of the aircraft's performance capabilities. Evaluation against a digital terrain elevation map – basing on digital terrain elevation data (DTED) – detects potential terrain conflicts in front of the aircraft. A recommendation for an effective evasis manoeuver will be given.

3.3.3 System Interpreter

The *system interpreter* (SI) [5, 6] monitors the aircraft's subsystems (main system, primary flight system, navigation systems, etc.). Any detected malfunction is evaluated by an on board diagnostic to determine it's reason.

3.3.4 Computer Vision External

The module *computer vision external* (CVE) [7] serves for two purposes. The primary job is to support a ILS/MLS like approach even on unequippted airfields. Additionally it detects conflicts concerning obstacles on the runway. Multiple sensor data, like gyros, accelerators, GPS, etc. are used for aircraft state estimation. Additionally a camera-system is used to determine the relative position to the runway.

3.3.5 Computer Vision Internal

The module *computer vision internal* (CVI) provides information concerning pilot's point of gaze. These are evaluated by a camera in the cockpit's front-panel, to the pilot's opposite. The information, for instance the moving line of sight to a control surface or to a special indicator, could be used to confirm the need for a warning or a hint. Especially with regard to an additional *resource model* that will make modeling the crew more complete, information of eye fixations is essential.

3.3.6 Tactical Situation Interpreter

The *tactical situation interpreter's* (TSI) main contribution is the computation of a threat map [8]. The calculation is based upon digital terrain elevation data (DTED) and the threat's models. Particular objects from a given list of tactical elements are regarded as threats such as surface-to-air missiles (SAM) or radar sites. A threat model contains the parameters

- maximum range,
- operationability,
- efficiency along range and
- respective models for threat area overlapping.

Figure 3 shows the principle steps of the algorithm for the threat value calculation.

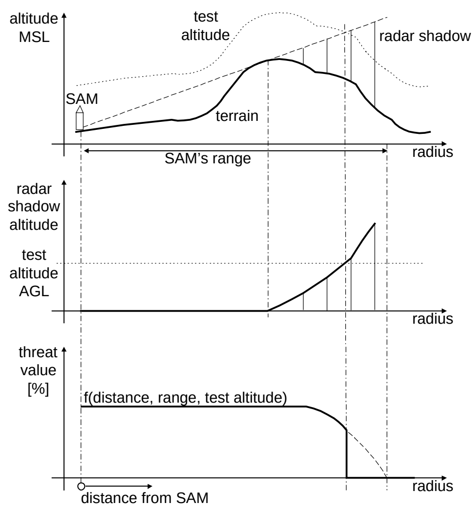

Figure 3: Threat Map Calculation

Due to the characteristics of the threat's radar systems and respective radar shadows resulting from the terrain structure, the altitude above ground up to which an aircraft is not detectable by the hostile radar beams can be derived from the DTED database. Given a certain test altitude a threat value of zero can be assumed below these radar beams. Above the threat value is calculated as a function of the individual model parameter. The threat values are calculated for ten discrete altitudes above ground level (test altitudes every 50 meters in the z-axis) and for each terrain elevation grid point (longitude/latitude coordinates). Area overlapping of threats is taken into consideration by probability calculus.

3.4 Pilot Behavior Interpretation

3.4.1 Piloting Expert

The *piloting expert* (PE) is constructed as a model of pilot crew and covers normative and individual crew behavior. On the basis of this knowledge, expected pilot actions are determined, considering flight plan, local ATC instructions, aircraft and environmental constraints.

Normative Pilot Behavior

The *normative model* [9] describes deterministic pilot behavior as documented in pilot handbooks and air traffic regulations. Modeling is done primarily within the domain of rule-based behavior, but covers admissible tolerances also. Pilot behavior can be separated into situation assessment and action processing components. Modeling is done for all flight segments (taxi, takeoff, departure, IFR-cruise, tactical flight, drop, approach, landing) and concerns the following tasks:

a) situation assessment
- recognition of actual flight segment
- recognition of process of plan execution related to flight plan procedures

b) pilot actions / performance
- primary flight guidance (altitude, course, airspeed, power setting, climb/descent rate, pitch attitude)
- drop procedure
- operation of flaps, gear speed brakes
- opeartion of ramp
- radio navigation
- communication with ATC and C&C

Petri nets were chosen as most suitable for knowledge representation purposes.

Individual Pilot Behavior

The *normative model* is being enhanced by providing information on the individual parameters. Fundamental for an adaptive model [10] is the assumption that normative regulations and procedures are still the guidelines, even when they are amended and adapted by the individual pilot.

Normative statements derived from the petri net model are customized in order to achieve a description of individual behavior by

1. varying the transition parameters of the petri net (on-line)
2. varying the structure within a petri net (off-line)

3.4.2 Pilot Intent and Error Recognition

The module *pilot intent and error recognition* (PIER) monitors pilot's activities and mission events in order to interpret and understand the pilot's actions [11]. Expected crew actions are compared with the actual behavior shown by the crew (Figure 4). If discrepancies will be detected the module PIER tries to figure out, weather the deviation was caused erroneously or intentionally. Detected errors are issued to *flight situation and threat interpreter*. Error detection will help the pilot to correct slips and to optimize his situation awareness during committing a mistake by focusing his attention on most important or critical events.

By monitoring pilot actions as well as the mission context, the system is able to compare the pilot's action to a set of behavior hypotheses. In case of an intentional deviation from the flight plan, the module checks, if the behavior fits to the given set of intent hypotheses.

These hypotheses represent behavior patterns of pilots, for example, when commencing a missed approach or avoid a thunderstorm. With the intention recognized, support like re-planning is initiated, and the overall loop could be closed without further inputs of the pilot.

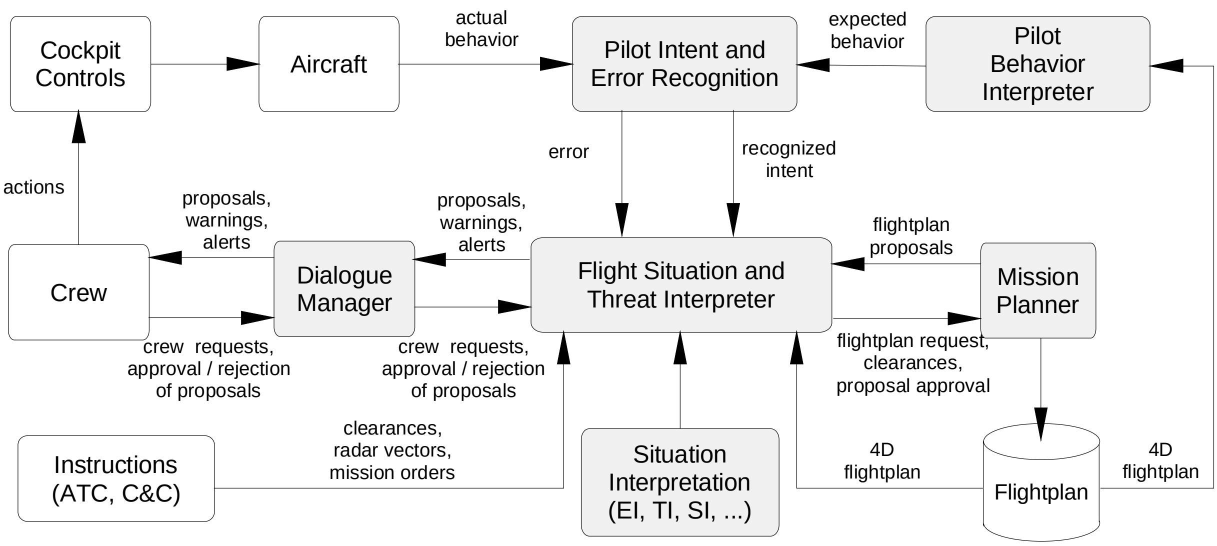

Figure 4: Pilot Behavior Interpretation and Flight Situation and Threat Interpretation

3.5 Flight Situation and Threat Interpretation

The module *flight situation and threat interpreter* (FTI) represents the central module of the assistant. It deals with the situation assessment and conflict resolution. The process of *situation diagnostic* and the *decision finding of how to proceed* – recall Figure 1 – are the primarily jobs of the FTI. Situational objects, provided by preceding modules (e.g. EI, TI, SI, etc.), are further processed. The complete image of the situation is evaluated against

- goals,
- plans and
- pilot activities.

Mission dependent goals are derived from the mission order. The mission order comprises instructions and constraints, which are to be kept (e.g. entrance-corridors to gaming area, drop-point, TOT, etc.). Taking into consideration the mission order, the FTI initiates the module *mission planner* (Figure 4) to generate a complete, conflict-free flightplan. If the mission order leads the aircraft into a threatened area, the low altitude flight planner is started additionally for the calculation of a low altitude flightplan as well as a trajectory. FTI controls the planning parameters. They are provided to the planning modules and comprise origin and destination, corridors to be planned through, civil and tactical waypoints as well as detailed drop procedures. Crew constraints, e.g. personal route preferences are included as well. Generated routes are proposed to the cockpit crew, and are accepted, modified or refused respectively.

Misleading crew intents and errors, recognized by the module PIER are monitored and crew warnings will be initiated. Intentionally, conflict-free deviations are incorporated in the actual flightplan.

Monitoring of the flightplan and evaluation against the situation is done permanently. Conflicts within the planned route, e.g. new threats within the operation area or corridors, weather deterioration en-route or at destination, etc., will be recognized and suitable resolutions are started.

3.6 Mission Planning

3.6.1 Mission Planner

The module *mission planner* creates and maintains a 'take off'-to-landing mission flight plan, including routes, profiles, time- and fuel-planning based on knowledge about the mission plan, gaming area, destination, ATC instruction, aircraft status, environmental data, etc. [12]. External data sources (C^3, weather, results from reconnaissance, etc.) are incorporated into the plan. Events like failures of aircraft systems (navigational equipment, engines, etc.) weather changes and ATC or C&C instruction are taken into consideration. The mission planer covers the flight under instrument flight rules (IFR) as well as time management. Especially with regard to a TOT (time over target), fuel calculations and routes/profiles calculations the mission planner will assist the crew. The calculated route is presented as proposal to be accepted or modified. The 4D trajectory serves as knowledge source for other function blocks.

3.6.2 Low Altitude Flight Planner

The aim of the module *low-altitude flight planner* (LAP) [13] is the calculation of a 3D route between the given planning constraints – controlled by the FTI – with a maximum probability of survival in a hostile environment. This is achieved by avoiding threatened areas if possible, minimizing the exposure to unknown threats and keeping clear of the terrain. Therefore, the planning constraints, the tactical elements and the resulting threat map, the terrain elevation data and the aircraft performance data are taken into consideration. The system consists out of three functional sub-modules:

Danger Analysis

The *danger analysis* incorporates the threat map calculation as described in chapter 3.3.6. Additionally, the visibility at each point is calculated without assuming any particular threats. The algorithm issues lower danger values on the side of valleys than in the center. Finally, the danger analysis utilizes the calculation of a ground collision probability, which is particularly high in rough terrain. This feature leads to generally higher flight altitudes in the absence of threats. An overall danger value is calculated for each terrain grid point.

Moding and Control

The *moding* and *control* checks the flight status and assembles the target point and the planning area for the *optimization* according to the mission constraints. The optimization provides an array of optimal directions to the target point. As long as a re-planning does not imply a new target point another optimization run is not required.

Path Selection

The *path selection* depends on the current planning mode (initial planning or re-planning). It constructs a terrain grid based flight path from a given start point, respectively present aircraft position to the target point. The *output assembly* functions *trajectory synthesis* and *plan analysis* form the *low-altitude flight planner* output.

In order to be monitored by a pilot model based assistant system, the representation of the detailed trajectory has to be reduced to a waypoint based low altitude flight plan, which represents the general considerations to be followed in the human planning of low level missions.

Additionally, the low-level flight plan is given by a detailed trajectory representation.

3.7 Crew-Interface

Communication between CAMA and crew plays an important role. The kind of information to be transmitted in either direction varies with respect to the different modules. The information flow from the machine to the crew and vice versa is controlled exclusively by the module *dialogue manager* (DM) [14]. The many different kinds of messages require a processing in order to use an appropriate display device and to present the message at the right time. The module *dialogue manager* ranks the output messages and the most important message is issued first. As output devices both, a graphic/alphanumeric color display and a speech synthesizer are used.

More complex information, e.g. the current flight plan, are depicted on a horizontal situation display. The horizontal situation display is an interactive touch-sensitive map display organized in a number of layers which allows the crew to select optional map-presentations in any combination. It allows to depict tactical and threat information as well as a variety of navigational elements and a topographical map similar to the currently used low flying chart paper-maps. A second display contains the alpha-numeric flight-log and is used

for in-flight departure-, approach- or missed-approach-briefings.
Commencing the approach to the destination airport, the pilot will be assisted with a combined linguistic and graphical briefing, describing the characteristics and any dangers associated with the approach.
Brief warnings and hints are used to make the crew aware of a necessary and expected action and are transmitted verbally using the speech synthesizer [15].
The input information flow is established by use of speech recognition in addition to conventional input mechanisms. Intuitive direct *voice input* relieves the pilot of a lengthy and tedious alpha-numerical input task. Voice control seems to be the best solution to deal with mass data. The total on-board vocabulary will be very large and is broken down into sub-sets according to context. In order to improve speech recognition performance, almost the complete knowledge of CAMA is used for contextual decoding to provide situation dependent syntaxes. Thus, the complexity of the overall language model is reduced significantly such that the system can achieve high recognition rates.
The use of speech input and output devices also reflect the idea of human-centered development with respect to effective communication.

4. Conclusion

The knowledge-based system CAMA improves the crew's situation awareness. Comprehensive situation assessment by the machine in parallel to the crew's situation assessment is realized with subject to a human-centered automation. Monitoring, planning and decision aiding functions provide a safe and successful mission and improve the mission effectioness.
The actual integration phase of CAMA will end in June 1998 with a man-in-the-loop full mission simulation campaign. After these simulator tests CAMA will be integrated in the experimental cockpit of the ATTAS test aircraft of the German Aerospace Research Establishment (DLR) and will be demonstrated in flight experiments which are scheduled for early 1999.

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