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Assistant systems for aircraft guidance: cognitive man-machine cooperation

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Abstract

This paper presents the concept of cognitive assistant systems which represents an approach to ensure the highest degree possible of situation awareness of the flight crew as well as a satisfactory workload level. This concept offers the solution to counteract susceptibility to pilot errors typical of lack of attention or other cognitive limitations. It is founded on cognitive system engineering. This technology enables a cockpit design in order to systematically comply with the requirements of 'Human-Centred Automation (HCA)'. The underlying approach behind the concept has become real with the development of the cockpit assistant system prototype family CASSY/CAMA as described in this paper. CASSY/CAMA has been extensively tested in a flight simulator and successfully field tested with the ATTAS (Advanced Technologies Testing Aircraft System) of the DLR. Some of the test results with CAMA will be presented in this paper. © 2001 Éditions scientifiques et médicales Elsevier SAS

cognitive assistant system / cognitive engineering / cockpit systems / automation / flight safety / cooperative man-machine systems

Zusammenfassung

Assistenzsysteme für die Flugzeugführung – kognitive Mensch-Maschine Kooperation. Dieser Beitrag stellt das Konzept kognitiver Assistenzsysteme dar, das einen Ansatz dafür repräsentiert, wie ein höchstmöglicher Grad an Situationsbewußtsein der Pilotenbesatzung ohne Überbeanspruchung bei der Missionsdurchführung zu erreichen ist. Dieses Konzept bietet eine Lösung, der Anfälligkeit des Menschen, und damit auch des Piloten, zu begegnen, aufgrund von begrenztem Aufmerksamkeitsvermögen und anderen Grenzen kognitiver Fähigkeiten fehlerhaft zu handeln. Es basiert darauf, daß es mittlerweile technologisch möglich ist, kognitive Systeme technisch zu realisieren und somit Cockpitsysteme auslegen zu können, die den Forderungen der "Human-centred Automation (HCA)" entsprechen. Dieser Ansatz wurde mit der Entwicklung der Prototypen CASSY/CAMA in die Realität umgesetzt. CASSY/CAMA wurden umfassend im Flugsimulator getestet und mit dem ATTAS (Advanced Technologies Testing Aircraft System) des DLR erfolgreich im Fluge erprobt. Einige der Erprobungsergebnisse werden dargestellt.© 2001 Éditions scientifiques et médicales Elsevier SAS

Kognitives Assistenzsystem / Kognitive Systeme / Cockpitsysteme / Automation / Flugsicherheit / Kooperative Mensch-Maschine Systeme

1. Introduction

Advances in electronics and computer technology have a profound effect on modern aircraft and aviation as such. Computer controlled avionics and electronic displays have become common features on the flight deck. Powerful computer technology is involved in signal and information processing to generate information packages for the aircrew and furnish display formats and to transmit signals to and from control devices and avionics

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components. Another quantum leap of cockpit system functionality, along with additional aircrew responsibility, will occur when CNS/ATM (Communication, Navigation and Surveillance/Air Traftic Management), as expected for the near future, will allow for Area Navigation and 'Free Flight'.

However, it is not sufficient to just computerize the crew station the way it is done today. To let crew station developments keep pace with developments in CNS/ATM, is not just a matter of introducing new communication links, bringing more information about navigational data and traffic along with automated information processing into the cockpit. More than ever before, cooperative interaction between the human cockpit team and the systems the team has to deal with is becoming the crucial factor. The aircrew has to interact with the cockpit systems in a similar cooperative way as humans interact among each other.

How can this be accomplished? First of all, principal design requirements have to be established to take the cooperative approach into account. These can be stated like those by [10], where the basic requirement (1) below is addressing the system performance needed to most effectively ensure pilot situation awareness:

(1) it must be ensured the representation of the full picture of the flight situation, including that the attention of the cockpit crew is guided towards the objectively most urgent task or sub-task as demanded in that situation;

and basic requirement (2) is formulated to avoid pilot overcharge, in particular as to planning/decision making/plan execution tasks. It reads:

(2) a situation with overcharge of the cockpit crew might come up even when situation awareness has been achieved by the pilot crew. In this case, the assistant system has to transfer the situation into a normal one which can be handled by the crew in a normal manner.

These requirements, which are in line with human-centred automation, too, as defined by [2], can be met by the so-called 'cognitive' approach. 'Cognitive automation' is the way to further increase productivity through automation without loss of safety (see *figure 1*). Cognitive automation technology already has been used for some time, mostly, however, in application domains other than aviation. Therefore, one does not start from scratch, fortunately. These impressive achievements of cognitive engineering can be exploited for aviation as well.

2. The cognitive approach

The difference between cognitive and conventional automation can be illustrated by Rasmussen's scheme of human cognitive behaviour (see *figure 2*) which became widely known in the 1980s [14]. As shown in this figure, conventional automation covers only about half of the functional elements which are part of human cognition. In particular, the formation of a comprehensive picture of the situation, which takes all three behavioural levels (feature formation, recognition, identification), is very sparsely covered by conventionally automated systems [12]. Therefore, it is not surprising that conventional automation is virtually not enough to support pilots regarding situation awareness, as required in the aforementioned basic requirement (1).

Therefore, in parallel to new developments in cockpit automation, such as CNS etc., which go along with increased functional complexity, new ways of automation other than conventional automation and in addition to conventional automation have to be introduced, i.e. to incorporate human-like cognitive capabilities into cockpit systems, enabling processing of abstract knowledge in order to:

– independently assess and keep ready necessary situation-relevant information about the goals the aircrew is pursuing, the relevant aircraft environment, aircraft systems and aircrew activities;
– understand the flight situation by independently interpreting the situation in the light of the goals;
– detect pilots' intents and possible errors;
– know which information the crew needs;
– support necessary re-planning and decision making; and
– initiate human-like communication to ensure that the pilot's situation awareness is evened up with what is detected as conflicts or opportunities by the

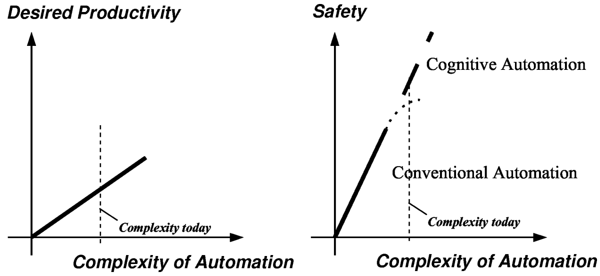

Figure 1. The effect of conventional and cognitive automation on desired productivity and safety.

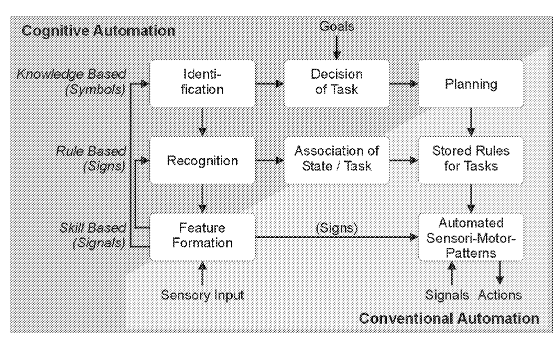

Figure 2. Conventional versus cognitive automation.

systems, not to leave the pilot alone with presentations which do not care about what the pilot has understood about the situation and what he actually perceives or does not perceive.

This is the change needed in the crew station which will provide really effective support for the sake of both mission effectiveness and safety. On the basis of these capabilities one can effectively and pointedly account for all at the same time:

– assisting the human pilot to let him play his peculiar excellencies most satisfactorily;
– compensating for the deplorable but indisputable fact that the human pilot is virtually not able to assure one hundred percent error-free behavior; and
– easing crew coordination by an electronic 'third crew member'.

2.1. The cognitive process

Rasmussen's scheme provides a good guideline to understand the human cognitive process. The cognitive process as a technical process, designed to assist the aircrew, should be based on Rasmussen's scheme, too, in general, in order to make sure that the core functional traits of human cognition are covered. The distinction between different behavioral levels are not principally necessary, though. It forms the recognition-act cycle and is also called the cognitive loop. The cognitive process as a technical process is illustrated in *figure 3*. It comprises six cognitive sub-processes:

– reception of the real-world stimuli;
– situation interpretation;
– situation diagnosis;
– planning and decision making;
– scheduling of the tasks to be performed; and
– the execution of the actions derived.

2.2. Cognitive sub-processes

A cognitive sub-process works on the sensory inputs and communication data as input data ('InputData'), on the other sub-processes' outputs as well as on background domain knowledge [11]. The cognitive sub-processes provide the following outputs:

- situation interpretation: relevant world-objects ('RelvObj');
- situation diagnosis: relevant goals and conflicts/ opportunities ('RelvGoals');
- planning and decision making: intents and plans ('IntentPlan'); and
- scheduling of tasks: actual tasks and actions ('Tasks') to be done.

The whole of these outputs and input data can be called the 'Cognitive Yield'. The cognitive yield is dynamic and forms the dynamic 'mental model' [9] of the situation, the representation of the so-called situation knowledge at a given time. The background knowledge is represented by 'static' mental models. It is the fundamental basis for the knowledge-based sub-process functions of situation interpretation and diagnosis, as well as for planning, decision making and task scheduling [4].

The cognitive sub-processes, as well as their interdependencies, are described formally [1,25] in the following. The entire cognitive yield $\boldsymbol{S}$ can be described by a set $\boldsymbol{E}$ with subsets $\mathbf{E}$ of situation knowledge elements $\boldsymbol{e}$ and a set $\boldsymbol{R}$ of relations as subsets $\mathbf{R}$ of relational elements $\boldsymbol{r}$ between situation knowledge subsets or elements:

$$\boldsymbol{S} = \{\boldsymbol{E}, \boldsymbol{R}\}.$$

It will be available at each computation cycle and represents the actual situation knowledge in terms of the union of the input data and all of sub-process outputs or

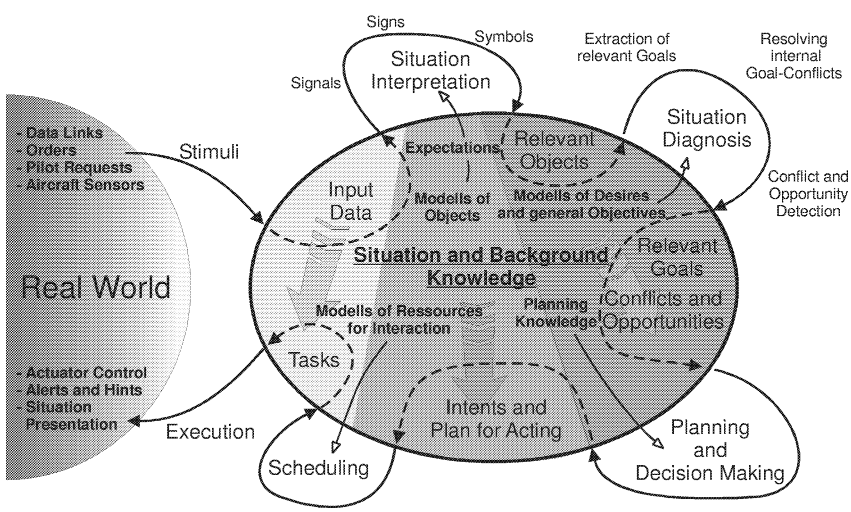

Figure 3. Cognitive process [24].

combinations of them. Often, this simply results in:

$$\boldsymbol{S} = \mathbf{S}_{\mathrm{InptData}} \cup \underbrace{\mathbf{S}_{\mathrm{RelvObj}} \cup \mathbf{S}_{\mathrm{RelvGoals}} \cup \mathbf{S}_{\mathrm{IntentPlan}} \cup \mathbf{S}_{\mathrm{Tasks}}}_{\substack{\text{Cognitive Yield derived within} \\ \text{Cognitive Sub-Processes}}},$$

disregarding the relations between situational elements of different cognitive sub-processes.

The classification of situations, as well as the comprehension of a situation, is based upon three criteria: content, structure and semantic. The 'match of content' takes into consideration solely the existence of the relevant situational knowledge elements, the 'match of structure and semantics' deals with the background knowledge pertinent to the relevant situation knowledge elements, the correct allocation of types of pertinent relations between situational knowledge elements and the proper semantic contents of these relations. Therefore,

$$\begin{array}{l} \quad \text{match of content} \\ + \text{ match of structure} \\ + \text{ match of semantics} \\ \hline = 100\,\%\text{ situation comprehension.} \end{array}$$

In more detail, the yield of the interpretation sub-process, $\mathbf{S}_{\mathrm{RelvObj}}$, can be described by the set $\mathbf{E}_{\mathrm{RelvObj}}$ with pertinent relations $\mathbf{R}_{\mathrm{RelvObj}}$ as part of $\mathbf{R}$. The set $\mathbf{E}_{\mathrm{RelvObj}}$ contains the set of all abstract or concrete world-objects of relevance. They will be described by a subset of features and a subset of properties.

The determination of $\mathbf{S}_{\mathrm{RelvGoals}}$ as part 1 of the sub-process 'situation diagnosis' is crucial for everything which follows in the cognitive process. Therefore, this sub-process is described now in some detail.

One of the most powerful capabilities of a cognitive system is its potential of knowledge-based behavior and its problem solving capability. Knowledge-based behavior is driven by process-intrinsic goals. They are part of the background knowledge resource. Therefore, a model of these goals is essential within such a system and is the basis for:

– situation comprehension, leading to situation awareness;
– cooperative behavior; and
– operator-centered explanation of the system's intentions.

Here, in general, a goal is represented by a frame, which comes with characteristics and capabilities of the following attributes and methods:

⇒ name of goal;
⇒ origin of goal;
⇒ relevance of goal;
⇒ weight;
⇒ inference knowledge;
⇒ characteristic hyperplane;
⇒ sub-goal reference;
⇒ sub-goal operator; and
⇒ goal approval (truth).

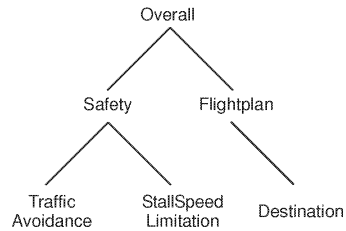

Figure 4. "Hierarchy of Goals" – tree representation (not complete).

The origin of a goal identifies whether the goal has its origin in the system itself or if it is issued by an external agency. The relevance of a goal depends on the match of actual $\mathbf{S}_{\mathrm{RelvObj}}$ with the set of all possible situation patterns $\mathbf{S}_{\mathrm{RelvObj}}$ complying with the goal. The goals are weighted for the purpose of prioritization of certain goals against others. Inference knowledge holds the expertise to evaluate a given situation with respect to conflicts and opportunities. This knowledge is used to approve a goal as conflict free, i.e. to check the complete picture $\mathbf{S}_{\mathrm{a}}$ of the actual situation against the characteristic hyperplane which delimits all goal-supporting situation patterns in the situation hyperspace. The approval of a goal depends on the approval of subordinated goals. References to these subgoals are covered within the goal frame. Goal operators provide the approvals for the subordinated goals. Situation diagnosis of an actual goal under consideration evaluates the goal approval (truth) and classifies a situation as conflicting or supportive.

Within the model introduced here, the overall goal situation is represented by two data structures:

– an overall characteristic hyperplane in the situation hyperspace representing the intersection of the goal-supporting situation patterns with respect to all relevant goals; and
– a goal tree structure, representing symbolically the hierarchy of all possible goals (see *figure 4*) and by use of it, in addition, representing the hierarchy of the relevant goals.

An intent is the decision to act for goal achievement. Intents are directly assigned to a goal and the structure of an intent is closely related to the goal's structure. Achieving a set of goals requires planning. Planning means to find a suitable set of tasks – broken down into a set of actions – which is capable of complying with the set of intents. The set of intents, the assigned sets of tasks and pertinent relations form $\mathbf{S}_{\mathrm{IntentPlan}}$.

In turn, the set of tasks, the assigned set of actions and pertinent relations form $\mathbf{S}_{\mathrm{Tasks}}$.

2.3. Knowledge acquisition

The acquisition of knowledge and its formal structuring and use within a knowledge-based system is a challenge the artificial intelligence as well as the cognitive psychology community has been facing for many years. The question is how to separate ‘data’ from ‘information’ and ‘information’ from ‘knowledge’.

Knowledge-sharing between pilot and a cognitive assistant system takes place on situational knowledge (via communication) and background knowledge (via off-line knowledge-acquisition).

Here, the knowledge acquisition task concerns the aviation domain, in particular, military air transport in the following example.

For knowledge elicitation, preliminary analysis of a military transport mission has identified four topics of relevance:

- operator related topics;
- mission related topics;
- vehicle related topics; and
- air traffic regulation related topics.

Military regulations and tactics are neither straightforward nor well documented and are more guidelines than regulations. Therefore, knowledge acquisition directly draws on the cockpit crew. Knowledge acquisition has been performed in close cooperation with the 1st Air-Lifter Wing 61, Landsberg. The elicitation of the general objectives, while performing the tactical flight sections, is performed by the semi-formal group-elicitation-method [3] (see *figure 5*) and takes into consideration the 3 phases of a tactical transport mission:

- transition into and out of the tactical area via a tactical corridor;
- low-level flight via a minimum-risk-route (MRR) to the target-approach-point (TAP); and
- drop preparation, release of the load as well as the recovering maneuvers.

The mission related topics are the goals originated by a higher command and control agency. These are the Air Traffic Control (ATC), coordinating solely the civil air traffic, and the Airborne Command and Control Center (ABCCC) of the Airborne Warning and Control System

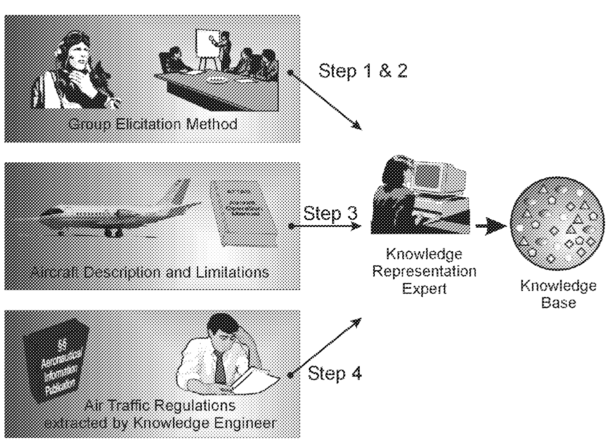

Figure 5. Knowledge acquisition process for a model of pilots’ general objectives.

(AWACS), responsible for the management of forces within the tactical areas.

The vehicle related topics are taking into consideration the goals responsible for the aircraft guidance tasks, such as:

- to aviate;
- to navigate;
- to communicate; and
- to manage systems.

Compared with tactical regulations, the ATC orders and instructions are based primarily upon air traffic regulations, which are straightforward and well documented. They are subdivided into:

- general rules;
- visual flight rules (VFR); and
- instrument flight rules (IFR).

This knowledge acquisition of the mission related and the air traffic related topics is directly based upon ‘aeronautic information publications’ and is performed by the knowledge engineer himself.

2.4. Model achitecture

The analysis of the cognitive process has led to a distributed system architecture (see *figure 6*). Each cognitive task is assigned to a functional unit, responsible for a proper execution of its assigned task. Multiple intelligent agent-based systems are supporting this design [25].

For a coordinated run of these task-units/agents, they have to consider the overall goal situation. The coordinated communication between the agents plays an important role [8]. The system introduced here uses ‘cooperation primitives’ which are derived from speech act theory [16]. The speech act theory is based upon the ‘cooperation types’ and ‘cooperation objects’. Here, the ‘cognitive components’ represent the ‘cooperation objects’.

The architecture of the model is based upon a Common Object Request Broker Architecture (CORBA). CORBA allows applications to communicate with each other no matter where they are located or who has designed them.

Core elements of the model are representations of the cognitive states of the knowledge-based level. CORBA servers provide the ‘mental models’:

- domain-knowledge-base (relations, attribute-, object- and goal-templates);
- maps of terrain and threat (interpreted);
- representation of environment (belief-server); and
- representation of objectives (desire-server).

CORBA clients are performing the cognitive tasks of:

- sensory and communication input;
- perception (interpretation of data and instantiation of relevant objects) and situation diagnosis (extraction of relevant goals and inference of goal approval).

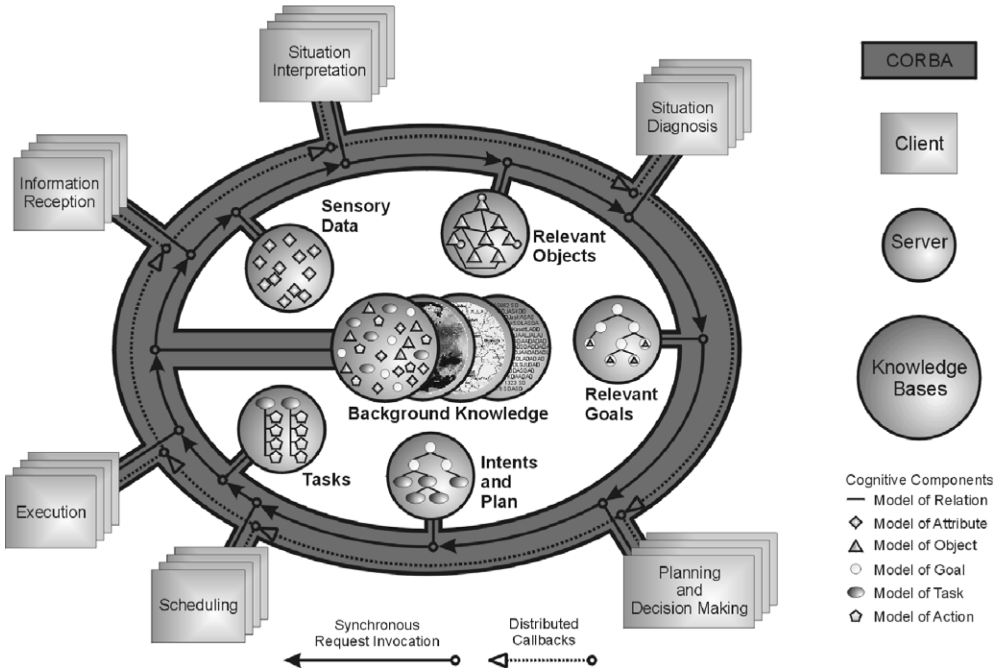

Figure 6. Model's architecture.

3. A prototype for a cognitive assistant system

Military transport aircraft fly low level missions under adverse weather conditions. The workload of the pilots can be very high due to these challenges and the variety of mission tasks. Additionally, the scenario changes at a high rate and a quick reaction is required at times. All this might cause both physical and cognitive problems for the crew.

This scenario represents working conditions on the flight deck where cognitive assistance could be particularly helpful. Therefore, the German MoD started a program, called CAMA (Crew Assistant Military Aircraft), in order to have demonstrated the power of cognitive automation in the aircraft cockpit. CAMA as a prototype cognitive assistant is based on the experience with CASSY (Cockpit ASsistant SYstem), which was developed earlier as a transport aircraft cockpit aid for flight under Instrument Flight Rules (IFR). CAMA works under extended operational conditions of military transport including flying under IFR. It has been developed by the University of German Armed Forces Munich in close cooperation with the DaimlerChrysler Aerospace, ESG (Elektronik System GmbH) and DLR (Deutsches Zentrum für Luft- und Raumfahrt).

CAMA is designed according to the aforementioned basic requirements for a cognitive assistant system [20, 23].

3.1. Core elements of CAMA

The functional structure of CAMA comprises several functional units, each supporting the execution of a specific task category as depicted in *figure 7*.

The functional units of CAMA reflect the functions of the cognitive loop as described above. As today's cockpits include a number of off-the-shelf components e.g. EGPWS, TCAS, the architectural structure of CAMA will allow for their easy integration, even if not all of them are part of CAMA in its present configuration.

The perception of all relevant situation elements of the real world inside and outside the cockpit, according to the situation monitoring as part of the cognitive system, is performed by the 'environment interpretation' as well as by the 'interpretation of the aircraft state'. Thereby, information concerning the actual weather, the proximity to the terrain and the technical environment is monitored. This comprises thunderstorms, areas of turbulence, atmospheric conditions e.g. wind, other airborne vehicles, and aircraft subsystems. Additionally, data from computer vision systems are included for autonomous recognition of relevant objects such as landing strips and obstacles, aiding landing under low visibility conditions on unequipped airfields. All these pieces of relevant information are put together to form the central situation representation that provides all data the other functional units of CAMA might need or might produce for further processing, such as the 'evaluation and the interpretation of the pilot's actions and resources'. This core element

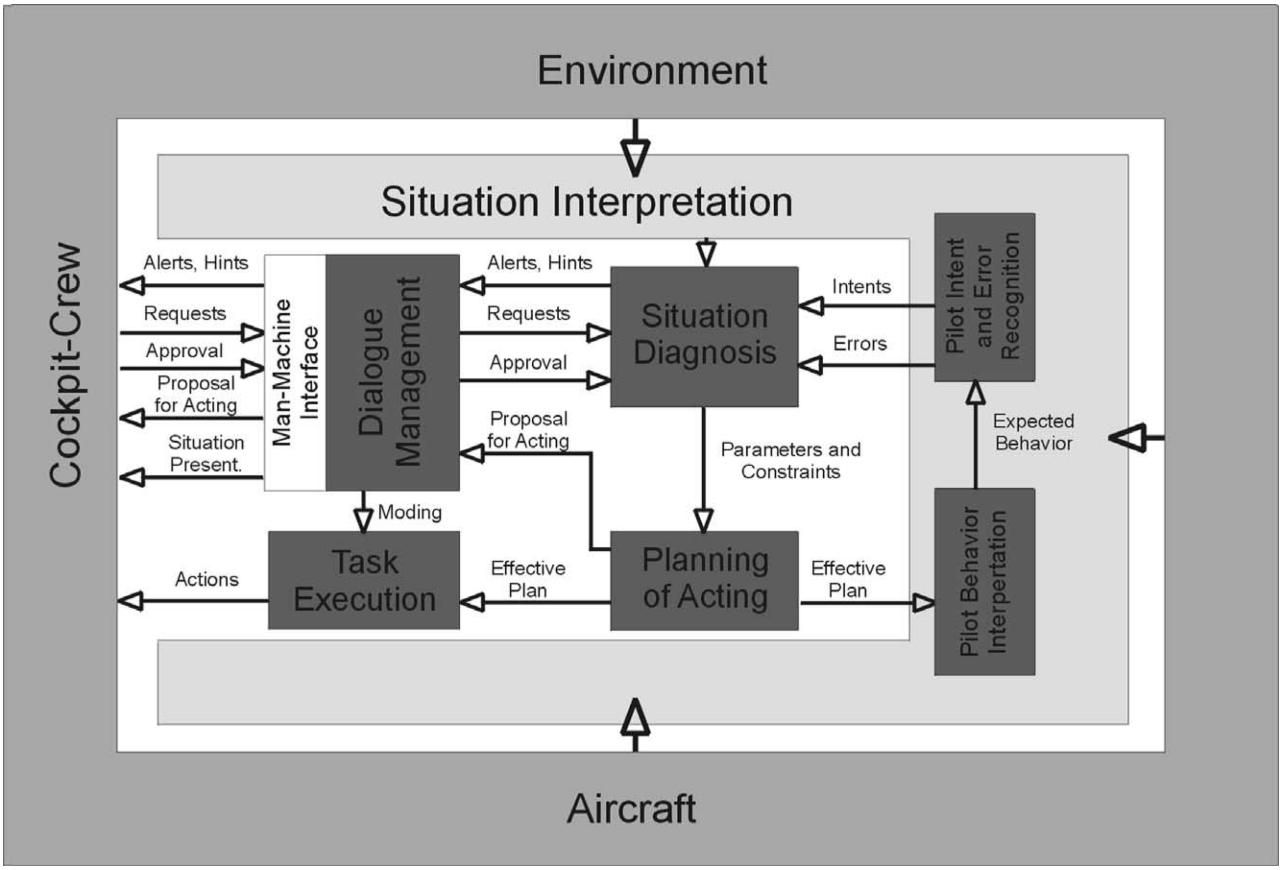

Figure 7. Functional structure of CAMA.

of CAMA forms a close functional relationship with the diagnosis and detection of conflicts and opportunities according to the general layout of a cognitive system. The relevant objects of the real world, like the actual pilot behavior as being known as part of the central situation representation, are evaluated against the expected behavior of the pilot, the predicted state of the aircraft and against the overall mission objectives. In order to monitor the pilot's behavior the assistant system needs a representation of the expected pilot actions. In CAMA a normative model describes the 'pilot's behavior' close to that as documented in handbooks and air traffic regulations [15]. An adaptive model covers behavioral traits of the individual pilot [22]. If the actual pilot's behavior differs from the internal representations of CAMA then it can be classified into either 'errors' or 'intents' [21,26]. This classification is based on the representation of the mission objectives and flight plan goals. These can be explicitly stated by the pilot as inputs via the MMI or can be implicitly contained in the pilot's intent which is continuously monitored by CAMA.

In a case of a possible traffic conflict, for example, CAMA detects that the actual behavior does not comply with the objective of 'safety' and issues visual and acoustic advice as part of the Traffic Alert and Collision Avoidance Systems (TCAS).

Ground proximity is constantly monitored. Therefore, all possible flight trajectories, achievable through full exploitation of the aircraft's performance capabilities, are checked for safe terrain avoidance (using a DTED (Digital Elevation Data) database). Again a warning, visual and by voice, is issued in case of violations of safety margins.

CAMA also generates 'proposals' as part of the conflict resolution which involves planning and decision making support [13,17,18]. This functionality ranges from very short term planning proposals for e.g. collision and terrain avoidance, to long term strategic planning. This enables the assistant system not only to detect the possible conflict, but to generate a strategy to solve the conflict. The relevant data needed are passed over from the situation representation. In case of overall flight planning all accessible information about the flight is passed over to the mission planner. This includes mission oriented goals and constraints that can be derived from the mission order (e.g. entrance corridors to gaming area, drop-point, time over target etc.). A 'takeoff-to-landing' mission flight plan is then generated. The IFR flight plan as part of it, for example, includes the lateral flight path segments, the vertical profile, time estimates and fuel planning. New mission constraints (e.g. a changed exit corridor from gaming area) or ATC instructions are considered during the planning process. If the mission order leads into an area with hostile radar coverage, the Low Altitude Planner is started accordingly, generating a minimum risk route 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 the airplane clear of terrain. Therefore, the mission constraints, the tactical elements and the resulting threat map, the terrain elevation data and the aircraft performance data are all taken into account. The generated routes are passed to the crew and are accepted, modified or rejected by them.

The communication between crew and cognitive process is the key functionality to let the cooperative approach eventually work out. The 'Dialogue Management' module of CAMA ensures that this communication is provided to support situation awareness in the best way possible in all flight conditions [5,7]. The messages from the system are configured depending on the situational context and features (signals, signs, symbols (see *figure 2*)) the pilot is looking for according to his mental models. Pilot inputs can be performed by speech, touch screens as well as conventional line select keys or switches.

Pilot inputs can be:
- request of flight plan proposal;
- activation, modification or rejection of proposals;
- activation of actions related to warnings;
- retrieval of information;
- autopilot operations;
- configuration of the MMI.

CAMA outputs can be:
- presentation of calculated flight plan proposals;
- situation presentation;
- warnings about detected conflicts;
- recommendation about explicit actions;
- messages in reply to requests;
- acknowledgement of speech input;
- presentation of complex actions.

Several MMI devices provide support for the flight guidance task. For flying in low altitudes under visual conditions a primary flight display provides a 3-dimensional presentation of the surrounding environment [17,18].

3.2. Results of simulator and flight trials

CAMA was tested in the flight simulator of the University of the German Armed Forces Munich and flight trials were also conducted. The flight trials were the first successful ones worldwide of a cognitive cockpit crew assistant except those some years ago for CASSY, the prototype development of a knowledge-based cockpit assistant for commercial flights under IFR (Instrument Flight Rules), also developed at the same university in cooperation with Dornier.

In November 1997 and May 1998 the first flight simulator test runs of CAMA were conducted. 10 German Airforce transport pilots (Airlifter Wing 61, Landsberg) participated as test subjects.

In addition, there were two periods of flight trials with the ATTAS (Advanced Technology and Testing Aircraft System) test aircraft of the DLR which amounted to a total of 15:50 hours of flight testing with CAMA in operation. A number of modifications have been made after the first period of flight trials. Therefore, representative results were mainly gained from the second period of flight trials in October 2000 with 5 test flights (7:15 hours in total), flown by 4 German Airforce transport pilots (two of them were test pilots).

In both test environments, the flight simulator and the flight trials, the pilots were tasked with full scale military air transport missions. This comprised the preflight mission briefing, takeoff from base, an IFR flight segment to the ingress corridor, a low level flight through the Black Forest to a drop zone. The low level flight over the hostile area represented a dynamic tactical scenario with multiple SAM stations (Surface-to-Air Missiles). After the drop was accomplished the flight continued to the egress corridor, followed by an IFR flight segment to the home base.

The IFR segment incorporated:
- adverse weather conditions;
- high density airspace;
- changing availability of landing sites;
- ATC communication (e.g. clearances, radar-vectoring, redirection).

The tactical segment incorporated:
- varying SAM sites;
- drop procedure;
- changed egress corridor;
- redirect to new destination.

Each test flight was finished by a debriefing. Here, the pilot's overall acceptance of the cognitive assistant system was documented through a questionnaire with the following topics to be rated:
- test environment;
- situation awareness;
- assistance quality;
- pilot acceptance.

All ratings were given within a range from 1 to 7, where 1 represents the best and 7 the worst score. A selection of the results is shown in *figures 8*, *9* and *10*, showing the means values of the ratings. The ratings of the flight simulator test runs are marked by an **S** and the flight test results are marked by an **F**. A more detailed documentation of the test runs and its results is given in [6,19].

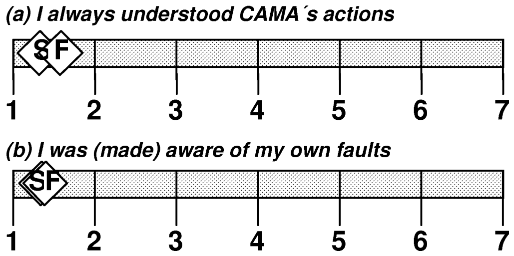

Figure 8. Evaluation of the cooperative approach of CAMA (S = Simulator test runs, F = Flight trials).

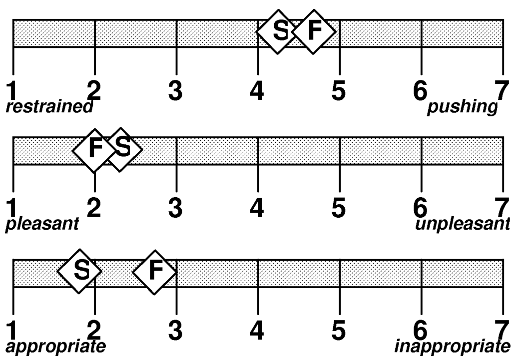

Figure 9. Acceptance of CAMA by pilots (S = Simulator test runs, F = Flight trials).

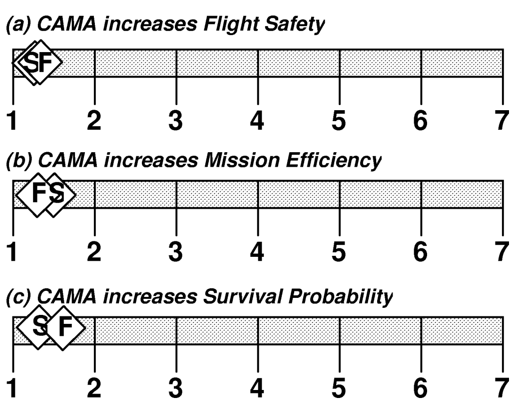

Figure 10. Overall evaluation of CAMA (S = Simulator test runs, F = Flight trials).

4. Conclusions

As air traffic increases and systems become more and more complex the demands on the cockpit crew have reached a state where the handling of conventional automation becomes critical.

The time has come where future cockpit systems will no longer be designed on a vague basis of specifications. The advances in cognitive engineering technology have brought about means to systematically reflect requirements for human-centred automation into clear-cut specifications and cockpit system development.

It is therefore appropriate to make the first significant steps for a cognitive assistant system, in order to support the aircrew regarding enhancement of situation awareness, handling of multifunctional tasks and situation-dependent balancing of workload, for the sake of mission effectiveness and safety. The presented approach of cognitive assistance and its realization in the prototype system CAMA has been described. The benefits were demonstrated in the course of simulator trials and flight demonstrations.

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