Cognitive Man-Machine-Cooperation

Modeling Operators' General Objectives and its Role within a Cockpit Assistant System

Anton Walsdorf and Reiner Onken, *Member, IEEE*

ABSTRACT

Modern cockpit environments, covering highly integrated and complex automatic functions, pose various demands on the crew. In unusual situations the crew often is overtaxed and acts erroneously. Pilots' tasks alter with increased automation as to decreasing physical activities and increasing cognitive activities. The complexity of planning and decision-making tasks takes pilots' mental capacity. Aircraft manufacturers and flying organizations try to alleviate crew decision-making as much as possible. This is done by means of automation and by establishing standard procedures and checklists to cover anticipated failures or emergencies. So far, automation often leads to 'Clumsiness', which is considered to be a major reason for severe deficiencies concerning the interaction between cockpit crew and aircraft systems. Cognitive systems appear to be a promising approach to overcome these deficiencies in future cockpits. They cover the capabilities for situation interpretation, planning and decision making as well as autonomous execution of a plan. Cognitive assistant systems are designed to make use of these capabilities in favor of a cooperative approach. The cognitive process and its cognitive components are introduced.

The cooperation between man and cognitive assistant system poses new demands. An explicit 'mental model' is a fundamental requirement for the assistant system. Analysis, behavior, design and the role of explicit 'mental models' within a cognitive cockpit assistant system are described. Methods for knowledge acquisition and representation are discussed with respect to a model of general objectives, which the crew of a military transport aircraft has in mind. The implementation using a CORBA environment and the validation by in-flight data of the 'Crew Assistant Military Aircraft' CAMA are briefly described.

Dipl.-Ing. Anton Walsdorf
Prof. Dr.-Ing. Reiner Onken
Institut für Systemdynamik und Flugmechanik
Universität der Bundeswehr München
Werner-Heisenberg-Weg 39
85577 Neubiberg
Germany
http://www.unibw-muenchen.de/
Email: Anton.Walsdorf@UniBw-Muenchen.de
Email: Reiner.Onken@UniBw-Muenchen.de

COGNITIVE MAN-MACHINE-COOPERATION

The evolution towards the modern cockpit environment brought severe changes to the operator. Increase of

- systems' complexity
- automated functions
- managerial cockpit tasks
- mission capabilities and
- planning and decision-making tasks

has become operational without increase of the resources of the cockpit crew (see [1],[2] and [3]). Newer design concepts have identified this problems (see[4], [5] and [6]) and are taking into consideration the limitations of the human operator. The approach of a 'human centered design' proposes the following recommendations (see [7]):

I. Human operators must be actively involved.
II. Human operators must be adequately informed.
III. Human operators must be able to monitor the automation assisting them.
IV. Automated systems must also monitor the human operator.
V. Automated systems must be predictable.
VI. Every intelligent system element must know the intent of other intelligent system elements (including the human operator).

Besides the demands I-III for an improved man-machine-interfacing of the 'human centered machine', requirements IV-VI implicate a cooperative approach for a human centered system.

Effective cooperation by contributing with one's own individual strengths subject to a mutual task brings several benefits and improves overall performance. The benefits of an effective man-machine-cooperation by communication is based on deliberative (intent-monitoring) and negotiative (goal-sharing) behavior.

In a multi-player environment, effective crews are characterized by (from [8], see [9] and [10]):

0-7803-6583-6/00/$10.00 © 2000 IEEE

- good situation awareness,
- effective crew resource management,
- high level of meta-cognition and
- shared mental models.

This imposes that a cooperative approach must lead to cognitive machine capabilities. Human cognition capabilities result into three behavioral levels (see [11]):

- level of skill-based behavior,
- level of rule-based behavior and
- level of knowledge-based behavior.

Each level is based upon the perception of the surrounding world through receptors (see [12]). The subsequent interpretation of the stimuli through signals, signs and symbols leads to situation comprehension and awareness. The extraction of goals as being identified to be relevant for the actual situation, the diagnosis of conflicts and/or potential opportunities and the generation of a plan how to act are the knowledge-based capabilities. The consciously controlled association of recognized signs with the task and a pertinent set of stored rules describes the rule based behavior level. Skill-based behavior is the direct highly integrated, automated reaction onto simple situational signals and signs by activating automated sensori-motor patterns. A hierarchical dependency between the three levels ensures the goal-oriented behavior of the subordinated levels.

The analogue cognitive machine process is illustrated in Figure 1.

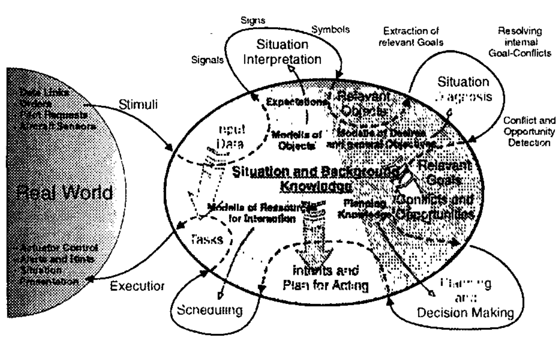

Figure 1: Cognitive Process (see [13])

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.

The cognitive sub-processes work on input data (sensory inputs, communication data) as well as on other situation and background domain knowledge. The outputs of these cognitive sub-processes are:

- relevant world-features/objects,
- relevant goals and conflicts/opportunities,
- intents and plans and
- tasks and actions to be done.

These outputs can be called the "Cognitive Yield". There are system approaches, including expert systems, which cover part of the cognitive machine process, often not doing more than they are explicitly asked to do by the operator. Autonomous cognitive systems or cognitive assistant systems as highly cooperative systems are supposed to cover the entire cognitive machine process and to offer all levels of support without needing explicit instructions.

COGNITIVE SUB-PROCESSES

The cognitive sub-processes play a key role for intelligent behavior. Their cognitive yield, resulting from the cognitive sub-processes, forms the dynamic 'mental model' (see [14]) of the situation, the representation of the so-called situation knowledge. The mental models again, also including the background knowledge, are in turn the basis for the knowledge-based sub-processes of situation interpretation and diagnosis as well as for planning and decision making (see [15]). The cognitive sub-processes as well as their interdependencies are described formally (see [16]) in the following:

The cognitive yield $\boldsymbol{S}$, representing the actual situation knowledge in terms of sub-process outputs or combinations of them, can be described by a set $\boldsymbol{E}$ of subsets $\mathbf{E}$ of situation knowledge elements $\boldsymbol{e}$ and a set $\boldsymbol{R}$ of relations as subsets $\mathbf{R}$ of elements $\boldsymbol{r}$ between situation knowledge subsets or elements:

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

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' are concerned with the background knowledge, pertinent to the relevant situation knowledge elements, the correct allocation types of pertinent relations between situational knowledge elements and the proper contents of these relations. Therefore,

match of content
\+ match of structure
\+ match of semantics

= 100 % situation comprehension

For each computation cycle of the cognitive process, the complete picture $\mathbf{S_a}$ of the actual situation comprises all relevant situation knowledge elements and pertinent relations as provided by the cognitive sub-processes:

$$S_a = E_{InptData} \cup E_{RelvObj} \cup E_{RelvGoals} \cup E_{IntentPlan} \cup E_{Tasks} \cup R_a$$

with $\mathbf{R_a}$ being equal to all relations between situation knowledge elements pertinent to actual outputs of the cognitive sub-processes.

Often, this simply results in

$$S_a = S_{InptData} \cup \underbrace{S_{RelvObj} \cup S_{RelvGoals} \cup S_{IntentPlan} \cup S_{Tasks}}_{\text{Derived Situations within Cognitive Process}},$$

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

$$S_{RelvObj} = SituationIntp(S_{InptData}, \text{Mdls Objects})$$

$$S_{RelvGoals} = SituationDiagn._1(S_{InptData}, \text{Mdls Goals})$$

$$\begin{pmatrix} S_{Conflict} \\ S_{Opportunity} \end{pmatrix} = SituationDiagn._2(S_{S_a \setminus S_{RelvGoals}}, S_{RelvGoals})$$

$$S_{IntentPlan} = Planning(S_{InptData}, S_{Cflct}, S_{Oppt.}, \text{PlanKwldg})$$

$$S_{Task} = Scheduling(S_{InptData}, S_{IntentPlan}, \text{Modls Resources})$$

In more detail, the yield of the interpretation sub-process, $\mathbf{S_{RelvObj}}$, can be described by the set $\mathbf{E_{RelvObj}}$ with pertinent relations $\mathbf{R_{RelvObj}}$ as part of $\mathbf{R_a}$. The set $\mathbf{E_{RelvObj}}$ contains the set of all abstract or concrete world-objects $\mathbf{O_{Relv}}$ of relevance. They will be described by a subset F of features f and a subset P of properties p:

$$O_{Relv} = \{F, P\}$$

Therefore, $\mathbf{S_{RelvObj}}$, as subset of the overall situation $\mathbf{S_a}$, is given as:

$$S_{RelvObj} = \{O_{RelvObj}, R_{RelvObj}\}$$

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

All possible desires and objectives form a set G of goals g, which is part of the background knowledge resource. Each goal g is then evaluated against the situation pattern $\mathbf{S_{RelvObj}}$ in order to determine, whether it is relevant or not. The relevance criterion as part of the goal's model is represented by a set of situation patterns $\mathbf{S_{C1}}$ associated to each g:

$$\text{IF } S_{RelvObj} \in S_{C1} \text{ THEN } g \rightarrow g_r \text{ ENDIF}$$

The set G_r of all relevant goals g_r and pertinent $R_{RelvGoal}$ form $\mathbf{S_{RelvGoals}}$:

$$S_{RelvGoals} = \{G_r, R_{RelvGoal}\}$$

Relevant goals are activated within the 'mental model' immediately or after parameterization by situational data if required.

Within part 2 of 'situation diagnosis', $\mathbf{S_{RelvObj}}$ is rated against $\mathbf{S_{RelvGoals}}$ to detect potential conflicts or opportunities. In case, $\mathbf{S_{RelvObj}}$ supports a goal g_r by matching the set of goal-supporting situation patterns $\mathbf{S_{C2}}$, this goal becomes the supported goal g_r *:

$$\text{IF } S_a \in S_{C2} \text{ THEN } g_r \rightarrow g_r^* \text{ ENDIF}$$

This also includes opportunities.

If $\mathbf{S_{RelvObj}}$ is not a subset of $\mathbf{S_{C2}}$, it is conflicting the goal g_r and becomes $\overline{g}_r$:

$$\text{IF } S_a \notin S_{C2} \text{ THEN } g_r \rightarrow \bar{g}_r \text{ ENDIF}$$

The overall goal-supporting situation S_H is represented by a overall-hyperplane of the intersection S_{C2} of set $S_{RelvGoals}$.
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 one. Achieving a set of goals requires planning. Planning means to find a suitable set T of tasks t – broken down into a set A of actions a – which is capable to comply with the set I of intents i. A set I of intents i, the assigned sets T of tasks t and pertinent relations R_{Task} form S_{Plan}.

$$S_{Plan} = \{I, T, R_{Task}\}$$

A set T of tasks t, the assigned set A of actions a and pertinent relations R_{Action} form the S_{Tasks}:

$$S_{Tasks} = \{T, A, R_{Task}\}$$

MODELING OPERATORS' GOALS

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 the operator goals. Therefore, a model of operator 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,
⇨ hyperplane,
⇨ sub-goal reference,
⇨ sub-goal operator and
⇨ goal approval (truth).

The origin of a goal g identifies whether the goal is originated by the system itself or if it is issued by an external agency. The relevance of a goal depends on the match of $S_{RelvObj}$ with S_{C1}. 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 instantiated into a hyperplane g_H under consideration of perceived situational elements. The representation of a goal by a hyperplane has been originated by the requirement to share $S_{RelvGoals}$ within an application of cooperative, distributed and heterogeneous system's architecture. The approval of a goal g depends on the approval of subordinated goals g_{sub}. References to these g_{sub} are covered within g. Goal operators provide the approvals for the subordinated goals. Situation diagnosis of an actual goal under consideration evaluates the goal approval (truth) g_t and classifies a situation as conflicting ($g_t << 1$) or supportive ($g_t >> 0$) and by that the goal as approved or as conflicted.
Within the model introduced here, the overall goal situation is represented by two data structures:

- a overall goal-hyperplane S_H, representing the intersection of the goal-supporting situation patterns S_{C2} with respect to all relevant goals and
- a tree structure, representing symbolically the hierarchy of all relevant goals.

Example
The cognitive sub-process of situation diagnosis is briefly illustrated for the task of aircraft guidance. Herein, the reception of the data concerning the 'real-world' are mapped and instantiated within $S_{RelvObj}$ by the sub-process of 'situation-interpretation', using the stored object-models, into an aircraft-object, an destination-object and another consorting aircraft-object. Then $S_{RelvObj}$ covers three objects, which are partially related:

$$S_{RelvObj} = \left\{ \begin{matrix} o_{Aircraft}, r_{airborne} \\ o_{Traffic}, r_{approaches}, o_{Aircraft} \\ o_{Aircraft}, r_{has}, o_{Destination} \end{matrix} \right\}$$

Subsequently, the first sub-process of 'situation-diagnosis' commences extracting relevant goals from the set of all possible goals by matching $s_{RelvObj}$ with S_{C1} of each goal:

$$s_{RelvObj} \in sc1_{Overall}\{o_{Aircraft}\} \rightarrow g_{r_{Overall}}$$
$$s_{RelvObj} \in sc1_{Safety}\{o_{Aircraft}\} \rightarrow g_{r_{Safety}}$$
$$s_{RelvObj} \in sc1_{Flightplan}\{o_{Aircraft}\} \rightarrow g_{r_{Flightplan}}$$
$$s_{RelvObj} \in sc1_{StallSpeed}\{o_{Aircraft}, r_{airborne}\} \rightarrow g_{r_{StallSpeed}}$$
$$s_{RelvObj} \in sc1_{TrafficAvoid}\{o_{Traffic}, r_{approaches}, o_{Aircraft}\} \rightarrow g_{r_{TrafficAvoid}}$$
$$s_{RelvObj} \in sc1_{Destination}\{o_{Aircraft}, r_{has}, o_{Destination}\} \rightarrow g_{r_{Destination}}$$

This results in the representation of $\mathbf{S_{RelvGoals}}$ by the hyperplane and the tree representation (see figure 2):

$$s_{RelvGoals} = \left\{ \begin{array}{l} g_{r_{Safety}}, r_{isSubGoal}, g_{r_{Overall}} \\ g_{r_{Flightplan}}, r_{isSubGoal}, g_{r_{Overall}} \\ g_{r_{StallSpeed}}, r_{isSubGoal}, g_{r_{Safety}} \\ g_{r_{TrafficAvoid}}, r_{isSubGoal}, g_{r_{Safety}} \\ g_{r_{Destination}}, r_{isSubGoal}, g_{r_{Flightplan}} \end{array} \right\}$$

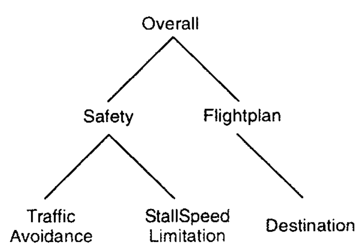

Figure 2: "Hierarchy of Goals" – Tree Representation

Conflict and opportunity assessment is then performed within the second step of 'situation diagnosis'. Situation patterns – relevant for the approval of a goal – are evaluated. For instance, the model of $g_{TrafficAvoid}$ allows to evaluate situation patterns comprising world-objects $o_{Traffic}$ and $o_{Aircraft}$ in $r_{approach}$ relations. By means of inference knowledge evaluates object's features $f_{Position}$, $f_{Heading}$ and f_{Speed} of $\mathbf{o}_{Traffic}$ and $\mathbf{o}_{Aircraft}$ are evaluated by extrapolating the tendency of the distance between $\mathbf{o}_{Traffic}$ and $\mathbf{o}_{Aircraft}$, which forms the truth criterion of $g_{TrafficAvoid}$.

The overall goal approval is performed by the evaluation against the hyperplane.

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 is facing since many years. The question is how to separate 'data' from 'information' and 'information' from 'knowledge'.

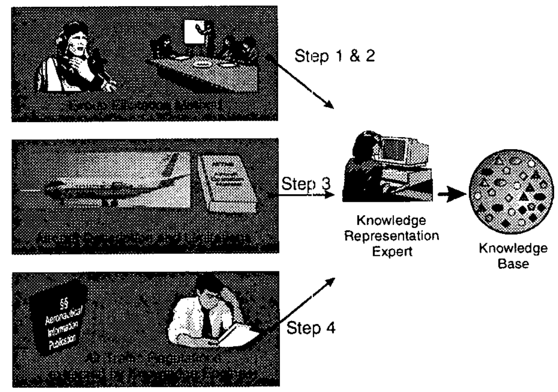

Figure 3: Knowledge Acquisition Process for a Model of Pilots general Objectives

Knowledge-sharing between the pilot and a cognitive assistant system takes place on situational knowledge (via communication) and background knowledge (via off-line knowledge-acquisition).
Within this work the knowledge acquisition task concerns the aviation domain, in particular military air transport.

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.

The military regulations and tactics are neither straightforward nor well documented and are more guidelines than regulations. Therefore, the 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 under hostile conditions, is performed by the semi-formal group-elicitation-method (see figure 3 and [17]) 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 (MMR) 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 instance. These are the Air Traffic Control (ATC), solely coordinating the civil traffic, and the Airborne Command and Control Center (ABCCC) of the Airborne Warning and Control System (AWACS), responsible for the management of the forces within the tactical areas.
The vehicle related topics are taking into consideration the goals responsible for the aircraft guidance tasks, as:

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

Compared with the tactical regulations, the ATC orders and instructions are based primarily upon the 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 directly upon the 'aeronautic information publications' and is performed by the knowledge engineer himself.

KNOWLEDGE REPRESENTATION

The knowledge acquisition process results in a formal representation of the general objectives over all flight phases, the pertinent relations, associations and priorities. The knowledge elicited is represented within the inference knowledge of a goal.
Regarding the cognitive sub-process of situation diagnosis, a simplified knowledge language has been developed for the cognitive task of situation diagnosis. A modeling language supports the design and structuring of the knowledge as well as its maintenance. The language provides constructs to describe object relations, attributes as well as templates for world-objects and goals. Relations between the cognitive sub-processes are taken into consideration, the inference knowledge of the goals as well as the completeness of the internal knowledge specification are checked automatically. Three types of knowledge representations have been implemented:

- fuzzy knowledge,
- diagrammatic knowledge and
- informal knowledge.

The fuzzy knowledge describes e.g. the expert-knowledge concerning situation assessments. The diagrammatic knowledge representation describes e.g. the aircraft-characteristics, documented within the flight book. More abstract coherence are described by the informal knowledge.

MODEL ARCHITECTURE

The analysis of the cognitive process led to a distributed system architecture. 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 (see [18]).
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. The system introduced here uses *cooperation primitives* which are derived from the speech act theory (see [19]). 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) (see Figure 4). CORBA allows applications to communicate with eachother no matter where they are located or who has designed them.

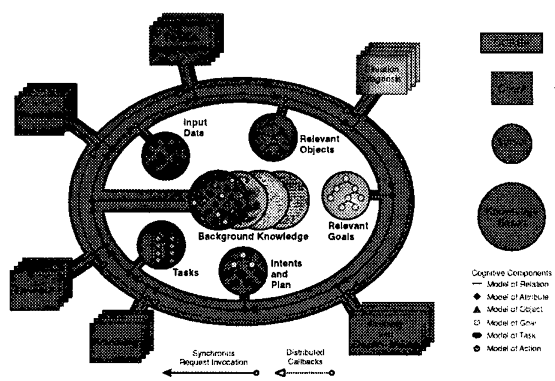

Figure 4: Model's System Environment

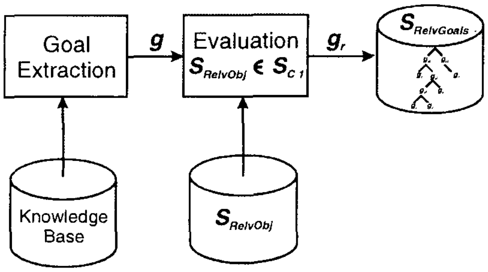

Figure 5: Extraction of Relevant Goals

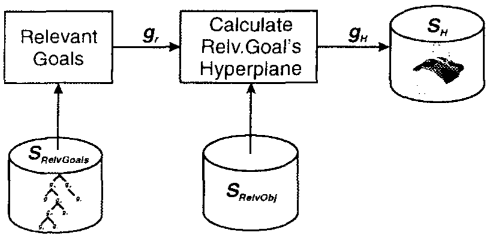

Figure 6: Calculation of Overall Goal Hyperplane

Core elements of the model are representations of the cognitive states of the knowledge-based level. CORBA server provide the 'mental models':

- domain-knowledge-base (relations, attribute-, object- and goal-templates),
- maps of terrain (DTED) 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 situation assessment)

The process of goal extraction is illustrated in Figure 5 and Figure 6.

MODEL TEST ENVIRONMENT

The goal-model is linked to the Crew Assistant Military Aircraft CAMA (see [20]), an cognitive assistant system for military transport aircraft. The CAMA project has been launched in 1992 by the german Ministry of Defence under close co-operation between the DaimlerChrysler Aerospace AG, the Elektroniksystem und Logistik GmbH, the German Aerospace Center DLR and the University of the Federal German Forces in Munich.

CAMA supports the cockpit crew during a complete tactical mission, performing autonomously the tasks of:

- situation interpretation,
- situation diagnosis,
- planning and decision making and
- task execution.

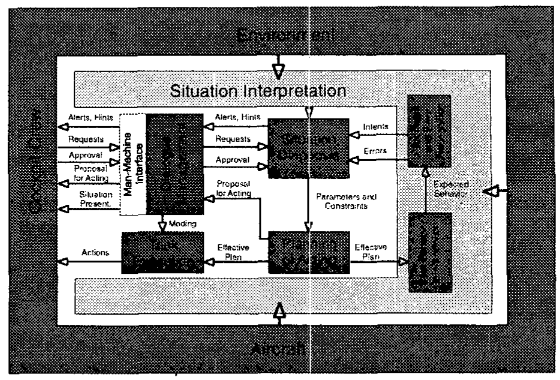

Figure 7: CAMA functional architecture

CAMA assists through:

- improving situation awareness,
- offering solutions to planning and decision making tasks,
- providing necessary data and
- operating the aircraft on crew request.

Core elements of CAMA are illustrated in Figure 7. CAMA was evaluated by 10 military transport pilots in flight-simulator trials at the University of the Bundeswehr, Munich in November 1997 and May 1998 (see [21]).

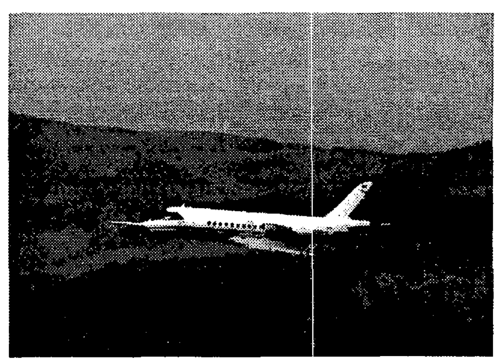

Figure 8: CAMA Flight Tests in the Kinzig valley of the Black Forest.

VALIDATION

Currently, CAMA is under evaluation in flight tests on board of the ATTAS (Advanced Technology Testing Aircraft System) of the German Aerospace Centre DLR. Flight tests have been performed in march (see Figure 8) and are further scheduled for fall 2000. The in-flight records of the in-flight of CAMA are evaluated off-line to validate the model of operator's overall objectives within a cognitive cockpit assistant system (see Figure 9).

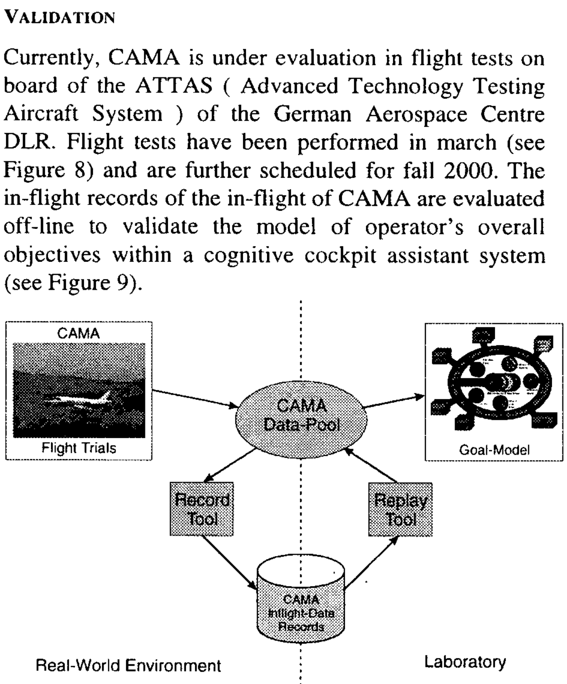

Figure 9: Validation of the Goal Model

CONCLUSION

Cognitive technology provides both autonomous and cooperative systems advantages against conventionally automated systems. The representation of systems' 'mental states' by 'mental models' within the knowledge-based level is essential for correct and comprehensive situation comprehension. It provides powerful bents of the system, applicable within the 'human centered approach'. Cooperation between man and machine by intent-monitoring and goal-sharing increases acceptance on user side. Cognitive assistant systems are capable to improve mission effectiveness as well as safety.

LITERATURE

[1] E. L. Wiener: Human Factors in Aviation: Academic Press, San Diego, California, 1993.

[2] B. B. Morgan Jr., D. A. Herschler, E. L. Wiener, and E. Salas: Implications of automation technology for aircrew coordination and performance. In W. R. Rouse, editor, Advances in Man-Machine Systems Research, volume 6, Greenwich, CT, Journal Artificial Intelligence, 1993.

[3] N. B. Sarter, and D. D. Woods: Strong, silent, and 'out-of-the-loop' properties of advanced (cockpit) automation and their impact on human-automation interaction. Techrtical Report 95-TR-01. Ohio State University Cognitive Systems Engineering Laboratory, February 1995.

[4] M. R. Endsley and E. O. Kiris: The out-of-the-loop performance problem and level of control in automation. Human Factors, pages 381-394, 1995.

[5] Federal Aviation Administration: Human Factors Team Report on: The Interface between Flightcrews and Modern Flight Deck Systems, June 18, 1996.

[6] D. Harris, editor: Human Factors for Flight Deck Certification – Proceedings of the European Workshop to Develop Human Factors Guidelines for Flight Deck Certification. Cranfield University Press, 25.-26. March, 1997.

[7] C. E. Billings: Human centered automation: a concept and guidelines. NASA Technical Memorandum 103885, Moffett Field, CA, August 1991

[8] J. M. Orasanu: Decision-making in the Cockpit. In E. L. Wiener, B. G. Kanki, and R. L. Helmreich, editors, Cockpit Resource Management. Academic Press, San Diego, 1995.

[9] P. B. Luh, K. R. Pattipati, and D. L. Kleinmann: Task and Resource Coordination in Human Teams. In Proceedings of 5th Int. Symp. Of Intelligent Contr., 1990.

[10] E. L. Wiener: Cockpit Resource Management. Academic Press, San Diego, California, 1993.

[11] J. Rassmussen: Skills, Rules and Knowledge; signals, signs, ad symbols, and other distinctions in human performance models. In IEEE Transaction on Systems, Man and Cybernetics, volume SMC-13, pages 257-266, 1983.

[12] R. Guski: Wahrnehmung – eine Einführung in die Psychologie der menschlichen Informationsaufnahme. Urban Taschenbücher, W. Kohlhammer GmbH, Stuttgart, 1989.

[13] A. Walsdorf, H. Putzer, and R. Onken: The cognitive process and its application within cockpit assistant systems. In IEEE / IEEEJ / JSAI International Conference on Intelligent Transportation Systems, Tokyo, Japan, 5.-8. October 1999.

[14] P. N. Johnson-Laird: Mental Models. Press Syndicate of the University of Cambridge, 1983.

[15] J. A. Cannon-Bowers and E. Salas: Cognitive psychology and team training: Shared mental models in complex systems. In Proceedings of Annual Meeting Soc. Industrial and Organization Psychology, 1990.

[16] J. Barwise and J. Perry: Situationen und Einstellung – Grundlagen der Situationssemantik. Walter de Gruyter, Berlin, 1987.

[17] G. Boy: The group elicitation method: An introduction. In N. Shadbolt, K. O'Hara, and G. Schreiber, editors, Advances in Knowledge Acquisition, 9th European Knowledge Workshop, EKAW '96, Nottingham, United Kingdom, pages 290-305, May 1996.

[18] N. R. Jennings and M. J. Wooldridge, editors: Agent Technology – Foundations, Applications and Markets. Springer Verlag Heidelberg, 1998.

[19] J. R. Searle: Speech Acts. Cambridge University Press

[20] A. Walsdorf and R. Onken: Intelligent crew assistant for military transport aircraft. In NATO RTO System Concepts and Integration Panel Symposium. Sensor Data Fusion and Integration of the Human Element, Ottawa, Canada, 13.-17. September 1998.

[21] Schulte, A., Stütz, P., "Evaluation of the Cockpit Assistant Military Aircraft CAMA", NATO System Concepts and Integration Panel Symposium. Sensor Data Fusion and Integration of the Human Element. Ottawa, Canada, 14-17 September 1998.