CASSY - COCKPIT ASSISTANT SYSTEM FOR IFR OPERATION

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Abstract

The paper presents the knowledge-based Cockpit Assistant System CASSY, which is currently being developed and tested in a close cooperation between the University of the German Armed Forces, Munich and the DASA-Dornier company. To improve flight safety under instrument flight conditions CASSY, like an expert copilot, recommends flight plan revisions when needed, warns the pilot, if he deviates from his Air Traffic Control (ATC) clearance and monitors aircraft systems. The basic requirements for the development of CASSY are explained and described as well as its functions, interfaces and modular structure. The integration of the system into the modern two-men cockpit is pointed out and the simulation and flight experiments are presented.

Background

During the last decade (1984 - 1993) the total number of fatal airline accidents stayed almost constant, but at a very low level, though [Airline Safety Review, 94](1). This level of annually more than 1000 fatalities in average (in more than 40 accidents) is still unacceptable, regarding the fact that most of these accidents possibly could have been prevented by making appropriate use of technology. In fact, more and more high technology has been applied in aircraft systems, but without great effect in flight safety. Consistently, the question is, why did these efforts not have all the desired effects and how should future efforts look like.

Human error is the major cause in most of the accidents (estimations range from 60% to 85 % e.g. [IATA,89](2) [ICAO,91](3)[Chambers,85](4)) . The human cockpit crew seems to be the weakest part of the entire aircraft system. Thus, at the first glance, substituting as many human functions as possible by automatic ones seems reasonable also with respect to efficiency. In fact, the technological evolution provides a great potential for automation. As a result, many systems and functions are already automated in modern cockpits.

However, it is generally recognized that not all automation efforts have improved the working situation of the cockpit crew. Often technological options were the driving element for automation rather than the user's needs [Hollnagel,93](5).

Experience with applied automation concepts have shown that considering the specific qualities of the human operator must be the basis for all automation efforts, trying to achieve the so-called human-centered automation [Billings,91](6). Very helpful information can be derived from findings about human information processing and cognitive behaviour like [Rasmussen,83](7). All this can be effectively fused and exploited by the concept of knowledge-based pilot assistance systems.

Worldwide there are several proposals of research and development teams for pilot assistant systems in civil and military applications [Amalberti,92](8)[Geddes,92](9)[Rudolph,92](10)[Bittermann,93](11). This paper discusses the german approach of a knowledge based assistant system CASSY for regional IFR flights. This system already in its second generation [Dudek,90][12] is being developed and implemented. It will be flight tested in May this year.

Present flight situation

The steady introduction of more complex systems into modern aviation and the rapid increase in air traffic have moved the pilot's primary task from maneuvring the aircraft towards the more difficult task of modern aircraft mission management [Jouanneaux,93](13).

Thus, the global flight situation, a pilot must be aware of, has become very complex. Constraints from Air Traffic Control and airline, changing meterological conditions as well as the present condition of the human operators influence the performance of guiding and controlling a flight vehicle system (which the pilot crew cannot fully understand) along a restricted flight path in a very dense airspace. It is obviously far beyond human capablities that the pilot is aware of the complete situation with all its details and facets, to assure an appropriate reaction on all kinds of occurring events.

An excerpt of the present cockpit situation confronting the cockpit crew in modern aircraft is illustrated in figure 1.

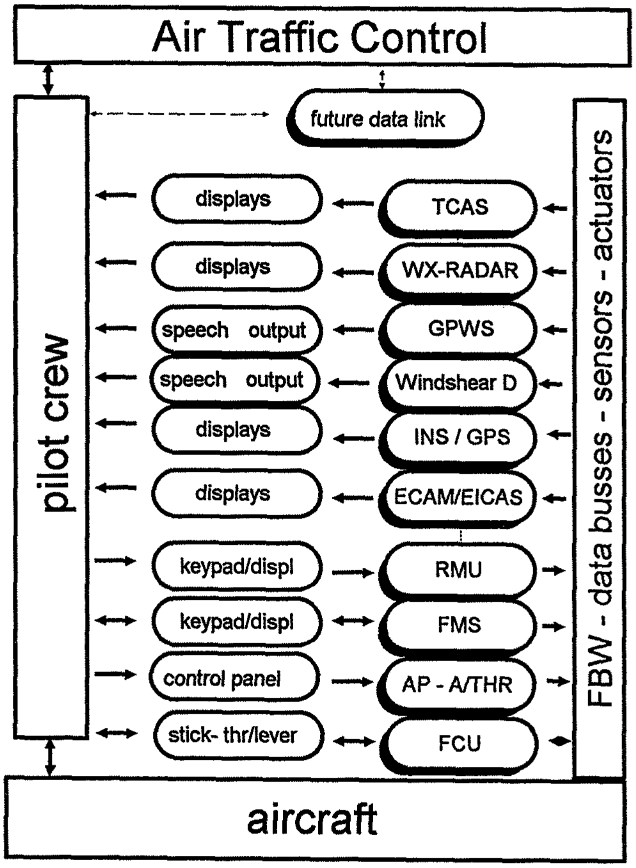

Figure 1: Present cockpit situation

It is left to the crew members to figure out what is most important and most urgent in a specific situation and to concentrate on what selected task. Wrong decisions in this context can have fatal consequences and are often sufficient reason for the occurence of an accident. For example, the relatively great amount of controlled flights into terrain (CFIT; 20% - 30% of the fatal accidents) can quite clearly be attributed to a lack of situation awareness.[Endsley,92][(14)]

These situation awareness problems are a result of the aforementioned possible overcharges of the crew, which on the one hand might be partially caused by automation [Wiener,89][(15)] but on the other hand can only be prevented by using more, but different automation such as electronic crew member assistance.

Basic Requirements

The kind of automation, which is needed, should not just be a reaction to single accident cases or try to improve economical efficiency of single subsystems. It should reflect the basic requirements for electronic assistance and be designed on a brought human-oriented basis.

In general, this electronic crew member assistance should be aimed at ***avoiding overcharges and resulting errors of the crew, i.e. keeping the degree of crew demand and workload at a normally executable level for each situation and corresponding task.***

To achieve this goal two basic requirements for machine support in flight guidance [Onken, 93][(16)] can be stated, categorized in correspondance to the main functional elements of the pilot crew work process like situation assessment, planning and plan execution:

1.) The clearly dominant ***basic requirement (1)*** to prevent or overcome ***overcharges concerning situation awareness***:

On the basis of comprehensive machine knowledge of the flight situation resulting in smart presentations of situation-relevant messages, it must be ensured that the attention of the cockpit crew is directed towards the situation-specific, most urgent task or subtask.

2.) Consistently, as a follow up to requirement (1), the ***basic requirement (2)*** to overcome ***overcharges in behavioural aspects other than situation assessment***, i.e., when the reaction upon the assessed situation is to be determined and executed:

The particular overdemanding situation has to be transformed by decision and execution aids towards another one which can be handled by the cockpit crew on an appropriate demand and workload level.

This formulation of requirements for a human-centered design distinctly points out that whatever technical specifications are made in support of the cockpit crew, they might be questionable when the specification for the situation assessment capability of the support system (requirement (1)), including the assessment of the crew's situation, is neglectful and sloppy. How can the support system work on directing the crew's attention, when it cannot assess the global situation on its own ?

Thus, if the specification fails with regard to requirement (1), this cannot be compensated by whatever automated support designed to comply with requirement (2) only. Unfortunately, this inadequacy usually was the case in the past. Prevention of overcharges concerning situation assessment was not worked into the specifications in the systematic manner as it is suggested in requirement(1).
Requirement (1), in fact, leads to verifiable specifications for the aspect of human-centered automation !

Core features of an electronic crew member

To comply with the stated requirements it was said that the assistant must be able to fully understand the situation, which includes its interpretation, to be aware of what is most important and most urgent, and to communicate with the human operator in an appropriate way, i.e. to act like a knowledgeable third crew member, who is quiet, when everything is working properly, but who carefully pinpoints necessities to act. The goal should be ***a situation dependent flexible, co-operative distribution of tasking*** between the electronic and the human crew member.

Understanding the situation

The complete understanding of the situation requires the building of a well defined knowledge base, consisting of static and dynamic knowledge about all elements, which possibly influence the crew and its environment. These elements include data and knowledge about the aircraft, its environment and resources, information about tasks and subtasks to accomplish mission goals and subgoals and information about the crew condition. Further descriptions of the situation and its constraints can be taken from e.g. [Figarol,93](17).

To gain this information the assistant must consist of - or have access to - some basic modules:

- data basis for static aircraft and environment data (such as aircraft performance and equipment and navigation data)
- monitoring modules for health status of aircraft systems, and dynamic environment data, such as air traffic and weather information
- planning and decision aiding modules, able to generate and update the global mission plan and its subgoals to react on adverse situations
- a sophisticated crew model, consisting of knowledge about crew resources as well as of knowledge about behavioural sequences and error contingencies
- modules to recognize and identify the current crew behaviour and intention
- interfaces to gather information from the external world, i. e. Air Traffic Control, the airline, aircraft subsystems and other aircrafts

The way, in which this knowledge is being interpreted, makes the difference between the human and the electronic crew member. The electronic crew member is capable of taking all accessible information into consideration, whereas the human has to decide on fragmental excerpts of situational information due to information processing limits. Capacity restrictions also lead to a much higher amount of time in complex decision making for humans. Furthermore, a computer system will always draw exactly the same conclusion in exactly the same situation, it cannot be grumpy.

On the other hand, at the present state of the art automatic systems only guarantee the correct reaction to a situation, for which they have been explicitly designed, which they have learned. Therefore, the potential user should be involved as much as possible into the system design. Just like a human the system may succeed or fail in handling unforeseen and/or unknown situations. Thus, as long as the human operator has more experience than the system and human decision making in an unknown situation is superior to machine decision making, the human operator should be the decisive part in a complex process environment.

At the time being, knowledge-based assistant systems are far from holding any final decision authority in critical situations. They rather assist the cockpit crew by giving advisory and warning messages.

Communication with the crew

To achieve a most effective communication between human and electronic crew member, the crew interface must be designed very carefully. Since the present state of HCI in modern aircraft is not overall sufficient, e.g. [Dyck,93](18), new technologies have to be used to a much greater extent.

An information overflow in the visual channel should be avoided, although it must be used as the channel with the highest processing capacity. The auditive channel should be more exploited, which will be eased by the introduction of new technologies for ATC communication (Data Link). There speech can be used in either direction. In addition to the already realized speech output, speech input is a very potential communication medium, which is close to natural communication. If speech recognition is sufficiently reliable, it will be very effective. Conventional input devices should remain for certain tasks and for redundancy and flexibility purposes.

To accomplish the stated basic requirements, information transfer has to be controlled and managed in a centralized way. This communication management is only possible, if the responsible module is well informed about the global situation. Therefore all other modules of the electronic crew member are somehow service modules for the communication manager.

Function structure of CASSY

The previous considerations led to a structure of the cockpit assistant system with two major parts:

- Core modules for
  - situation assessment
  - planning and decision making
  - plan execution
- Communication management

Since both parts are strongly dependent on each other, they can only work properly as a complete system, which is sharing the knowledge.

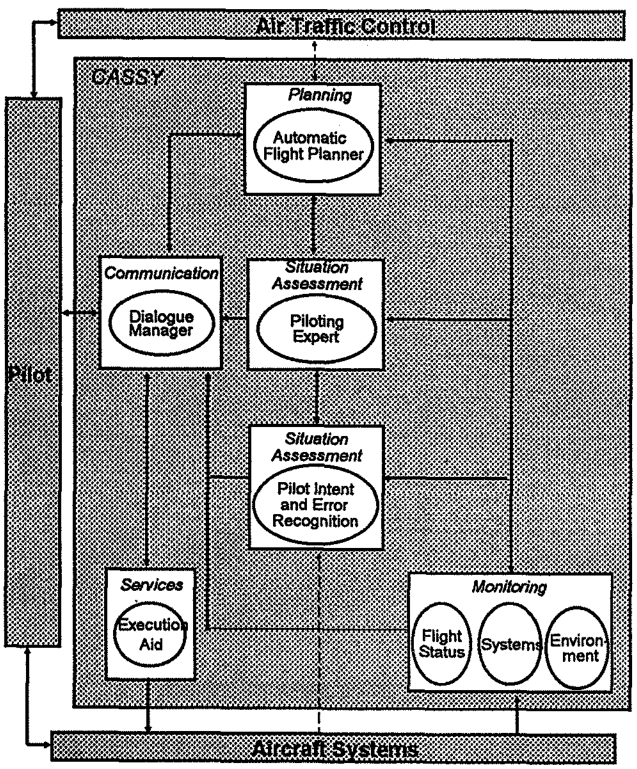

Figure 2 : Structure of CASSY

In figure 2 the major CASSY components and the information flow are indicated. Obviously a big amount of communication is required. Therefore the global situation is stored in a central object-oriented situation representation, which is accessible for each module. The binary connections between the modules are mainly used for the transfer of control data. Extensive information is transferred via the situation representation. This representation encompasses the global picture of the situation at any time and is the basis for the Dialogue Manager to present it to the crew .

The core of CASSY

The central information flow of the core elements takes place within the central column of figure 2. Figure 3 explains the information condensation and transformation of the three elements Automatic Flight Planner (AFP), Piloting Expert (PE) and Pilot Intent and Error Recognition (PIER), which may be entitled the'core of CASSY'.

Automatic Flight Planner (AFP):

The Automatic Flight Planner [Prévôt, 93][19] comprises the entire flight planning knowledge for generating a complete global flight plan. This flight plan includes a detailed 3-D/4-D trajectory plan as well as alternate airports and emergency fields and possible conflicts along the intended flight. The basis for the planning tasks is the access to the knowledge about the global situation and to navigational and aircraft data bases. The destination for the flight is the only information, which is needed from the pilot crew. All other information can be extracted from the situation representation.

The extensive planning knowledge can be used in different ways. The initial flight plan for the flight can be generated by the AFP. During the flight the AFP is activated autonomously, when an adverse situation demands a modification of the flight plan. Therefore the flight situation is investigated for conflicts with the flight plan. Such conflicts can result from e.g. new ATC instructions, changing weather conditions or system failures.

In the replanning process one or more proposals will be presented to the crew, which can be accepted, modified or neglected. Only a plan agreed upon the crew will be instantiated as further flight plan. Besides the autonomous activation of the replanning functions, the pilot crew can make use of the planning knowledge for decision making purposes at any time. Requests for routing and trajectory alternatives or alternate airports can be made with any number of directives and/or constraints. The generated recommendations have no influence on the mission plan, unless they are activated explicitly by the human crew.

In parallel to these functions, the AFP periodically updates the flight plan with respect to usable radio aids, current wind conditions and the actual flight progress.

The specific presentation of the resulting situation-dependent flight plan to the crew by the Dialogue Manager serves directly the realization of basic requirement (1). With its extensive aid in decision making, the AFP also supports requirement (2).

Piloting Expert (PE):

To find necessities for support of the pilot crew, the crew behaviour must be assessed and monitored. Therefore a reference behaviour and an estimation of the remaining resources must be established. This can only be done by processing a crew model of flying the specific aircraft type.

The Piloting Expert is responsible for processing this crew model, which covers normative and individual crew behaviour regarding plan execution [Ruckdeschel, 94][20].

The normative model describes the deterministic pilot behaviour. Most of it is documented in pilot handbooks and air traffic regulations. The knowledge base is represented as petri-nets. The individual model contains behavioural parameters of the pilot and is designed as a real-time adaptive component

The flight plan, as generated by the AFP, is the reference for both, the pilot crew and the PE. The PE uses it, with regard to the current flight progress, to elaborate the currently expected crew action patterns and the remaining resources as well as admissible tolerances for executing these actions.

The connection of this expected behaviour with the resources of the crew enables the assistant system to decide, whether a situation with overcharge will be most likely present. The comparison of the expected behaviour to the actual behaviour, as done in the PIER module, indicates if a situation with overcharge has already occured. Thus, the PE serves both requirements (1) and (2).

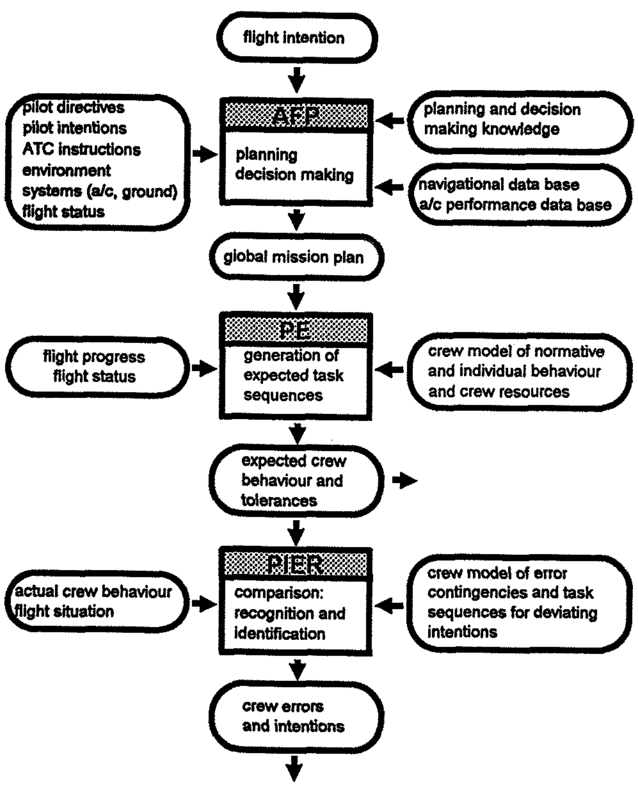

Figure 3: Central information flow of core modules

Pilot Intent and Error Recognition (PIER):

The comparison between the expected and the actual crew behaviour is carried out in the Pilot Intent and Error Recognition module [Wittig,93][21]. In case of a deviation, the PIER has to figure out, if it is erroneous or intentional. In the first case, warnings and hints are transferred to the pilot crew by means of the Dialogue Manager in order to correct the error. In the second case a classification process has identified possible crew intentions.

The intent recognition is performed by use of an inference algorithm based on known intent hypotheses. A crew model of behaviour is processed for each hypothesis. Over time more and more hypotheses are rejected until eventually one may remain as pilot crew intent.

The intent is reported to the AFP for flight plan modification purposes and to the pilot crew, to ensure the intent has been evaluated correctly. The PIER supports the pilot's situation awareness and therefore mainly supports the basic requirment (1).

Monitoring and Executional Services:

The monitoring modules as well as the executional service modules are very close to already developed and applied modules in modern aircraft. Therefore the CASSY-modules for monitoring and execution aiding can be seen as data fusion and interface modules to highly developed aircraft systems. This aspect will be regarded in the scope of the chapter about integrating the system into the aircraft. These modules are an absolute need for the assistant system, since they are all serving directly the basic requirements. In the following some functional aspects are described.

Monitoring Modules

Besides the monitoring of the pilot crew, three main areas of interest for situation monitoring can be figured out. The ***Monitor of Flight Status*** provides the crew and the electronic assistant with data about the present flight state and the flight progress. It reports the arrival at any subgoals of interest of flight.

The status of the aircraft systems is monitored by the ***Monitor of Systems***. Information about defects on aircraft systems are rendered to the crew and the other CASSY core elements, since replanning could be necessary and the expected crew behaviour could be different, subsequent to the modified system configuration. A comprehensive knowledge base about the A/C system functions is not available so far in CASSY. It would be very desirable, though, and will be added at a later state.

The ***Monitor of Environment*** gathers information for the assessment and evaluation of surrounding traffic and weather conditions. When deviations to the stored situation are identified, they are reported to the pilot crew and the CASSY modules.

Execution Aid

The Execution Aid offers a variety of optional service functions, which the crew can request by speech via the Dialogue Manager. The services include configuration management, radio management, autopilot settings and navigational and performance calculations.

Communication

Communication plays an important role in assisting the human operator in order to realize the basic requirements. The need for a centralized communication management becomes quite obvious, when the necessary communication amount between the human crew members and the assistant system is regarded. In figure 4 this information flow is presented.

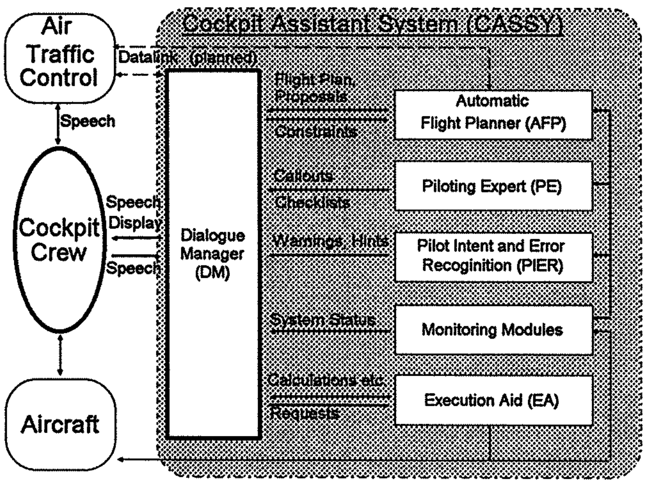

Figure 4: CASSY - Crew Communication

Dialogue Manager (DM):

Within CASSY communication management is realized by the Dialogue Manager [Gerlach,93][22]. It is responsible for co-ordinating the output information flow to the crew and for understanding and coding the input information flow from the crew.

The DM has got access to two components to present the situation to the crew: A speech synthesizer, which allows varying voices and a graphical display (coloured). Warnings and hints are mainly transferred by speech output. More complex information, like the flight situation is presented primarily on the display. Both devices are complementing each other. Another important fact is, that all messages to the crew are evaluated by the DM before output to find a priority ranking. This ensures that the most important and most urgent information is always presented first.

The major input device to CASSY is speech. Therefore a speaker independent speech recognizer is used, which allows on-line switching of active syntaxes. Thus, a context-dependent speech recognition is enabled, which improves the recognition rates. Context-dependent in this case means, that the possible speech input, which has to be recognized, can be defined with respect to the current flight phase, flight plan, autopilot and configuration settings etc. Therefore the complexity of the language model can be reduced significantly with respect to the actual situation.

As long as no datalink to ATC is available, all ATC information must be figured out by the Dialogue Manager by other means. This is done via the speech recognition channel, picking up the obligatory acknowledgements of the ATC instructions by the pilot.

A very promising idea for the improvement of the communication management is the integration of a crew resource model into the knowledge base of the DM, which is currently under development. As one result it will be possible to adapt the information flow to the crew to their actual state of information processing resources.

Obviously, the Dialogue Manager supports both requirements (1) and (2)

Flying with CASSY

One major driving factor for developing CASSY with the described structure has been to improve the present working situation of the aircrew. Therefore it seems reasonable to give a more concrete description of the resulting working situation with CASSY.

During a normal flight, in which no problems occur, the pilot crew will hardly become aware of the assistant system's activities, unless a support function is requested. The flight situation is presented on the display. This means that the flight plan, as generated by the AFP, is displayed, necessary frequencies are indicated, possible conflicts, endangering

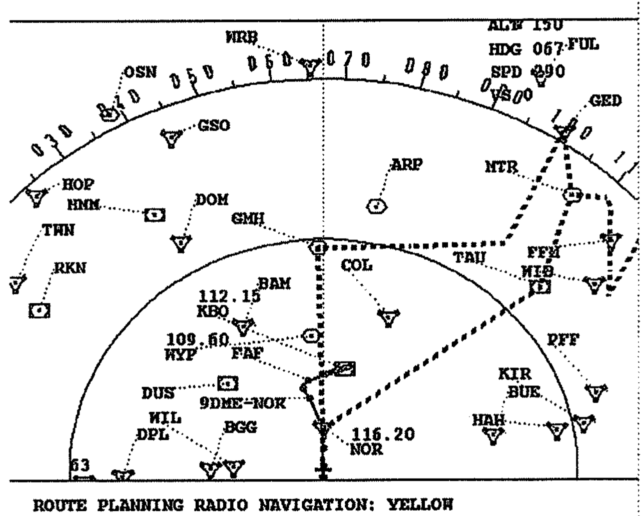

Figure 5: Flight plan map with rerouting proposals

the flight ahead, like thunderstorm areas or missing clearances are illustrated and the next best emergency field is permanently displayed. Figure 5 shows the CASSY display for a specific flight situation.

The flight plan is permanently adapted to the flight progress and ATC-instructions. Every new ATC instruction will be inserted into the flight plan, autonomously. In case of altitude or speed constraints the trajectory profile is updated with regard to the new clearance. Thus, the pilot crew can gather information about the cleared flight-level and the economically optimal flight level just by looking on the display.

Radar Vectors of ATC are also included autonomously into the flight plan and the point, when the aircraft will re-enter a standard routing or reach the final approach is estimated, so that the flight plan remains complete. The resulting actual nominal values for indicated airspeed, magnetic heading, altitude and vertical velocity are indicated permanently to serve as reference for the crew.

Monitoring of Crew Behaviour

Only, in case the crew deviates from these nominal values and the individual tolerances, a hint will be given to correct the error. When the pilot performs a control movement into the right direction, i. e. the trend is correct, the system will be quiet again. When the error is not being corrected after a certain time, the intent recognition module tries to figure out this intention and reports it to the flight planning module to modify the flight plan, accordingly.

The following items are part of the monitoring of the actual crew behaviour at the present state of implementation:

- primary flight data: altitude, course, airspeed, power setting, climb/descent rate, pitch attitude
- configuration :operation of flaps, landing gear, speed brakes
- radio navigation settings

The data are also checked for violations of danger limits, e.g.:

- descent below the minimum safe altitude
- violation of minimum or maximum speed for the current aircraft configuration

Planning and decision support

The planning and decisison support, given by CASSY autonomously, as a result of a detected conflict, or on crew request includes:

- Selection of the best alternate airports
- Selection of the best emergency fields
- route planning
- profile planning
- time planning

All this support is based on the current global situation, including atmosphere data, aircraft systems data etc. and requires minimal crew inputs, although the planning process might be performed quite interactively.

An example for a complex rerouting process is given in figure 6. The aircraft (callsign "CASSY1") approaches Cologne airport in critical weather conditions. During arrival the Monitor of Systems detects a failure of the on-board ILS system. This information is transferred to the crew by CASSY, using speech output. Also the consequences are evaluated, autonomously, which leads to a complex rerouting process, since the weather conditions at Cologne are insufficient for a non-precision approach.

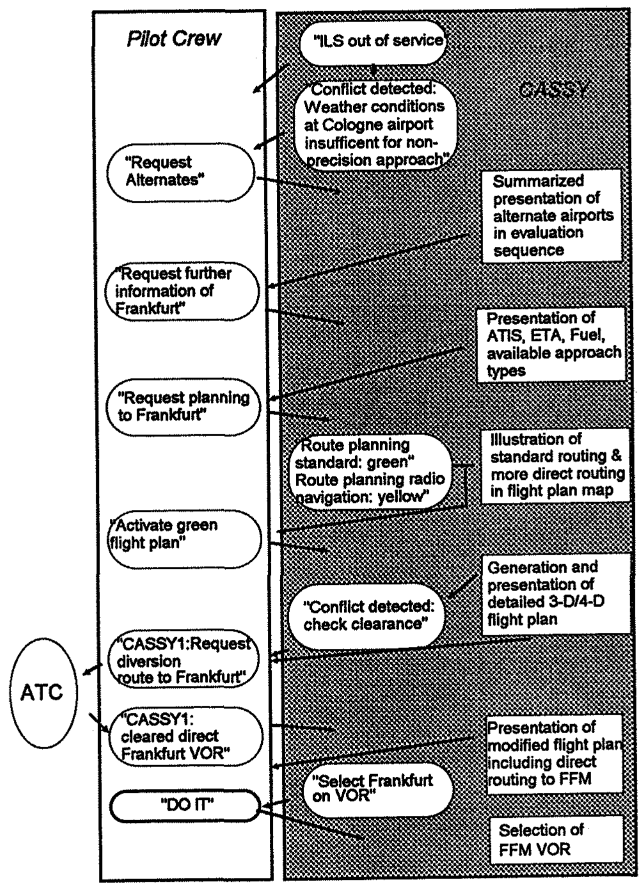

Figure 6 : Complex interactive modification

After the selection of the best alternate airport a rerouting is requested. CASSY offers different alternatives, a routing via the standard arrival route and a more direct routing, using suitable radio aids (example in figure 5). In this case the crew activates the standard routing without modification. CASSY generates the detailed flight plan, but reminds the crew of the missing clearance. When the crew requests the clearance ATC instructs the pilots to proceed directly to FFM VOR. This instruction is integrated by CASSY into the flight plan and the execution is monitored. In this example the crew forgot to enter the frequency of FFM VOR into the RMU. The hint to select this frequency is first given after a certain period of time, since the crew needs some time to cope with the new situation. The crew might respond by assigning this data insertion to CASSY by using the 'DO IT' command.

Integration into modern aircraft

As mentioned earlier in the paper, a modern aircraft cockpit represents a great number of highly developed self-contained automatic systems, which all serve their specific tasks. The approach of integrating a cockpit assistant is not to replace all existing systems by 'the one and only system'. Neither it should be the simple addition of another black box.

Reflecting the present cockpit situation (figure 1), the cockpit assistant should be integrated as the connective part between the different aeronautical susbsystems, including the aircraft systems, the pilot crew and the aircraft environment. The existing subsystems should be exploited as basic information sources or they serve in executional tasks. A possible constellation of an integrated cockpit assistant is illustrated in figure 7.

The comparison of both figures (figure 1 and figure 7) illustrates, that the situation directly in front of the pilot crew is much easier to survey with the integrated assistant system. The use of the existing systems enables the Cockpit Assistant to perform a crosscheck and a condensation of the data from the different information sources before presenting the information to the pilot. This corresponds very well to the basic requirements, too.

On the other hand, the remoteness between the pilot inputs and the aircraft effectors increases. Therefore the primary flight controls should be directly accessible and conventional input devices should remain, where they are most effective. The pilot crew should be encouraged to make as much use of these inputs as appropriate.

The presented integration of the assistant system is an outlook to the future and should be the final goal. At the present state CASSY cannot be connected to all the other subsystems but most of the functionalities can be provided with the present infrastructure of the aircraft. Most of the essentially required data are already available and can be read from the avionics data bus. The data link to ATC can be bridged by speech input. Speech output devices are already part of a modern airline cockpit and the necessary display area is also there. The working situation for the aircrew with cockpit assistant was demonstrated in simulator runs. Flight tests are scheduled for May this year.

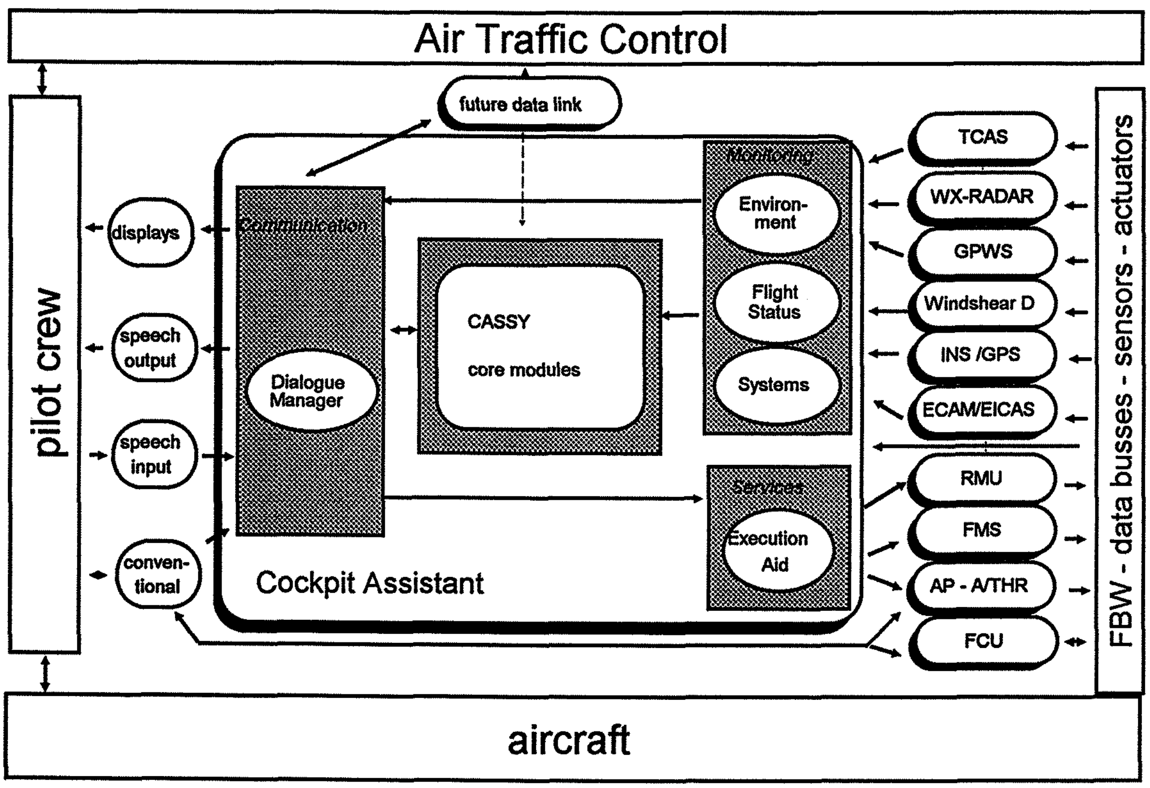

Figure 7: Cockpit situation with integrated assistant

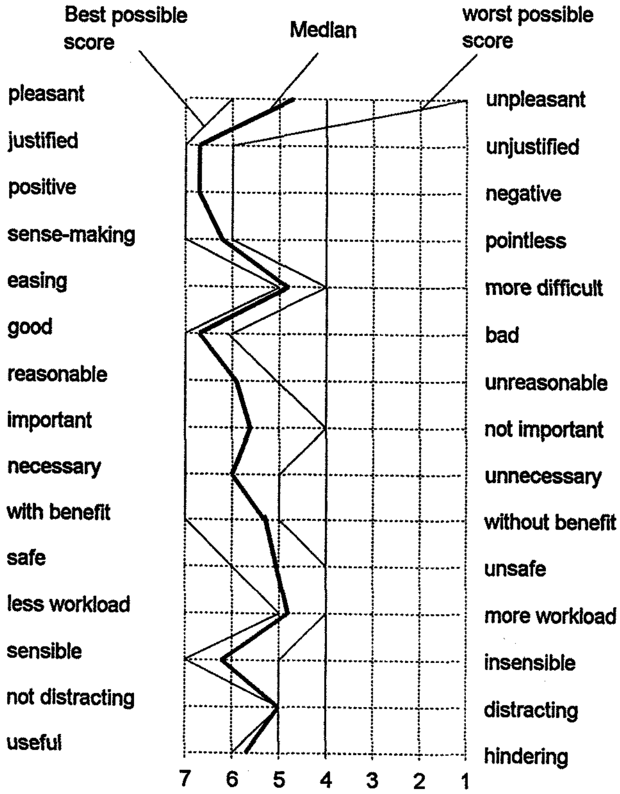

Figure 8: Evaluation of crew monitoring

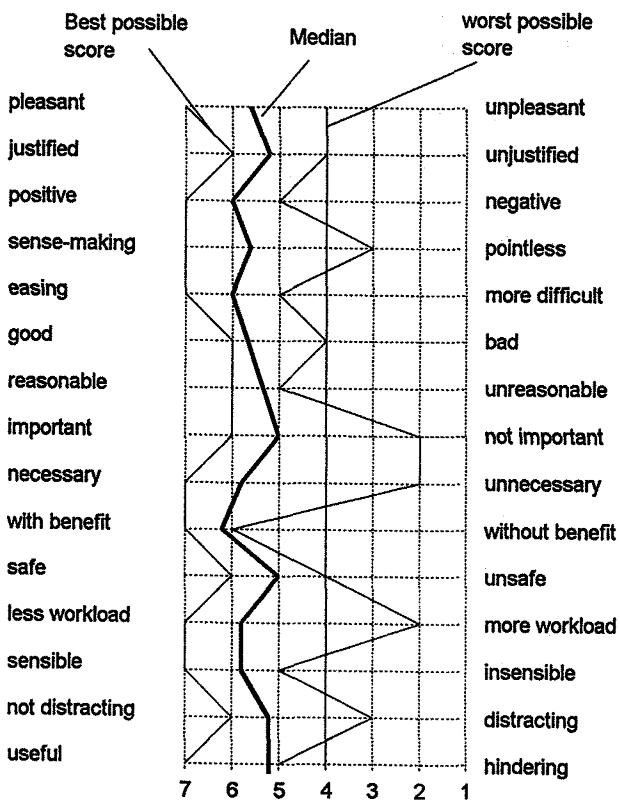

Figure 9: Evaluation of planning support

Simulator testing

For simulator test runs CASSY has been implemented into two different flight simulators at the University of the German Armed Forces, Munich and at DASA-Dornier in Friedrichshafen. The simulator in Munich is a one-seat fixed base simulator with artificial stick force and artificial outside vision capabilities. The modelled aircraft is a twin engine jet, representing a typical regional aircraft.

In Friedrichshafen the system has been integrated into the Dornier DO-328 simulator, which represents a modern glass cockpit.

The very first extensive simulator experiments have already been made in Munich in 1989 with the CASSY-predecessor ASPIO [Onken,92](23). These experiments, which were concentrated on the approach flight phase, led to the following results:

- flight accuracy was significantly improved
- all pilot errors were detected and corrected
- planning and decision processes were significantly accelerated
- pilot workload was slightly reduced.
- the Cockpit Assistant was well accepted by the pilots

During the further development of CASSY pilots have been consultated at any decisive step and in 1993 the next extensive experiments have been made in Munich and in Friedrichshafen. These experiments covered all flight phases and a big amount of typical events disturbing the flight.

The basic tendency of the former results was confirmed by the pilots (airline). Picking two of the main areas of evaluation "monitoring of the crew behaviour" and "planning and decision support", the figures 8 and 9 show the results of the pilot scores. In these cases the scoring technique of semantic differntials was used.

Flight tests

After successful simulator tests, the performance of the system has to be demonstrated in flight experiments. These flight tests, which are scheduled for spring '94, are presently prepared. The flight tests are conducted in co-operation with the German Aerospace Research Department (DLR) and DASA-Dornier. CASSY will be integrated into the experimental cockpit of the ATTAS test A/C of the DLR. For testing typical IFR scenarios, the Frankfurt area has been chosen. In addition, two flights from Braunschweig to Hamburg and vice versa are also scheduled.

For the assistant system a Silicon Graphics IRIS-Indigo workstation has been chosen as experimental hardware. The interfaces to the other aircraft susbsystems are realized by using ethernet. The speech in- and output devices will be connected via a standard RS 232 interface.

Conclusion

The present working situation of the aircrew in a complex transport mission environment demands further improvements to ensure human-centered design and resulting maximal flight safety. The simple addition of more isolated automatic systems for certain subtasks is not the way to go to solve the oncoming problems. The design of new automatic systems has to reflect the basic requirements for machine support to achieve a co-operative distribution of tasking between the human and the electronic crew member.

The Cockpit Assistant System CASSY is being developed as a co-operative support system, which is primarily focused on realizing the basic requirements. Although there is still a long way to go, such a system could be integrated into a next generation cockpit. All hitherto existing results of experiments and questionaires confirm this approach.

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