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Pilot's assistant in tactical transport missions -

Crew Assistant Military Aircraft CAMA

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Dipl.-Ing. Andreas Lenz
Prof. Dr.-Ing. Reiner Onken
University of Armed Forces Munich
Werner-Heisenberg-Weg 39
D 85577 Neubiberg / Munich
Germany
Tel. -49-89-6004-2233 or -3452
Fax -49-89-6004-2082
andreas.lenz@unibw-muenchen.de reiner.onken@unibw-muenchen.de

Summary: New information technology promises more information and advanced automated functions in future cockpits of military aircraft. However the cognitive human capabilities stay the same. This may result in an overload of the human pilot. Cognitive assistant systems are being developed to compensate for this mismatch. This paper introduces principals of cognitive systems which exhibit human-like capabilities as interpretation and diagnosis of the situation, planning and decision making. Furthermore, CAMA (Crew Assistant Military Aircraft), a prototype of a cognitive assistant system, will be introduced. CAMA's functionality will be shown and some results from flight simulator test runs will be presented.

Motivation: Environment and scenarios of military transport missions have changed over the last few years and will definitely undergo even more changes in the next decade. New information technology, including telecommunication as well as hardware which is continuously growing more powerful will find its way into the future military aircraft. Online data of upcoming threats, detailed weather information, terrain data and knowledge about weapon systems will be available. Combined air operations with participation of AWACS, fighters, bombers and transport aircraft are likely with the need for more communication.
There is a rising amount of mission-relevant information, that has to be processed by the human operator who is also in charge of flying the aircraft. Considering the complexity and manifold of automation in current cockpits and even more in those of the next generation it can clearly be seen, that it will become more and more difficult for the human to keep situation awareness and perform all the tasks in an efficient way without errors.
This leads to the central question:

How can we make the best use of the potential given by the new technologies without overloading the cognitive capabilities of the human operator ?

There is an approach where automation in the conventional way is being added to the cockpit, hoping for increased productivity and effectiveness. As we know from experience, however the conventional automation can increase safety only up to a certain level. Further increase of complexity in the conventional way can lead to a safety decline as shown in figure 1 in its principal relationships.

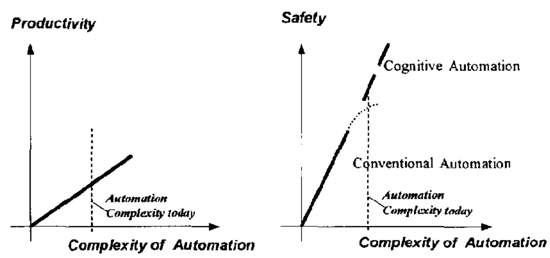

Figure 1: The Effect of Conventional and Cognitive Automation on Productivity and Safety

Recent accidents of commercial aircraft with state-of-the-art "conventional cockpit automation" provided sufficient evidence for this particular consequence. [1] identifies besides complexity as such also other design elements more or less as part of complexity like

- coupling of automated features,
- autonomy with unexpected self initiated machine behaviour and
- inadequate feedback

which are typical causes for respective mishaps. In military aviation the situation can be expected to be critical due to permanently increasing requirements for information processing.

Cognitive automation: How can this situation be dealt with? The critical point is, how automation can be done in an effective manner. Automation should not be a replacement for the pilot, but instead should work in a cooperative way with the pilot. In the ideal case it

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should work like a kind of "electronic crewmember", with the cognitive capabilities like those of the human, but without all its possible deficiencies.
[2] postulates *basic design requirements* founded on these cognitive capabilities:

Requirement (1) is to avoid failings in situation awareness and reads:
It must be ensured along with the representation of the full picture of the flight situation that the attention of the cockpit crew is guided towards the objectively most urgent task or sub-task as demanded in that situation.

Requirement (2) is to avoid overcharge in decision making/planning/plan execution and reads:

Situation awareness might have been achieved and still a situation with overcharge of the cockpit crew might come up. In this case the situation has to be automatically transferred into a situation which can be handled by the crew in a normal manner.

"Cognitive automation" is the only way to ensure increase of productivity through automation without loss of safety (see fig.1).
The difference between cognitive and conventional automation can also be illustrated by Rasmussen's scheme of human cognitive behaviour [3].

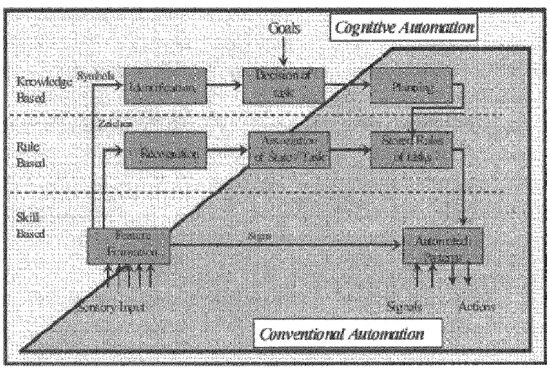

Figure 2: Conventional vs. cognitive Automation [4]

As figure 2 shows, conventional automation covers nearly the whole of skill based human behaviour. The rule based behaviour can only partly be covered, and on the knowledge based level only planning calculations can be provided by conventional automation.

Cognitive automation comprises the entire rule and knowledge based level, as well as the skill based level, thereby giving the system human like capabilities to:

- independently assess the current goals of the crew, as well as information about the aircraft, the environment including the tactical situation, the weapon systems and the aircrew activities
- understand the flight situation by independently interpreting the situation subject to the goals
- detect the pilot's intents and possible errors
- detect possible conflicts of current plans but also the opportunities arising from the changing environment
- know which information the crew needs
- support necessary re-planning and decision making
- initiate a natural, human-like communication to match the system's internal pictures of the situation with those of the pilot.

The symbiosis of cognitive automation combined with the strength of the human will lead to a more efficient and safer mission execution

The Cognitive Process: To realise the cognitive approach as a technical process human cognition provides a good guideline. The following core elements can be identified:

- Situation monitoring (perception and interpretation)
- Diagnosis of the situation
- Decision making and/or planning
- Execution/activation

They are forming the cognitive loop as shown in figure 3. The environment of the cognitive assistant, which is named the real world, presents stimuli, which can be detected by different kinds of sensory systems. Both the environmental stimuli outside and inside the cockpit are taken into account. This represents the *situation monitoring* element, which comprises the process of perception of all relevant situation features. This is closely interrelated with the process of situation analysis in order to achieve a certain level of abstraction, thereby establishing situation-relevant "objects" which help to understand what is different

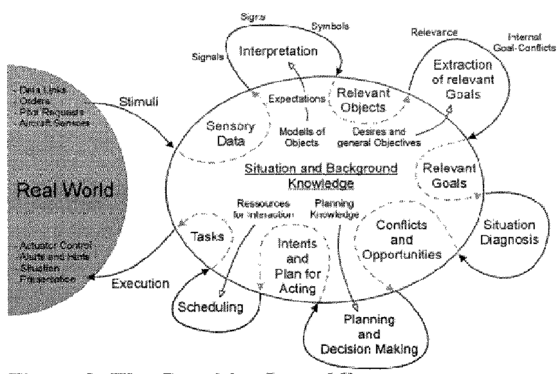

Figure 3: The Cognitive Loop [6]

between the expected and actual situation. These differences are dealt with in a higher level of abstraction by the so-called *situation diagnosis* process. The differences are evaluated against given objectives, the *relevant goals*, which are known to be pursued during the mission, and which are the same the aircrew has in mind. Only the knowledge about these goals makes situation awareness possible in the technical cognitive loop. Thereby conflicts and/or opportunities may be detected which may call for immediate actions or some flight plan changes.

In the latter case a *planning process* is activated to generate alternatives for interim-goals, plans, and actions. In compliance with the given overall objectives, the most appropriate ones are chosen for proposals.

Concerning the assistant system, the *execution* element of the cognitive process plays a very central and important role, as it includes the communication with the crew. It is carried it out on the basis of profound internal knowledge about what information the aircrew is looking for, why and when. On the other hand, the crew should at any time be able to ask for certain information within the system. A sophisticated MMI is required to accomplish this task.

It is also taken into consideration that the crew may react different compared to the systems proposals, because certain factors were not taken into consideration at system design time. Thereby, new stimuli are generated for the cognitive loop, which starts again and copes with the crews action. The feedback via these stimuli creates a kind of implicit communication.

CAMA – The Prototype of a Cognitive Assistant System:

Military transport missions put great demands on the crew. The typical scenario is composed of IFR and tactical flight sections, as shown in figure 4.

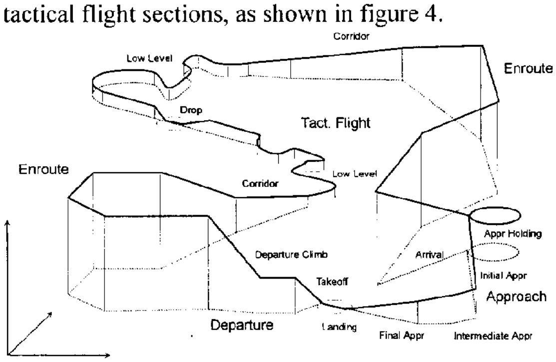

Figure 4: Mission Profile

While flying IFR, the aircraft may operate in a high density airspace. Separation to other aircraft has to be ensured. The tactical scenario is entered via a transition corridor. Constraints in time and space have to be met. Tactical flying will be mostly low level flying, using terrain masking, even under adverse weather conditions. Additionally, the scenario changes at a high rate along with quick reaction required at times. Concerning these conditions, technical cognitive assistance for the flight crew seems to be very promising.

Therefore, the German DoD started a program, called CAMA (Crew Assistant Military Aircraft), in order to have demonstrated the power of cognitive automation for transport missions. CAMA as a prototype cognitive assistant system has been developed by the University of German Armed Forces Munich in close cooperation with DaimlerChrysler Aerospace, ESG (Elektroniksystem und Logistik GmbH) and DLR (Deutsches Zentrum für Luft- und Raumfahrt) (see [7] [8]).

Structure and Functionality of CAMA:

The Crew Assistant Military Aircraft provides functionalities in compliance with many parts of the cognitive loop. Again as depicted in figure 5 the system is embedded in the real world environment. Information about this environment can be perceived by means of sensors and data links.

The outer layer of CAMA performs perception and interpretation of the relevant situation elements of the real world. The process of ***environment interpretation*** as well as the ***interpretation of the aircraft state*** provides information about the actual weather, the proximity to the terrain, other aircraft, as well as the current state of aircraft subsystems. Tactical information which consists of the mission task, ingress and egress corridors and actual threat situation may be fed into the system. Additionally, data from computer vision systems are included for machine perception of relevant obstacles like landing strips and obstacles on uncontrolled strips under low visibility conditions.

All these pieces of relevant information are put together to form a central situation representation that provides all the data which other CAMA modules might need or which are produced for further processing like the ***evaluation and the interpretation of the pilot's action.*** This core element of CAMA forms a close functional relationship with the inner functional layer of the system for diagnosis and detection of conflicts and opportunities. The elements of the central situation representation that represent the relevant objects of the real world are evaluated against the expected behaviour of the pilot, the predicted state of the aircraft and against the overall mission objectives.

In order to monitor the pilot's behaviour the assistant system needs a representation of the expected pilot actions. In CAMA a normative model [9] describes the ***pilot's behaviour*** close to that as documented in handbooks and air traffic regulations. An adaptive model [10] covers behavioural traits of the individual pilot flying. If the actual pilot behaviour differs from the internal representations of CAMA then it can be classified into either ***errors*** or ***intents*** (see [11] [12]) 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.

If the pilot behaviour is classified as an error a warning message is generated and a corrective action is proposed to the pilot. Upon a detected intent the internal plan is adapted accordingly. Thus an implicit communication between the pilot and the system takes place, which allows the pilot to react to the current situation without having to tell the system explicitly.

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

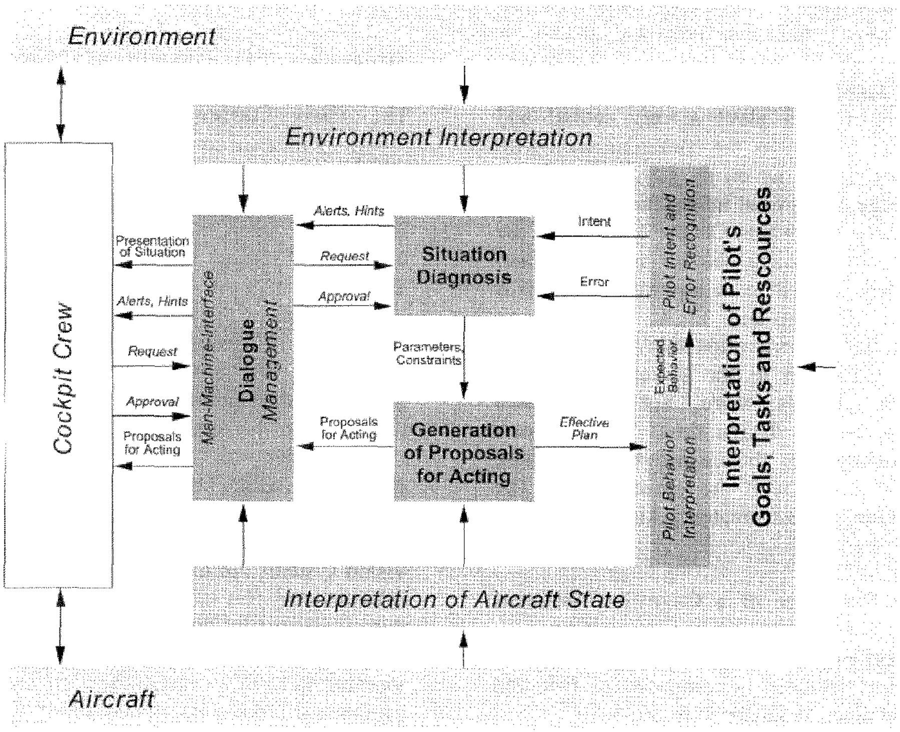

Figure 5: Functional structure of CAMA

vertical profile, time estimates and fuel planning [13] as well as information from a navigational database. Mission constraints which may change during the flight (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 (see [14] [15]) 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 aircraft 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 being accepted from them , modified or rejected respectively.
The calculation is done in terms of only a few seconds, always giving the pilot an idea of what would be a good plan in the current situation.

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

Ground proximity is continuously monitored. Therefore, all possible flight trajectories, achievable by full exploitation of the aircraft performance capabilities, are checked for terrain avoidance (using a Digital Elevation Data database). Again a warning is given, visual and by voice. In addition an evasive trajectory is generated.

CAMA also generates ***proposals for acting*** as part of the conflict resolution which involves planning and decision making support. This functionality ranges from very short term planning 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 conflict solving strategy. Again all relevant data needed is passed over from the situation representation module. In case of overall flight planning all accessible information about the flight is passed to the mission planner. This includes mission oriented goals and constraints that can be

The advanced functionality of CAMA requires a sophisticated user interface to let the pilot make advantage of the system capabilities. Care has to be taken in the design of the MMI, not to produce an extra cognitive workload.

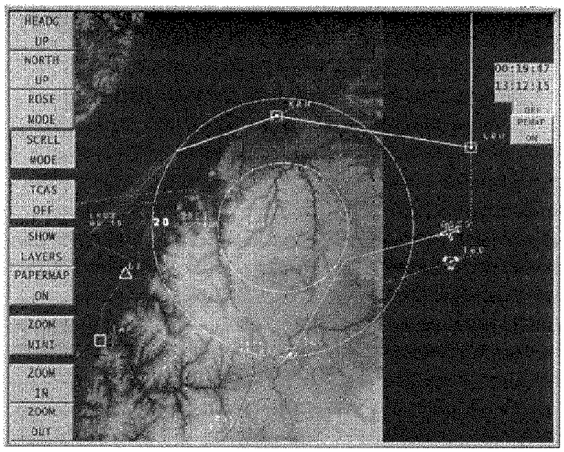

Figure 6: CAMA Nav-Display with Terrain and Tactical Elements

The ***Dialogue Management*** module [18] of CAMA ensures that the communication is provided to support situation awareness in the best way possible in all flight conditions. It is based on the multimodal approach, which means that all pilot inputs can be performed by speech, touch-sensitive screens as well as conventional line select keys or switches. Output makes use of the currently available display technology and is presented by means of three high resolution color displays. Speech output is used in parallel to textual messages. The simple graphical user interface delivers a good usability already after a short introduction to the system.

Pilot inputs can be:
- Request of flight planning actions
- Activation, modification or rejection of proposals
- Activation of actions related to warnings
- Retrieval of information
- Autopilot operations
- Configuration of the MMI
- Radio management

CAMA outputs can be:
- Presentation of calculated flight plan proposals in graphical as well as textual form
- Situation presentation including tactical and threat information
- Warnings about detected conflicts
- Recommendation about explicit actions
- Messages in reply to requests
- Acknowledgement of speech input
- Presentation of complex actions like briefings, checklists etc.

Several MMI devices provide support for the flight guidance task. For low level flying under difficult weather conditions the primary flight display can be switched to a 3-dimensional presentation of the surrounding environment [13].

Results of Simulator Flight Trials:
CAMA is integrated in the flight simulator of the University of the German Armed Forces, Munich. This simulator provides a wide field of view visual simulation. It is based on digital terrain and feature data and shows objects like rivers, streets, railroads and powerlines which makes it suitable for low level flight simulations based on terrestrial navigation. Three high resolution colour monitors with touch-overlay are used to display CAMA outputs. Also a number of realistic flight controls are available, including a throttle box, flaps, gear and spoiler levers, as well as an Airbus-type flight control unit for autopilot functions. All controls can be actively driven by CAMA on request of the pilot.

Figure 7: Test Flight Simulator

In November 1997 and May 1998 flight simulator test runs were conducted (see [17]). 10 German Airforce transport pilots (Airlifter Wing 61, Landsberg) were participating as test subjects. The pilots were tasked with full scale military air transport missions. This comprised a mission briefing with following takeoff from base, an IFR leg to the ingress corridor and a low level flight to a drop zone. The flight over hostile area contained a dynamic tactical scenario with multiple SAM stations (Surface to Air Missiles). After the drop was accomplished the flight was led to the egress corridor, followed by an IFR flight segment to the home base.
Each subject had to perform the mission three times. There was not much time needed for familiarisation and training on the system.
To set up an realistic level of workload several scenario items were put in the missions, which required an action by the pilot.

The IFR segment incorporated:
- Adverse weather conditions
- High density airspace (Other aircraft crossing the own flight path)
- 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

All ratings were given within a range from 1 to 7, where 1 represented the best and 7 the worst score. A choice of the results is shown in figure 8, 9 and 10, where the ratings are numbered due to the order of test runs.
A detailed and complete documentation of the test runs and its results is given in [17].

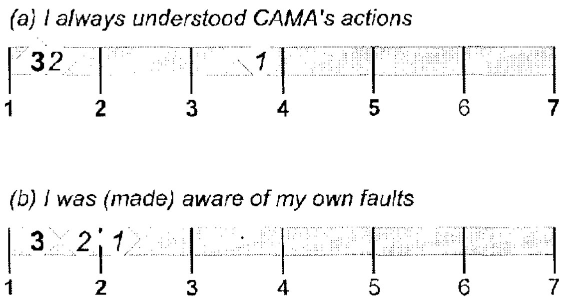

Figure 8: Evaluation of the Cooperative Approach of CAMA

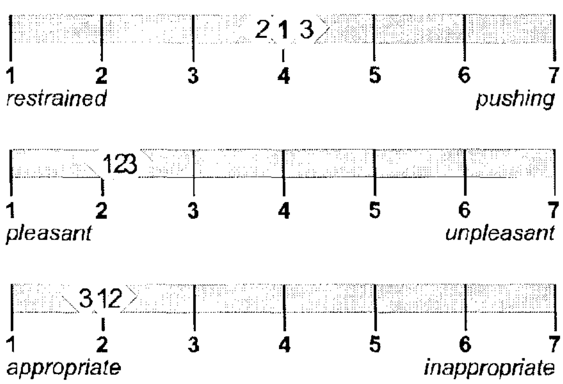

Figure 9: Acceptance of CAMA by Pilots

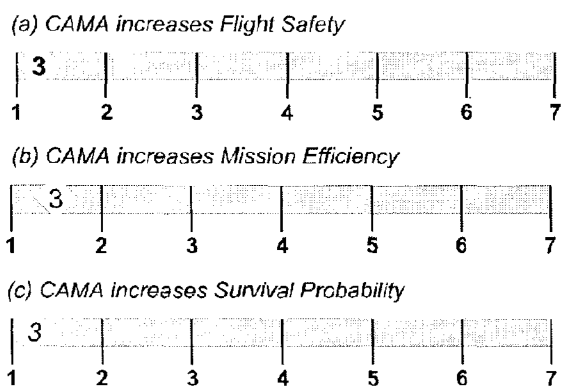

Figure 10: Overall Evaluation of CAMA

Especially the rating concerning the overall evalutaion as shown in figure 10 points out clearly the benefits of an assistant system like CAMA. Like the test subjects stated, CAMA:

- ***increases Flight Safety***
- ***increases Mission Efficiency***
- ***increases Survival Probability***

A more objective analysis of the flight simulator trials was done by [20] using an eye tracking system and a data recording tool. More information on this topic can be found in the respective paper in the same proceeding.

Actual research:

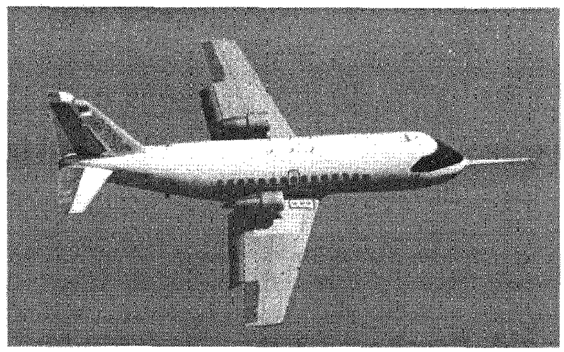

Figure 11: Experimental Aircraft ATTAS

Recently CAMA was being integrated in the in-flight simulator ATTAS of the DLR (shown in figure 11) and was successfully tested and demonstrated in several flight experiments in March 2000. Further trials are scheduled for November 2000. These flight tests comprised IFR and low level flight segments as they occur in a military air transport mission. Again subjects were experienced air transport pilots from the German Air Force. Data from sensor input as well as the internal system states were recorded, which will allow a replay of the conducted flights in the experimental flight simulator at the university of armed forces in Munich.

Conclusion: Future battlefield scenarios will be characterised by the availability of a greater amount of information. Onboard information processing puts great demand on the aircrew, which may lead to overcharging of the crew.
To cope with these changing conditions, the approach of a cognitive assistant system was investigated. It offers support to 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. It has become increasingly evident that this cannot be achieved without moving towards the cognitive approach.
The presented approach and its realisation in the prototype system CAMA has been demonstrated. The benefits are already demonstrated in the course of simulator trials and In-flight demonstrations.

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