CONCEPTUAL MODEL "STAGE" AND INTELLECTUAL SUPPORT OF THE SOLUTION PROCESS OF "TACTICAL PROBLEMS" BY CREWS OF AIRCRAFTS

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Abstract: *This paper is about the conceptual model "Stage" and its use in the development of on-board advisory expert systems of an operational goal setting (OAES-goal setting) and flight stages OAES-typical situation (TS).*

1. Introduction

In the last third of the twentieth century, DARPA of the USA announced the research work - "Pilot`s Assistant", which sets the task of developing operational recommendations to the crew on how to solve the task / problem on board of a combat aircraft. It was quickly discovered (in the USSR and in the USA) that such an "integrated system" would not be able to be created, that first it needs to work out another conceptual view of the aircraft (the conceptual model of the aircraft) and to determine the nomenclature of the systems supporting the crew decision process from this model's position, arising during the execution of the flight task. The description of the tasks and composition of such nomenclature were determined on the basis of the conceptual model "Stage" which is presented below.

2. Conceptual model "Stage" for the aircraft [1]

The model formalizes the flight process of the aircraft and classifies tasks that should be solved on its board.

The formalization of the flight process of the aircraft's flying activity includes a conceptual model of the flight process of an aircraft (a group of aircraft) (the upper part of Fig. 1).

The "Stage" model contains a set of assigned sessions of functioning (in the terms of reference (ToR) for the development of the anthropocentric object (A/O)) to the algorithmization (with the description of the general task of functioning (GTF) of each session); the presentation of each session through a semantic network of typical situations (or typical combat situations (TCSs)) and the presentation of each TS through a semantic network of problematic subsituations (PrS/Ss). Semantic networks are built on a cause-effect relationship.

As a rule, each GTF has attached expected external and intra-board threats which are described as a set of TS-threats.

The set of TS is finite and is constructed on the whole set of the functioning sessions (in the development of the aircraft).

It should be noted that each TS contains the ultimate goal of the TS and the way to achieve it, broken down by its PrS/S.

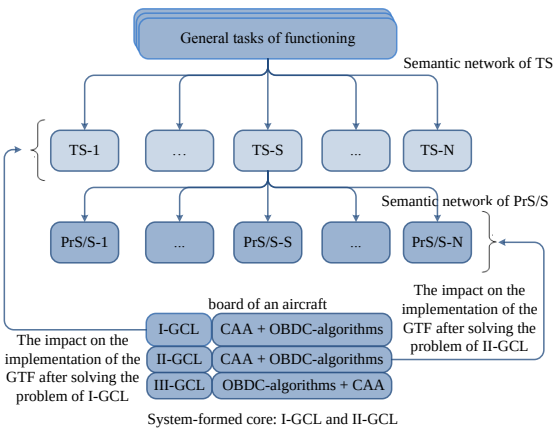

Fig.1. *The model of an aircraft "Stage" for the design of the on-board algorithmic and indication support (OA&IS) of the system-forming core of the aircraft*

Classification of aircraft tasks (the lower part of Fig. 1) includes the allocation on its board of three global control levels (GCLs), in each of them, the leading role of the crew activity algorithms (CAAs) or OBDC-algorithms programmed in on-board digital computers (OBDC) (OBDC-algorithms) are determined :

1. The first GCL is the level of operational goal-setting (I-GCL). In terms of the "Stage" model, the result of solving this problem is the assignment of the current TS. In Fig. 1, this is shown as a "feedback" from the I-GCL to the line of TS.

2. The second GCL is the level of constructing a rational method for achieving the TS (II-GCL, operatively assigned by I-GCL.) In terms of the "Stage" model, the II-GCL task is interpreted as the operational construction of a specific fragment of the semantic network of PrS/S of the assigned TS. in Fig. 1 this is shown as a "feedback" from II-GCL to the line of PrS/S of named TS;

3. The third GCL is the level of realization of the method of achieving the goal (III-GCL), designed on the II-GCL.

Tasks of the I-GCL and the II-GCL are solved in the system-forming core of the A/O. These tasks are usually called tactical.

In the "Stage" model it is established that the crew is necessarily involved in the solution of the tasks of the I-GCL and the II-GCL. In Figure 1, this is indicated by the abbreviation CAA. At the same time, the process of solving the problems of these GCLs by the crew is supported by the OBDC-algorithms. Full support of this process is possible only if on-board intelligent tactical level systems (OITLS) are deployed on board of the aircraft, which must solve the corresponding tasks and provide the crew with the recommended method for their solution. The implementation of recommendations by the onboard executive systems comes only after the crew has agreed to this. Because of this, such systems are classed as operationally advisory systems.

The "Stage" model classifies OITLS, highlighting:

- intelligent systems ((on-board intelligent systems) OIS_I-GCL), solving tasks of the I-GCL;
- intelligent systems (OIS_II-GCL), solving tasks of the II-GCL.

The model of the functioning of the aircraft group (Fig. 2). To develop an OA&IS for the operating of the aircraft group performing the same GTF, a three-level functional hierarchy of the group is adopted:

- a commander of the first level of control in the group (K-I). He's one in a group;
- the second-level commanders in the a group (K-II) subordinate to K-I. There are up to four of them in the a group;
- commanders of the third level of control in a group (K-III), subordinate to the commanders of K-II. Each K-II commander has up to four K-III commanders under control.

There are two information flows in the group: the flow of control (commands) from the top to down (KI⇒ KII⇒ KIII) and the flow of current information (the flow of notification) from the bottom to up (KI⇐KII⇐ KIII, KI⇐ KIII).

A group of aircraft before a session of functioning is preparing to perform GTF, receiving a priori information on the upcoming flight (flight assignment (FA)) to the board. During the flight, the number of the aircraft in the group may decrease, but in the remaining part the functional hierarchy of the group accepted before the session is operatively saved.

At each stage of the session, all the aircraft in the group are in the same TS.

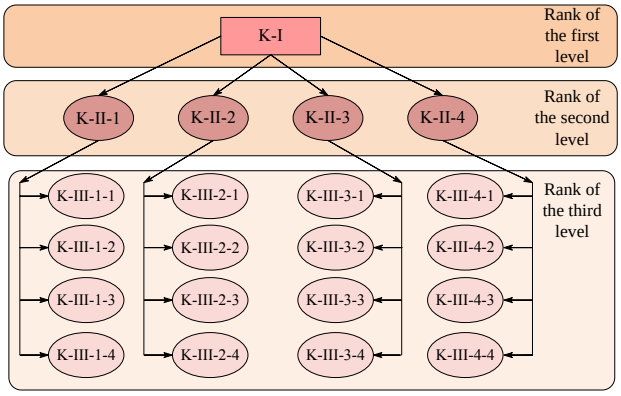

Fig.2. *The hierarchy in a group of aircraft*

Aircraft of the 4th generation in the development of OA&IS and crew`s guidance for their application were focused on the following conceptual model of the object.

In accordance with the ToR for the designing of the aircraft a number of possible episodes are identified, which can occur in flight. For each episode its OA&IS should be developed, regardless of the rest of the episodes. The concept of GTF in this model is absent. This conceptual model of an aircraft is called the conceptual model "Episode".

When using this model for the design of an OA&IS, the concepts of the GTF, flight stages and GCLs appear only in the aircraft application manual. Such episodes in the semantic network of PrS/Ss of the flight stage are shown to the crew "how to collect them".

However, even on the latest developments of the 4th generation aircraft, the designers found out the "Episode" model is inadequate, and there was a need to design an OA&IS using the new conceptual model of the aircraft, called the "Stage" model.

2.1. On-board intelligent tactical level systems

We will describe the composition and functions of the onboard intellectual systems that solve the problems of the system-forming core of the aircraft.

Computer intelligent systems to support the aircraft crew decision process of operational goal-setting (OIS_I-GCL)

The process of solving the task of operational goal setting by the crew is supported by the OIS_I-GCL: the Intelligent Information System "Situational Awareness of the Crew" (IIS-SAC) [3] and the on-board advisory expert system "Operational goal-setting" (OAES-goal setting) [4,5].

Both of these systems operate throughout the entire flight of the aircraft. They inform the crew about the emerged external and intra-board immediate threats (IIS-SAC) and recommend to the crew the current flight target (OAES-goal setting), taking into account the flight stage, the FA and the type of the threat that has arisen. We briefly describe these systems using information from [3 - 6].

The decision of the task by the crew of operational goal-setting includes three components: circumspection, situational awareness, situational confidence.

The crew's circumspection is supported by on-board algorithms (OBDC-algorithms) of integrated / complex information processing coming from on-board information systems, and OBDC-algorithms for allocating potential threats. Potential threats are presented to the crew on the information-control field (ICF) of the information frame of the information model of the external and intra-board situation, placed on the multifunctional display (MFD). An example of the presentation of the potential air threats on such model of the fighter Rafale, see [7].

Situational awareness of the crew is provided by the intellectual information system "Situational Awareness of the Crew".

The Intelligent Information System "Situational Awareness of the Crew" reveals among the observed potential threats to the implementation of the mission the immediate threats (ITs) and ranks them.

In its knowledge base (KB), which uses information from the OBDC-algorithm of the integrated processing of primary information and information from a number of on-board measuring systems, ITs are identified and their development are projected. Such a prognosis is used to determine a kind of "point / moment of non-return", when it will be impossible to effectively counteract the threat by existing resources onboard of the aircraft. Information about IT is presented to the crew on the ICF. Intelligent agents (threats, objects), mathematical models (MMs) of the collision "Threat - Object" with algorithms for calculating the "points of non-return" of these threats are included in the KB of the IIS-SAC. The threat that is most "close" to its "point of non-return" is declared a priority [3].

The ITs which are identified by the IIS-SAC are constantly presented to the crew on the ICF and through speech informants.

Situational confidence of the crew is provided by the on-board advisory expert system "Operational goal-setting" (OAES-goal setting).

The priority IT found in the IIS-SAC, which is "near" its "point of non-return" comes immediately to the OAES-goal setting. Among the other ITs, the OAES-goal setting will receive only a threat previously allocated by the crew.

The OAES-goal setting operates in three modes, each of which is activated under the following conditions [4,5].

Mode I is activated in the OAES-goal setting, when the aircraft is at the current stage of the implementation of the FA and the OAES-goal setting received an IT from the crew. In a number of cases, the OAES-goal setting can involve the crew to estimate the current situation.

In this mode, the previously positive experience of counteracting the identified threat is accumulated, formalized in its KB in the form of a knowledge matrix, is included in the OAES KB. Using the precedent conclusion in the KB, the priorities of possible solutions (precedents) of the crew are calculated [6]. The decision (selected TS) with the highest priority is recommended to the crew.

Mode II is activated in the OAES-goal setting, when the aircraft was in a situation of counteraction to the threat (TS-threat) and in it a signal "The Threat was Passed" was produced. OAES-goal setting involves the crew to estimate the current situation.

In this mode, in the KB of the OAES-goal setting is not always a reliable estimate of the current state of the aircraft and the state of its crew. Therefore, the OAES-goal setting requests this information from the crew and, in view of this, allocates those TS-flight stage, which the aircraft can still implement.

Mode III is activated in the OAES-goal setting when a threat occurs "near" its "point of non-return", received from the IIS-SAC. In this case, the IT enters the OAES-goal setting and the recommendations developed by it without the sanction of the crew activate the corresponding on-board intelligent tactical level system.

Computer intelligent systems to support the decision process of the aircraft crew for the task to design the way to achieve the operationally assigned current flight objective (OIS_II-GCL).

The on-board intelligent systems of the II-GCL include on-board advisory expert systems of typical flight situations (OAES-TS) [8].

An OAES-TS is one of the main components of the aircraft's flight intelligence (a new class of on-board algorithms) that operatively determine the rational methods of aircraft`s behavior in a typical flight situation. For each TS, a OAES-TS should be created. The conceptual model "Stage" is put in the structure of the KB of OAES-TS [2].

The "outside world" in which the OAES-TS will operate is the airborne information environment of the aircraft, formed by the output information of the on-board measuring systems, "standard" (not included in the knowledge base of the OAES-TS) OBDC-algorithms and signals from the ICF (Fig. 3).

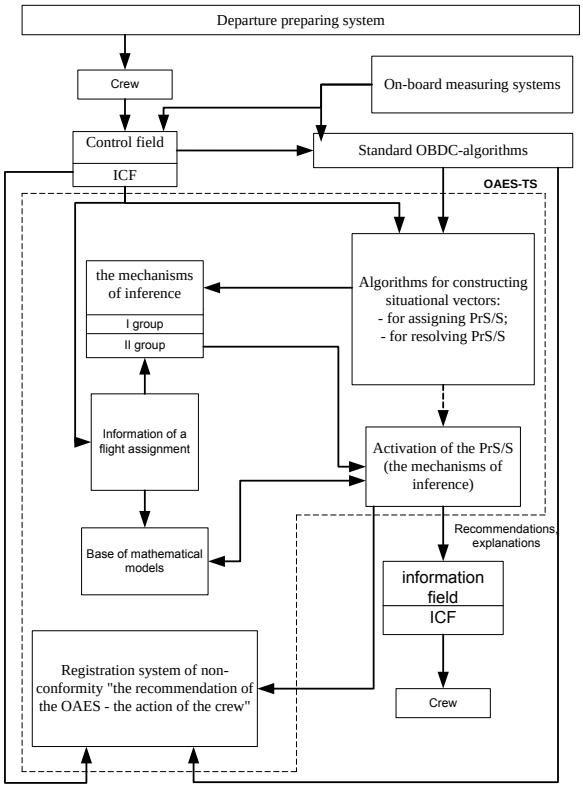

Fig. 3. *Functional diagram of the OAES-TS*

When preparing the aircraft / group of aircraft for a flight from the departure preparing system in the OAES-TS, a FA (a priori information) is loaded: a TS-FA network, a list of expected threats and a set of corresponding TS-threats.

In the process of performing the session for each significant PrS/S for performing the current TS, the OAES-TS prepares recommendations for the crew on its resolution with brief explanations. Recommendations and explanations to them appear on the ICF. The crew has the right not to accept the recommendation made by an OAES and resolve the arising PrS/S in a different way, without informing the OAES-TS about it. At the same time, the next recommendation of the OAES-TS will have to be worked out, taking into account the method implemented by the crew. Any ignoring by the crew of the constructed OAES recommendations is fixed in the on-board system of objective control (in Fig. 3 the block "Registration system of non-conformity ..."). After the end of the flight, this information is transferred to system of analyzing the results of the last flight.

The recommendations of the OAES-TS should be constantly coordinated with the activated model of the crew's behavior at the conceptual and operational levels. The crew perceives the outside world and the technical condition of the aircraft (the intra-board world) through their senses and the cabin information model of the external and intra-board situation on the ICF. Possessing professional training and having a priori information (the most general about the outside world and concrete about the upcoming session), the crew, within the framework of its activated model of behavior each time allocates the current problem (PrS/S) without informing the OAES-TS about it. The OAES-TS should give at the current time a valid and effective recommendation for this PrS/S for its resolution.

The presentation of the list of the main features of OAES-TS:

- it must solve all the problems of its TS (to be closed on TS problems);
- to have a limited dialogue with the crew (restrictions on the time limit issued to the crew by the external environment, and on the possibilities of input of information by the crew through the controls of the ICF);
- algorithms and rules in the KB should be guided by the structures of situational control algorithms;
- always be consistent with the activated conceptual model of the crew's behavior, developing recommendations for resolving the current problem at the level of a professional operator with sufficient significance for him,
- to have a "deferred" component of training.

At each stage of the flight, the crew, while solving the task of operational goal-setting (I-GCL), can activate the corresponding OAES-TS.

The KB of the OAES-TS consists of two hierarchical levels [8]. At the first level, according to the priori and current information, the corresponding PrS/S is activated on the base of production rules (Fig. 3). At the second level, the tasks of the activated PrS/S are solved and recommendations are presented to the crew.

We list the methods of solving problems used at this level (the mechanisms of inference): a multicriteria choice of an alternative, a conclusion based on a precedent, an optimization conclusion and production rules. In detail, the first two mechanisms are described in [6].

When implementing these mechanisms, mathematical models of the subject area fragments are used (Fig. 3 "Base of mathematical models").

2.2. Formalization of the general mission task "Escort of strike forces" in the interests of the commander of a group of escort fighters (an example of using the "Stage" model)

The general mission task (GMT) "Escort of strike forces (strike aircraft (SA))" is set to escort fighters (EF), which must directly accompany the SA to accomplish their mission.

The group of fighters is hierarchically ordered. The group is led by group commander K(EF)-I , which has subordinate commanders K(EF)-II subgroups.

Construction of the semantic network of typical situations in the GMT "Escort of strike forces" on the basis of the "Stage" model

When carrying out the formalization in the conceptual model "Stage" of the GMT the following TSs (flight stages) for commander K(EF)-I of the escort fighter group were identified:

- the take-off of group of the aircraft (TS "Take-off");
- the collection in air of EF and SA (TS "Collection-1"). The task of the commander of the EF group: to assemble the EF group, to lead the group to the point of meeting with the SA, to ensure the employment of EF places in the battle formations of the group;

- the flight of the EF group along the SA route (TS "Route-1"), the reflection of the hostile fighters (HF) attack by the whole EF group (TCS "Entering the group into the air battle" (TCS EGB-A)). The task of the commander of the EF group is to assign tactical reception of the HF reflection, to conduct tactical goal setting. TCS EGB-A usually occurs in the process of TS "Route-1", TS "Protection of the area" and TS "Route-2";
- collecting the EF group after completing the TCS EGB-A and meeting with SA (TS "Collection-2"). The task of the commander of the EF group: to ensure further support of the SA;
- the organization of the protection of the work area of the SA (TS "Protection of the area"). The task of the commander of the EF group is to prevent the enemy aircraft from attacking SA;
- the collection of the EF group and meeting with SA that have completed the attack of the targets (TS " Collection-3"). The task of the commander of the EF group is to ensure further support of the SA;
- the flight along the route with SA to the point of termination of their escort (TS "Route-2"). Task K(EF)-I: provide covering attack areas from which HF may appear; to repel an HF attack by a part of the EF group, to return this part of the group to the EF combat formations;
- the dissolution of the EF group and providing cover for the SA from HF attacks (TS "Dissolution of the Group"). Task K(EF)-I: establish order of priority of the landing, organize reflection of EF attacks.

The listed TS/TCS in the FA are presented by a semantic network in which the conditions for its occurrence are formulated for each TS/TCS (the result of a thorough study of the general mission task of fighters "Escort of strike forces", which is previously presented by a set of TSs/TCSs.

Construction of the semantic network of PrS/S in the TS Route-1

When carrying out the formalization in the conceptual model "Stage", the following PrS/Ss in the TS "Route-1 were selected:

- PrS/S (K(EF)-I) "correction of the formation of the EF". Task of the K(EF)-I - an operational change in the structure of the EF to cover the detected attack-dangerous direction;
- PrS/S (K(EF)-I) "Counteract the immediate threat to SA". Task of the K(EF)-I - allocation of the subgroup SA (dedicated group, commander K(EF)-II) to repel the attack of HF;
- PrS/S (K(EF)-I) "Return of the selected sub-group of fighters into the escort formation". Task of the K(EF)- having ascertained the status and capabilities of the selected group after the completion of its counteraction by the HF, it is compulsory to solve for the K(EF)-II the task of operational goal-setting before it.

The listed PrS/Ss are presented for the considered TS "Route-1" semantic network, in which for each PrS/S the conditions for its occurrence are formulated (the result of the deep study of the TS "Route-1", which is previously represented by a set of PrS/Ss).

The recommended solutions to the problems in the above PrS/Ss are prepared for the K(EF)-I by the on-board advisory expert system "OAES-Route-1".

4. Conclusion

1. A Statement of the task of determining the content and composition of tasks for operational intellectual support of the process of solving tactical decisions by the crew of an aircraft is possible only when the conceptual model "Episode" is changed to the conceptual model "Stage".
2. The composition of the onboard intellectual systems of a tactical level is defined:

- the Intelligent Information System "Situational Awareness of the Crew" (IIS SAC) and the on-board advisory expert system "Operational goal-setting" (OAES-goal-setting) that constantly work when the aircraft performs the flight task;
- a set of on-board advisory expert systems of typical situations / flight stages (OAES-TS), each of which operates at its own stage of flight.

The functions of the IIS SAC, the OAES-goal setting, the OAES-TS and the structure of their knowledge bases are described.

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