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ADVANCES IN NAVIGATION SUPPORT SYSTEMS BASED ON OPERATIONAL PILOT'S HEURISTICS

RECHERCHES SUR LES SYSTEMS D'AIDE A LA NAVIGATION BASES SUR LES HEURISTIQUES DE PILOTES DE COMBAT

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SUMMARY

The combination of the future high threat battlefield environment and the trend toward single seat combat aircraft provides the need to develop on-board decision support systems. The Pilot's Assistant offers a means of fulfilling such a requirement. While this concept covers different classes of aids, this paper focuses on the development of a navigation support system. Special attention has been paid to the quality of the man-machine interface of such a real-time aid. It is suggested that because the quality of this interface is critical, the best solution consists of computerising the man's navigational expertise, (rather than with optimal multi-expert software). Thus the eliciting of pilot expertise, while conducting low level nap-of-the-earth penetration missions has been important. An Artifical Intelligence Computer model of navigation is derived from this cognitive model with respect to the use of a concurrent object oriented language. An extended description of this programme is given in the paper, including ways of implementing the Pilot's Assistant in future French aircraft.

Keywords: Great Britain

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1 INTRODUCTION

For the pilot performing aerial missions, both the on-board systems and the external environment are becoming increasingly complex. The present situation will become even more critical in the future. Scenarios relating to the European theatre for the opposing air forces forecast an imbalance of 1 to 6 or even 1 to 10. Anti-aircraft cover of battle corps will be extremely dense and diversified (as forecast at the 1987 AGARD Conference on Man and Weapon Systems at Stuttgart). The overal scope of the missions has also become greater in terms of faster speeds, lower altitudes, by day and by night, and in all meteorological conditions. To function in this environment, the pilot of future French single-seat fighter aircraft will urgently need assistance to complete his tasks. This support, which will include navigation, will be provided by an ambitious system called "Co-pilote Electronique" or the "Pilot's Assistant".

The object of this paper is primarily to indicate the features of such a system and, secondly, to present a software architecture which meets the specifications already defined and which is oriented towards navigational support for a low altitude penetration mission.

2 SPECIFICATIONS FOR A SUPPORT SYSTEM

2.1 Limits of Automation

The large scale introduction of electronics on board military aircraft has assisted the pilot by considerably pushing back his saturation threshold. However, there is another side to the coin, and we are now beginning to appreciate this. Realisation occurred earlier in other areas of process control, notably in the sphere of nuclear power, where automation already functions to control complex situations. However, these are just the type of automatic aids which will have to be carried, in view of the difficulty of the procedures to be performed on board.

When associated with an automatic aid in performing a complex task, the human operator does not follow the development of the process continuously, but controls it solely from point to point. But very quickly he gives up his role as an active controller in the piloting process and becomes a supervisor[2,3]. When he takes over the system again, the passage from supervisor to an active state may take several seconds. AT 600 knots and 200 ft above the ground this may mean the difference between life and death. And he will have to take over, for besides the complexity, the tasks of the military pilot are performed in a world subject to rapid changes resulting in frequent asynchronous interruptions. (eg coping with threats, breakdowns, variations, invisibility, etc).

Another adverse effect on the operator of automation is the rapid decrease in his level of expertise, which becomes less operational, because his expertise is employed less[4,12,17]. At the least, a high degree of automation leads to standardisation of human performance, which may be desirable in certain spheres, but which is far from being the case in aerial combat. Is not man-aircraft coupling, which provides great variability of performance, preferable to a coupling which, while minimising the risks of poor performance, at the same time reduces the possibility of surpassing the standard? (See Ref 11).

2.2 What Supports and for What Pilot?

The preceding view of automation leads us to consider the problem of the man/machine interface not as a sub-problem to be treated as a corollary to automation of on-board systems, but as a central concept which will enable us to organise these systems correctly.

It is necessary to define the position of the pilot in the aircraft. At the present time, it must be recognised that we are far from reproducing by intelligent automation man's capacity for flexibility and adaptability. His ability to select information, to pursue parallel objectives, to evaluate situations from fragmentary or indirect data and to invent strategies, all require his presence in the aircraft.

To have a pilot in the aircraft means choosing to have a decision maker rather than a monitor. Thus, it means organising the on-board supports in such a way that they provide him with the maximum anticipation and give him time to form an appreciation of the situation, which is the sole condition for keeping the pilot ahead of events. The support may be envisaged in three ways:-

(i) Temporal (short, medium or long-term).

(ii) Nature of the support (acquisition of data, decisions, behaviour).

(iii) Recipients of the support (expert pilots or novices).

2.2.1 Temporal Dimensions of Support

To support the pilot signifies :-

(i) In the short term, to increase his capacity for survival by situational awareness in the following instance. It is noted that a representation in images of what will happen immediately if no action is taken is not only a powerful means of appraising a situation, but it is also a lever for reasoning. Thus the symbolic image of the velocity vector not merely indicates the point of impact of the aircraft, but is also an instrument in the short term reasoning of the pilot, which in low altitude flight, positions him level with the terrain peaks.

(ii) In medium and long term, to facilitate the global evaluations of the situation and anticipation of it by presenting in a synthetic manner the pertinent elements for medium and long-term use.

2.2.2 Nature of the support

Information required from a second database enables the pilot to form a correct representation of reality. It is a sphere where modern technologies can make a large contribution. For example, the scene of the overall situation (the big picture option described in Reference 1) can be displayed in front of the pilot's eyes on a helmet mounted display[7,10]. However, this produces the problem of how to fuse the data and display it on a single display. Work towards a Pilot Assistant or Pilot Aid forms an important aspect of research in the American projects of Pilot's Associate[16] and Electronic Co-pilot of Dassault-Breguet Aviation (Personal Communication Reference 5). These Pilot's Assistants are no longer restricted to the level of information acquisition, but are concerned with information processing and the working out of decisions. The progress of artificial intelligence has greatly contributed to the initiation of such projects for pilot support. The technical aspect is often the only one considered, leaving in shadow the problem of the coupling with the man. However, it is precisely this aspect which should determine the choice of techniques if it is desired to leave the pilot priority over the machine and the responsibility for the mission.

A third type of possible support is aid in piloting. It represents a natural extension of the preceding, going from advice and the defining of tactics to be used. This sophisticated automatic pilot could be switched on by the pilot to ensure navigation to a pre-determined flight plan, for a period of up to several minutes. Thus leaving the pilot with free time for recalculating the route or for reviewing the approach to the target. The pilot should be able, at any moment, to take over and rapidly assimilate the decisions taken by his system, both those in progress and those abandoned.

2.2.3 Recipients of Support

There are a number of questions which need to be addressed. Is the (intelligent) assistant for a pilot who is a specialist in one type of mission intended to be used also for another type, or for his customary mission? Is its object to support a novice, an expert, or both?

The literature in references 13 and 18 shows that information requirements differ for beginner and expert, and that the capacity for action and the use of tactics are clearly not the same. Two pilots having different levels of qualifications will need different expertise if they are to be aided effectively.

Expertise itself poses a problem: how is one to agree on knowledge provided by different experts on the same subject? As we note in combat aviation, different experts employ tactics which are sometimes opposite: where can the expertise be found for making a proper choice?

2.3 Architecture of Support Systems and Pilot Interfacing

The subject of this work relates essentially to the aids to reasoning and the conduct of the mission, or more precisely, navigational aids during low altitude penetration. In this framework, it will be shown how the architecture of the aid systems may result logically from a reflection of its coupling with the pilot. By its very nature, the aid to reasoning or the conduct of the mission will have to manipulate knowledge from various levels, exploit them in real-time, take into account a changing universe, and finally, take account of the pilots' strategies. It will depend, at least in part, on the sphere of realtime artificial intelligence, and will have to contain various types of expertise (navigation, dealing with threats, weapons systems, etc).

In general, it is the preserve of the cognitive psychologist and a sphere where the techniques of artificial intelligence compete in sophistication. But before the problem of technique can be solved, there is the problem of acquiring expertise. In fact, the expertise employed will depend upon the objective aimed at by the support system.

Is it a short-term, medium or long-term support? In the short and medium terms, if the pilot is intended to keep his role of decision maker, the support system will have to model his reasoning, at least in its presentation, so that it can harmonise with the pilot. In view of the time constraints, it is in fact advisable to avoid the pilot having to adapt and constrain his reasoning so as to be compatible with his on-board support system.

One of the characteristics of human cognitive functioning is to favour the short-term, by taking into account one or two important factors to solve the problem. It is well known that men do not reason in an optimal fashion over the longer term and have difficulty in coping with a large number of variables and difficulties. This will have to be borne in mind, and one will have to avoid, at least in the short term, presenting the pilot with reasoning, which although optimal in the long term, he will nevertheless need time to recognise as such. On the contrary, in the long term, it will be necessary to make use of the multiple factor and optimal calculation possibilities of a computer, provided that suitable presentation enables the pilot to understand it quickly.

3 ARCHITECTURE OF A NAVIGATION AID

3.1 Choice of a Model Based on the Operator

Summing up the preceding views on a pilot support system, it appeared that the possession of a model of the mental functioning of the pilot in the execution of his task was indispensible for developing a pilot support system. It is not merely a question of being interested superficially in his need for information and his ability to process it, but if one wishes to assist his reasoning and even to take his place for a limited period, it will be necessary to take account of his ways of solving problems in flight. We have gone further by basing our architecture of the navigational aid system on a cognitive model of the pilot. This means that we are implementing the ways of proceeding and the heuristics not only at a superficial level of the system, but that they in fact form the basis of it.

By this choice, we intend to improve the pilot's coupling with his aircraft; assisting him by means of a system functioning with the same logic and thereby improving his confidence in the support.

3.2 Application to the low altitude penetration mission.

As a result, in 1984 an 8 year research programme was initiated with the object of defining an architecture of an aid system which was to be called Pilot's Assistant for Future Fighter Aircraft. We focused mainly on the definition of an automatic navigational system capable of adapting to unexpected events in the mission and with programming as close as possible to the pilot's manner of performing. To resolve the problem of unifying expertise among pilots, we decided to favour consistency of expertise and therefore to make use of a single expert style. To justify this choice, we verify that in this way, the user of such an automatic system, whatever his own style of piloting, will have a good prediction of what the system's reaction will be in a given situation. Collecting the expertise and structuring it requires 3 years of research with interviews of the experts, analyses of the pilot's activities in the simulator and on a real mission. Other studies were carried out, and in parallel with other pilots, to collect complementary data, to identify different styles of piloting and to verify our hypotheses of the cognitive model.

The input of information into the model began two years ago. The physical test support consists of two work stations in a network. A Symbolics 3650 work station supports the programming of the automatic navigation system, which interacts with a Microvax on which a simulation model of a Dassault-Breguet aircraft runs. This Microvax also supports a graphical program which provides for visualisation of the reasoning of the system by animating and zooming in on the instruments of the on-board panel. This corresponds to the stages of cognitive activity of the pilot.

4 THE MISSION INVESTIGATED

The mission which concerns us is that of low altitude penetration by a Mirage F1Cr. In classic form, it consists of passing over an objective in order to act upon it (ie to destroy it, to photograph it, etc) at an exact time, after having navigated at very low altitude over hostile territory and then to return to a friendly base, still at low altitude. (See Fig.1).

The pilot has available his order for the mission, comprising a brief description of the objective with its coordinates and the time of passage, and the details provided by his briefing officer (ie threats, position of the lines, etc). He works out a plan for the mission on the ground in which he also takes account of the meteorological conditions, the aircraft available, etc. This preparatory phase leads to the choice of his approach to the objective and then to the precise determination of his route. These factors will be entered into the aircraft systems. He establishes his time-table for entry into and departure from the front lines (FEBA) and he will have to strictly adhere to them. The preparatory phase also enables the pilot to immerse himself in his mission and to imagine all possible variations which may occur during the mission.

The plan for the mission is precise and requires careful preparation and there is no question of modifing it greatly in flight. In fact, it is very difficult to re-plan in flight, at 600 knots and 200 ft above the ground.

In the end, carrying out a complex task, subject to strict time constraints and in accordance with a pre-determined plan, consists of processing the events by permanently controlling the distance and the disturbances imposed on the original plan. The central problem for the pilot is to arrive at his target on time, and also to adhere to his time-table over the front lines.

From a technical point of view, the mission breaks down into quasi-autonomous phases for which the pilot has available a standard procedure. Thus, in classic terms, the mission comprises a take-off and transit phase, followed by legs at low altitude up to the attack on the target. Afterwards there are the low altitude return paths to base.

5 THE COGNITIVE MODEL

The basis of our model refers to the theory of schemas which describes the organisation of knowledge of an expert in the form of mental procedures, called 'schemas', which are endowed with important properties. These are procedures, definition of the target to be attained by the procedure, possible incidents, sphere of application of the procedure, etc. Thus, it should be possible to structure the expertise by means of psychological notions of the plan, schemas and script, as defined in References 13 and 14.

The plan contains the abstract organisation of the stages to be satisfied to reach the target. It corresponds to planning of the main components of the mission and is used in the general conception of the activity.

The schema is a structure of knowledge which enables a sub-objective of the plan to be attained. It looks after immediate planning and the control of the activity. The knowledge of the schema can be structured in two parts as follows:-

1 The executive content, called script, which re-groups the procedures suitable for satisfying the objective of the schema. It is fed and updated by the notional content.

2 The notional content comprises the objective and the methods for evaluation of this objective, the decision rules for judging the validity, the pre-requisites for execution, the rules for coherence control, the strategies for achieving the different sub-objectives, the rules of skill, the constraints of the system and the description of potential incidents. It enables the parameters to be established from the real situation. It allows, also, rapid adjustment in case of an incident or unexpected event.

This knowledge enables the operator to understand the situation and to act on the immediate future by having available the anticipation model, but as well, it enables him to control the action in progress and to know what to do if the objective is not attained. The mission plan will thus be a sequence of schemas for achieving sub-objectives converging towards the achievement of the objective of the mission.

The model clearly demonstrates the flexibility of these procedures and their capacity for auto-adaptation to unforeseen constraints during the carrying out of the mission. This auto-adaptation may be affected locally at the level of the schema in progress or be passed on to the future schemas by transforming them. Another category of adaptation proceeds in an opposite direction, going from the plan to the schemas, particularly when there is a change of strategy or of tactics. A diagram of the auto-adaptation of the model of cognitive functioning of the pilot is given in Fig. 2. An example based on real observations provides a good summary of these 3 levels of adaptation:

In this example, a pilot becomes threatened by an unforeseen enemy at the start of the mission and he accelerates (this is a local adjustment of the schema while in action). This activity will restrict the duration of the schema and a certain number of checks or even adjustments for the following phase of the flight will not be carried out. They will have to be provided in following schemas.

The pre-requisites of the following schemas which have not yet been met will be prioritised and the schema suitably modified. But beyond this short term priority adjustment, the pilot will take measures to anticipate a deterioration of the situation by accelerating. Since he knows that he must not fly slowly, he will turn away from his intended path to lengthen it. (This is a new strategy). This strategy will have repercussions on the content of all th. procedures of the plan. (This is a diffusion of the plan). The model described permits auto-adaptation rapidly and effectively to a large number of difficulties without being reduced to much more formal and more time-consuming reasoning, of the type used in solving complex problems. This procedure seems to be a good reflection of the expertise of a fighter pilot.

6 THE INFORMATION PROCESSING MODEL

6.1 Introduction

The information processing model is constructed from the cognitive model and transposes the notions of plan, schema and script. Ref [6]. The representation by frames is particularly adapted to the description of entities of knowledge which can be manipulated in the execution content of the plan or of the schemas.

The two levels of functioning of the cognitive model can be recognised as local (short term control) and global (medium and long term control).

Four poles of knowledge (general control of the schema, execution of scripts, processing events and time control) emerge from the cognitive study. Each is modelled by a specific agent having the knowledge suitable for an area and capable of exchanging information with the others. Monitors are used for the components of schema, script, event and time.

To process this distributed knowledge and to take the action of the operator into account, a method of programming the model was selected, using techniques closely related to those employed in concurrent object oriented language. Ref [8].

This concurrent object oriented language differs from the classic notion of object oriented langage in the sense that each object of the language, (ie each active object) can function in parallel with the others. Communication and synchronisation is effected by the sending of messages. The variety of the concurrent object oriented languages which have been implemented is based on ABCL/1[19]. The messages may be of 3 types:-

(1) Sending an asynchronous message enables an object to send a message and to continue working without waiting for a reply.

(2) Sending a synchronous message represents a question from one object to another. The emitter is stopped insofar that it has not received a reply.

(3) Sending a message with a rendezvous. This is the case in which one object puts a question to another, and continues working until it attempts to make use of the reply. If it has arrived, it continues, otherwise it waits.

In addition to these types it is necessary to take into account asynchronous interruptions from the environment, and to modify, on command, the processing in progress by the objects. For this purpose, each message has an urgent field, denoted 'ordinary' or 'express' which in the case of 'express' enables its implementation to take place in precedence over 'ordinary' messages.

6.2 The Local Level

This models the execution of the schema. Before studying the architecture of this level in detail, the different situations will be presented which may arise in the execution of the schema to indicate the different levels of adaptation which are necessary. A schema for low altitude navigation in the dark or in poor meteorological conditions will be studied.

Example 1

The pilot detects the failure in his inertial navigation system by comparing the radar image with his radar chart. If this incident occurs very early in the sortie there will be an immediate insertion of the required correction into the script in progress. In this case it is a question of a purely local auto-adaptation.

Example 2

The fuel check is usually made at the end of the leg, when the pilot has a number of important things to do. If an error occurs, the processing of the incident will have to be carried over to the following leg, owing to the lack of time. It is no longer a local adaptation, but a question of slight modification of the following schema.

Example 3

Since insertion of processing cannot be deferred, it has caused a delay which cannot be made up in that leg of the sortee. The pilot will have to recalculate his time table on the following leg and thus possibly suppress actions which are not indispensible. It is thus a question of partial re-planning, following local adaptation, while the chief objective of the mission is not called into question.

Example 4

The pilot is threatened by enemy fire. This is the most complex level of adaptation which has already been described in the description of the cognitive model. It initiates, simultaneously, immediate adaptations to the local level and re-plans, with new strategies, for carrying out the complete mission (change of route, abandonment of the initial objective for a a secondary objective, etc).

6.2.1 The schema monitor is responsible for the local level and is the contact or link with the global level. In fact, it receives its successive schemas which are now parameters at the plan level and transmits the result to it after execution is completed. If there is an incident which exceeds the scope of the local level, the schema monitor alerts the global level. On one hand, it holds the description of the script and of the procedures (executive content). On the other hand, it holds the description of the target, the procedures for evaluating this target, heuristic methods for adapting this script to the real situation, procedures for coherence control organised in stack form and inserts into the dead time of the script (notional content). it will thus be able to produce the execution script and to transmit it to the script monitor which is responsible for its execution and which thus functions continuously. As regards everything concerning temporal restrictions, it will be assisted by the time monitor. Its last auxiliary is the event monitor to which it transmits progressively the information which it receives to update the list of possible incidents and which it will alert in case of an incident or an interruption in the flow of the script. It keeps control of the local level by centralising the important messages, adapting the script in progress, controlling the coherence stack and activating its auxiliaries as required.

6.2.2 The script monitor holds the description of the script which it has to run, as well as the methods for carrying out the different types of action of the script. In fact, it has been possible to list 3 types of actions:-

(i) the routines
(ii) the blocks
(iii) the sequences for which a specific programme has been developed

(i) the routines correspond to the pilot's action at the lowest level. They are instrument monitoring, control actions or checking of unexpected values. The routines themselves are also represented by means of frames. It can be shown whether they are immediately required or can be adjourned. Their acceptable ranges, durations, etc are are also shown. When the pilot aid is activated, it interacts directly with the parameters of the aircraft model and the associated display appears on the screen. The pilot aid routines are fundamental for modelling the aircraft state, whether they are pilot actions or checks. The pilot is continually awaiting the result, or results, which will enable him to continue his mission, such as reaching the next way-point. The estimate of the time required to achieve this result will give him time to carry out his tasks and possibly to complete certain house-keeping actions. This role of time estimation and of microplanning is the task of the local time monitor, which will be encountered again. During the reading routine, if the result is not achieved, a (threshold value), the schema monitor will activate the local time monitor and arrange to reactivate this reading routine later.

The routines are also used in the control procedures; the executive part being inserted into the script of the schema.

Examples of the routines are given below:-

(1) The routine to put the angle of attack at -10° at the start of a low level attack phase modifies the pitch of the aircraft and causes a symbology change on the head-up display and a pressure change on the stick handgrip.

(2) The routine for verifying the rate of descent on the vertical speed indicator causes a change in display reading since the instrument is permanently updated by the aircraft model.

(3) An estimate of the distance to the target on the navigation display causes a change on the display and enables the time to target to be predicted.

(ii) The blocks correspond to a sequence of routines aiming at the same objective and centred on the same instrument. The change on the instrument will remain displayed during the whole flow of the block. It will be possible to interrupt certain blocks and subsequently continue while others, however, are not divisable. In addition, inside a block certain routines may be transposed or deleted, while others may not. It will be necessary to take this into account in the organisation of the script. They are also represented in the form of frames. Some examples of blocks are given below:-

(1) The block for navigation control uses the head-up display and comprises 3 elementary checks (good target, good route, good guidance at speed). The order, although logical, is not mandatory. For example, it can be restarted in the case of interruption by forward air control.

(2) The control of radar in pulse repetition mode comprises the routine of change of mode and direction of the antenna. It was initially in high altitude mode. Here the command is imposed and the two actions are obligatory.

(3) The stand-bys model the moments when the pilot does nothing. It is a case of periods during which the pilot concentrates on awaiting a result, awaits the effects of the preceding action, or hasn't time to do anything else in the time available. For a pilot not to have any free time is disturbing, for he will then not be able to react easily to unexpected events. This is why he always anticipates the untoward event on take-off. Nevertheless stand-bys rarely appear explicitly on take-off in the prototype script. They are generated by the local mechanisms of auto-adaptation.

6.2.3 The local time monitor has 4 main functions for time control in the running of the schema:-

1 It holds the expertise for calculation of the time necessary for the routine of a block or for obtaining a result.

2 It is capable of reorganising the best solution in the time given and, depending on the priorities, relating to the sequence of the block and the routines of the script. This is a sphere of microplanning. This intervenes in control of waiting for results, the insertion of coherent actions and of the processing scripts in the case of incidents.

3 It exchanges information with the event monitor during the selection phase for the processing sub-schemas. This enables it to indicate the cost in time of the processing and its feasibility, taking into account the existing time constraints and the possibilities of insertion.

4 It controls the the time validity for achieving the schemas. In the case of an unexpected incident, it alerts the scnema monitor. If the running of the schema has taken more time than anticipated and a delay has occurred, it will be necessary to make up for this delay in the following schemas by deleting or carrying over the optional or less urgent actions. Thus there is functioning in parallel with the script monitor but also sequential functioning with the schema and event monitors since there is a stand-by for a reply in order to continue the processing.

6.2.4 The local event monitor holds the expertise for processing incidents. Its activity can be broken down into two successive phases:-

(i) a diagnostic phase.
(ii) a processing generation phase.

Incidents may be of two types:-

The result obtained is different from that expected.

The execution of the action in progress has been interrupted.

For both schemas, the event monitor is capable of rapidly finding the set of incidents which may occur at a given instant, since it takes account of the history of the schema in order to update this set dynamically and not to become congested with improbable events. The diagnostic phase is then simple and rapid and well reflects the pilot's behaviour. The event monitor decides the gravity of the incident and if it exceeeds its capacity the global level is alerted.

For each event the event monitor holds one or several processing sub-schemas. It then examines the possibility of insertion with the local time monitor (if time is short a less optimal but rapid solution will be preferred). If processing is not possible in the current schema the global level will be applied. The selected processing will be transmitted to it for insertion in the following schema. An example of local adaptation is shown in Fig.3. Parallelism can be found between the continuity of present execution by the script monitor and the preparation of immediate future, on the basis of the past by the event time and schema monitors.

6.3 The Global Level

It models the execution of the plan worked out during the preparation. It contains the sequence of the schemas selected to satisfy the different objectives of the plan and it controls the local level. It should be able to adapt the nominal plan according to the real situation and possibly to adapt to even deeper re-planning. Its architecture initiates that of the local level.

6.3.1 The plan monitor plays a role analogous to that of the schema monitor for the local level. It manipulates the notional content of the plan, and keeps track of the overall mission. It is kept informed about all of the important executive events and those transmitted at the local level. It then decides whether it can let the loop of auto-adaptation of the local level act or whether it should intervene for more deeper processing.

Example

An accummulation of minor incidents may be the forerunner of a serious situation. It holds in its executive content the sequence of the schemas which it has selected during the preparation. It continually updates the notional content of the following schemas according to the situation. Only the next schema is completely prepared and ready for execution. In fact, it is useless to know in detail what precisely has to be done in the 3 branches. Alternatively, it will have to take account of any event which influences its objectives.

It is aided in its executive role by the execution monitor. ie The global time monitor takes account of temporal aspects while the global event monitor covers unexpected and serious events.

6.3.2 At each moment, the execution monitor holds ready the next schema which is transmitted to it and updated by the plan monitor. It transmits this new schema to the schema monitor as soon as the schema in progress has been achieved.

6.3.3 On the one hand, the global time monitor has the same functions as its corresponding part of the global level. It evaluates the duration of the phases, the time potentially available, and it is charged with keeping the modifications of the plan within the limits imposed by the mission time table. In addition, it should control the liabilities transmitted by the schema in progress and decide where to insert them in the following schema. On the other hand it provides for control of the pilot's resources. In fact, an important time restriction is that a man cannot perform in parallel more than a maximum of two tasks. Thus, it will be necessary to share the temporal resources of our model operator between assessing at the global level and action at the local level. Assessment covers the tasks of comprehending a situation from study of the history and the adaptation or elaboration of the plan in order to anticipate future situations. When there is great pressure of time, the time allotted to the replanning is restricted and a simple but rapid solution is preferred. This constraint, in fact, may prove to be an aid in numerous failure situations where the search for optimal solutions is a complex problem. The global time monitor continually controls the time consistency of the operator's activity.

6.3.4 The global event monitor is responsible, like that of the local level, for providing together with the plan and time monitors, the evaluation of a serious failure situation which calls in question the mission plan and the choice of operations to remedy it. In fact, the sequence of schemas selected becomes obsolete and re-planning, or at the very least, a serious adaptation is required.

Example 1

In the case of unforeseen threats making the objective inaccessible, there will be re-planning to operate a secondary objective, the characteristics of which are already known to the plan in its notional content.

Example 2

In the case of missile engagement, the schema in progress will be abandoned in order to put an avoidance procedure into effect (eg breaklock, full reheat and acceleration away, etc) at the local level and evaluation of the situation based on knowledge of the whole scene at the global level.

For the moment only strategies for adaptation of the nominal plan are implemented. An illustration of operating the global level is given in Fig.4.

7 CONCLUSIONS AND PROSPECTS

The importance of a software architecture based on a cognitive model of the fighter pilot seems to be three-fold:

(i) It is an important solution of the problem of coupling the pilot with a support system. It provides a logic for the functioning and solution to problems, which is easily understood when time is short. The attainment in practice of a sophisticated interface based on such a system is a new field of study which is being explored. The first concern has been to define such an interface for the pilot's navigational assistant. This will provide the pilot with a summary of the actions carried out and in progress to facilitate his re-handling of the aircraft. Alternatively, there is a trend towards a model of the pilot's intentions which would enable the system at any moment to be appropriately involved during the course of the action.

(ii) The second significance of this architecture resides in the solutions it offers to control in real-time by artificial intelligence. In fact, the architecture even of human expertise (scheme and overall knowledge) provides an answer to the problems of modelling real-time reasoning. It is the organisation of knowledge which makes possible rapid processing of a small amount of data, whose relevance is, in general, adequate to provide a short-term answer. Control of the sequence of this short-term answer (which may be often non-optimal) is postponed until after periods of high time stress have passed.

(iii) Finally, this method of resolving a problem by a group of active objects is an alternative to the classic architectures of the inference engine type, and seems a natural way for programming this type of task.

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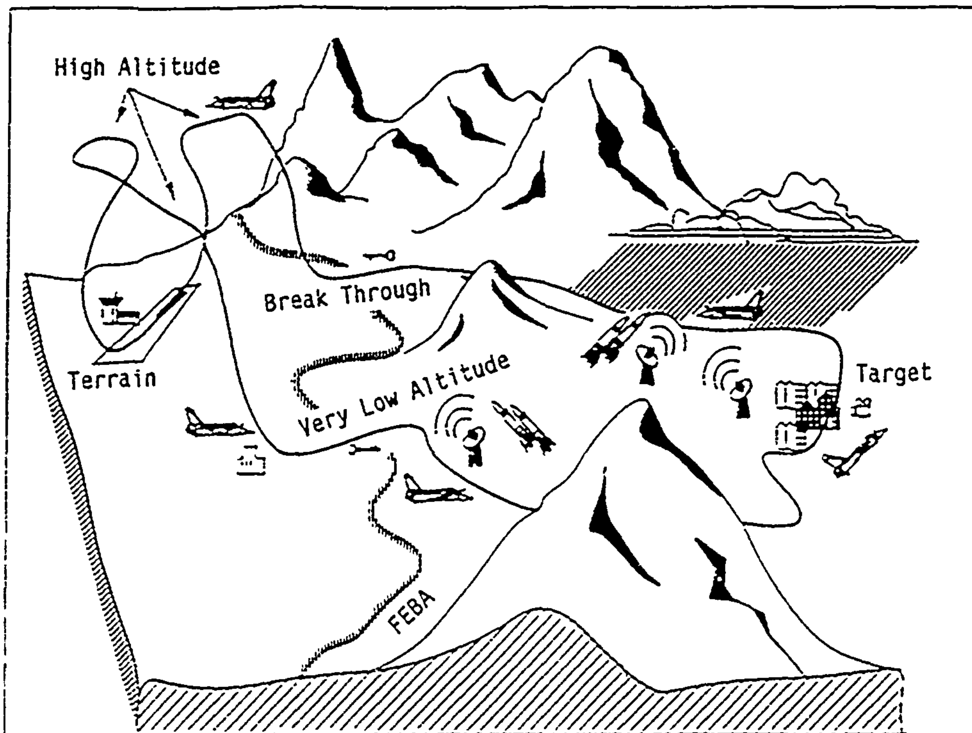

Figure 1. Penetration Mission at Low Altitude

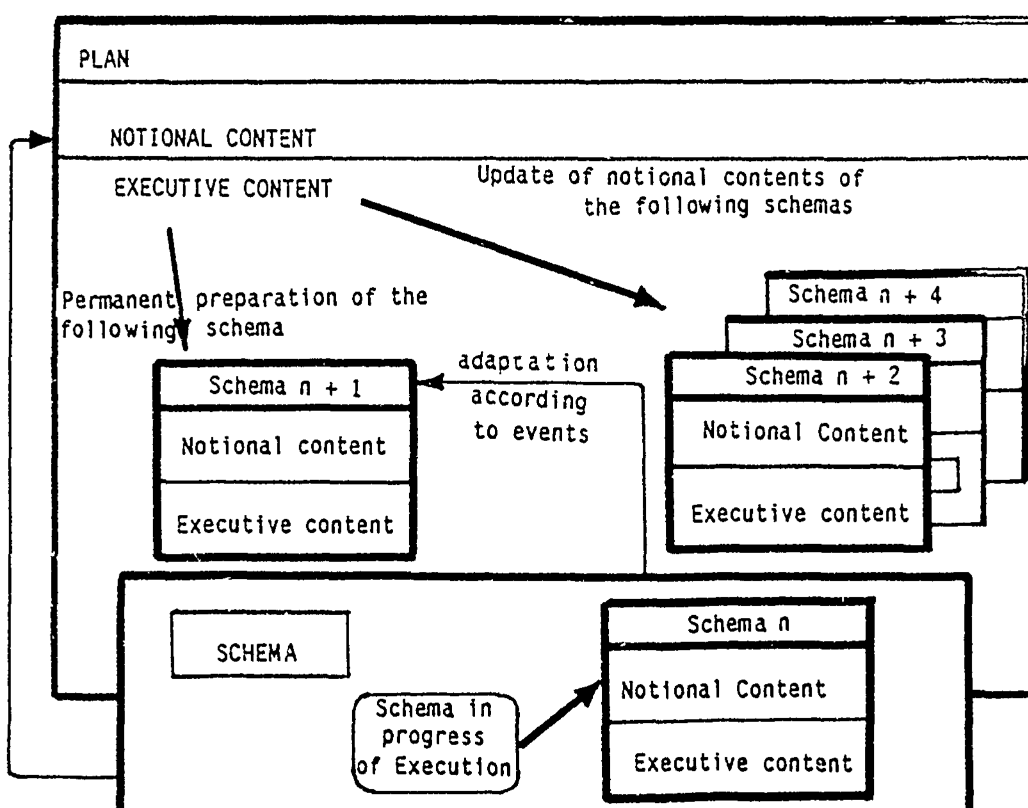

Figure 2. Cognitive Model of Auto-adaptation

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Figs 3&4

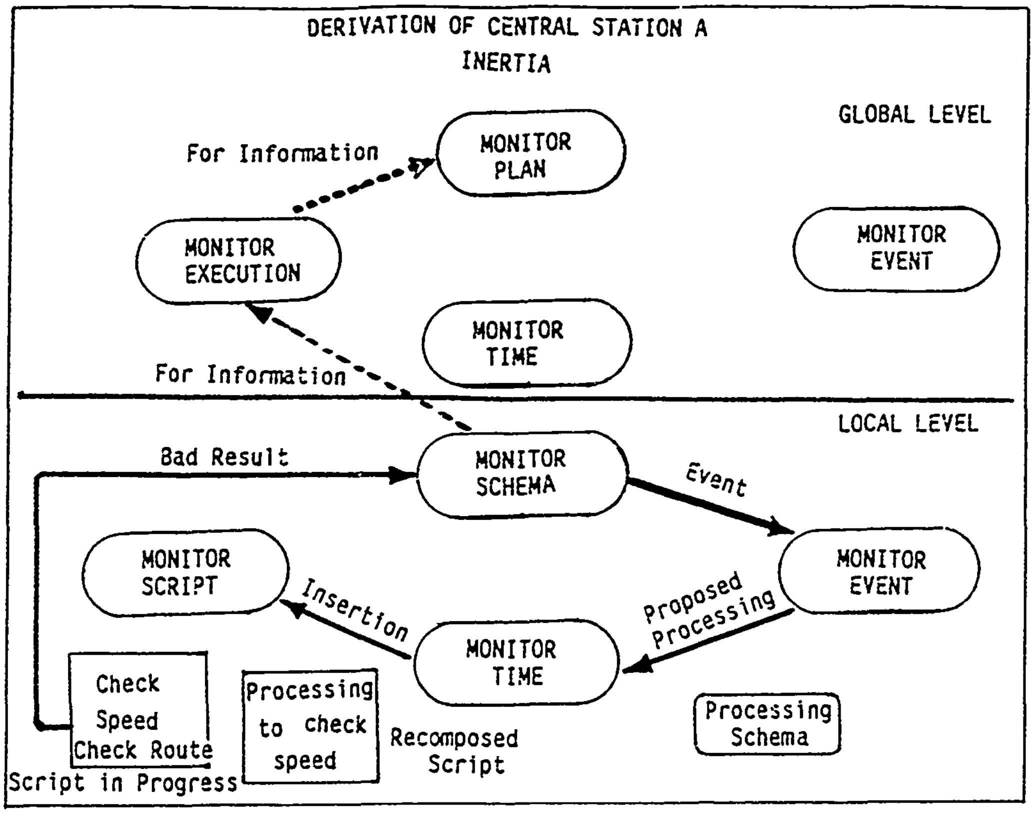

Figure 3. Local Accommodation

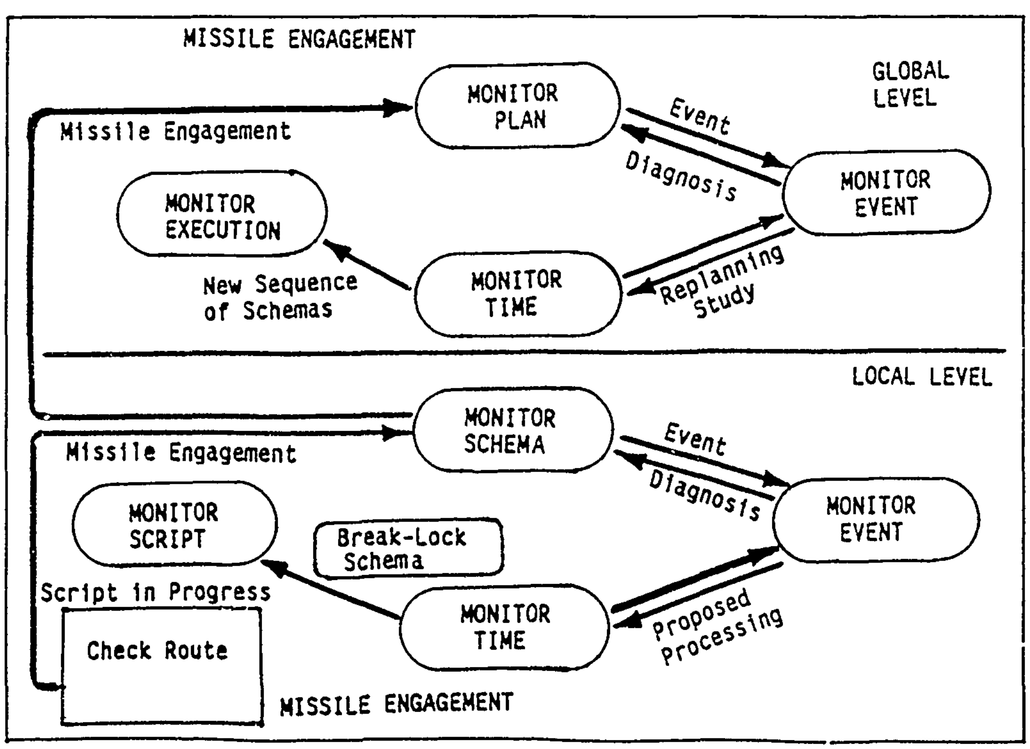

Figure 4. Local Accommodation and Replanning during a Missile Engagement

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