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REVIEW PAPER

Making the Mission Computer Intelligent – A Step Ahead

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ABSTRACT

Increasing the complexity of fighter aircraft like modern cockpit environments, covering highly integrated, and complex automatic functions, pose various demands on the crew and adding a heavy workload. Cognitive systems appear to be a promising approach to overcome these deficiencies in future combat aircraft. Developing human-centered automation and designing advanced technology that will capitalize on the relative strengths of humans and machines, are key to the success. This paper presents the approach of applying the artificial intelligence (AI) techniques in the critical mission computer (MC). The mission computer is the central controller of the entire avionics and acts as the front end to the pilot and all other avionic systems by providing all the sensors information, presenting the pilot-vehicle interface and thereby helping a lot in reducing the heavy workload of the pilot. Hence cognitive processing in the MC will make MC to act as an electronic crew assistant sharing the workload of the pilot and helping him in severe situations. Intricate aircraft systems increase the need for intelligent cooperation between pilots and aircraft which will be fulfilled by making the MC as smart or intelligent MC.

Keywords: Artificial intelligence, expert system, knowledge base, cognitive process

1. INTRODUCTION

This paper explores a conceptual approach for the development of the mission computer (MC) which is basically networked with other avionic subsystems to aid the pilot in mission planning, mission execution and workload management etc., with the use of AI techniques. This paper also explores the need for developing the intelligent mission computer (IMC) and the details of architecture in terms of the major components that can be implemented to augment the IMC with the cognitive approach.

2. BACKGROUND

The mission computer is the main system controller of the avionics in the combat aircraft and it must support a multi-mission aircraft with constantly changing needs to provide the pilot with the best situational awareness possible. To meet the extreme and ever-changing processing demands of modern fighter aircraft, the mission computer requires performing like pilot's associate /co-pilot in the cockpit.

2.1 Evolution of Mission Computers

Figure 1 depicts the evolution of mission computing over its 50-year lifespan[1]. Sensor capability and complexity drive mission demands which in turn drive the mission computer performance requirements. As early as 1970, engineers realized that a complex mission computer rivaling those used by scientists would be required to provide pilot assistance in managing his or her workload and thereby providing additional

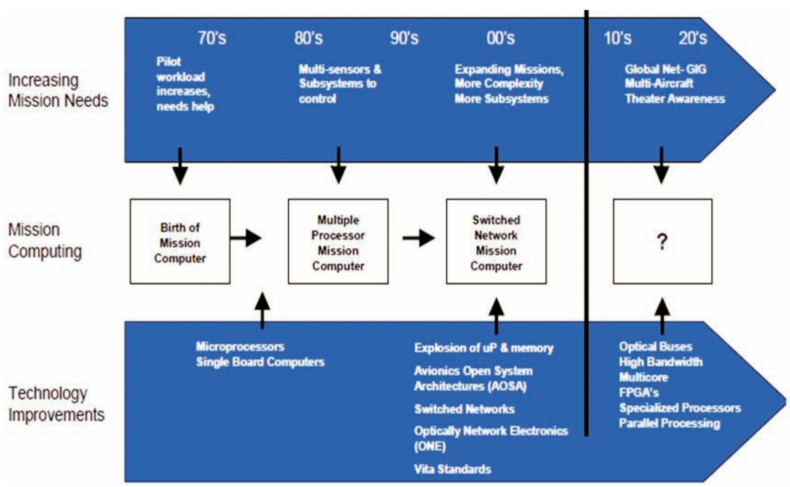

Figure 1. Expanding role of mission computer – requires a transition in technology as well as development philosophy.

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real-time decision support to the pilot. As we look back past 2010, the demand on mission processors will continue to grow as pilot workload and aircraft missions increase in capability and complexity. We are already seeing mission needs that will require a huge requirement for the pilot's associate which has been slowly integrated into the MC over the 20 years of advances in avionics industry.

All these advances in technology, forces the avionics experts to look into the artificial intelligence technology that make the MC to behave like a human being in the cockpit supporting the crew to reduce his intolerable workload in the dynamic tactical environment and hence the development of IMC is essential for a combat aircraft.

3. ARTIFICIAL INTELLIGENCE - AN OVERVIEW

With large scale introduction of electronics in modern warfare, it is now possible to consider the fusion of information provided by the sensors that may be incomplete, uncertain or even incorrect, and to attempt to mechanize the dynamics of the conflict. The process of such integration and automation in war is still in its infancy but the goal of competent automated decision-making is extremely attractive as this has the potential to generate decisions/commands, many orders of magnitude more quickly and reliably than by humans under stress conditions.

The accomplishment of such a task is expected to be achieved through a branch of computer science called artificial intelligence (AI). Various AI researchers have given various definitions of AI. One of the simplest defines AI as the branch of computer science which deals with making computer smarter by giving intelligence to it. The term intelligence covers many cognitive skills, including the ability to solve problems, learn, and understand language. Intelligence may be defined as the capability of a system to adapt its behavior to meet its goals in a wide range of environments. The traditional computing resources like calculators cannot be called intelligent although they give the right answers to challenging math problems, but everything they know is preprogrammed by people, they can never learn anything new.

AI's scientific goal is to acquire intelligence by building computer programs that exhibit intelligent behavior. It is concerned with the concepts and methods of symbolic inference or reasoning, by a computer. Expert system is one the branches of AI which has emerged quite differently in complex decision making problems. Since dynamic tactical environment requires complex decision making so IMC development will be focused on development and integration of different expert systems into one single unit.

4. INTELLIGENT MISSION COMPUTER

One approach for developing an intelligent mission computer (IMC) is developing an expert system for the functions of MC. An expert system is a problem solving and decision making system based on knowledge of its task domain. The area of human intellectual endeavor to be captured in an expert system is called the task domain. Since we are talking about mission computer we can consider avionics as its task domain. Task refers to some goal-oriented, problem-solving activity. Domain refers to the area within which the task is being performed. In the context of IMC, the task domain is the avionics and the typical tasks are the functions of MC such as mission planning, navigation, man-machine interface control, sensor management and health monitoring etc.:

AI programs that achieve expert-level competence in solving problems in specific task areas by bringing a body of knowledge about those tasks are called knowledge-based systems (KBS) or expert systems (ES). Every expert system consists of two principal components[3] as mentioned in Fig. 2.

- The knowledge base
- The reasoning or inference engine

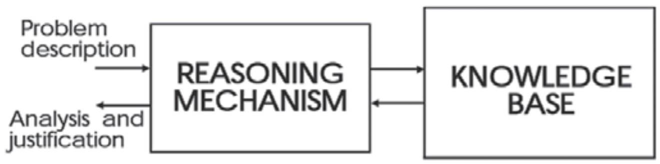

Figure 2. Expert system components.

The knowledge base of expert systems contains ;

- Factual knowledge is that knowledge of the task domain that is widely shared, typically found in textbooks or journals, and commonly agreed upon by those knowledgeable in the particular field.
- Heuristic knowledge is the less rigorous, more experiential, more judgmental knowledge of performance.

Again in the context of IMC, the factual knowledge refers to the basic flight parameters computational algorithms and the heuristics knowledge refers to the other avionics system health monitoring and mission planning etc. Expert systems of IMC proposed in this paper are rule-based systems. Components of a rule-based system are shown in Fig. 3.

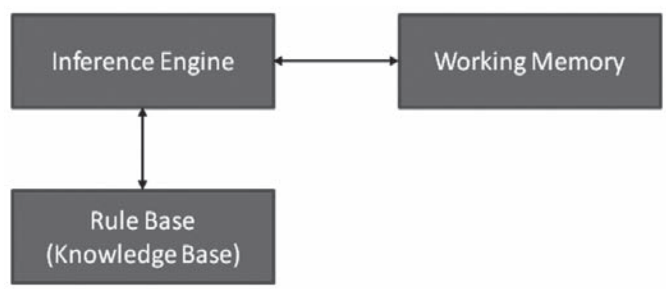

Figure 3. Components of a rule based system.

(a) *Working memory:* The working memory (WM) represents the set of facts known about the domain. The elements reflect the current state of the world. The WM typically contains information about the particular instance of the problem being addressed. For example during attack phase the details of the attack related parameters. The inference engine uses this information in conjunction with the rules in the rule base to derive additional information about the problem being solved.

(b) *Rule base:* The rule base (also called the knowledge base) is the set of rules which represents the knowledge about the domain. A rule consists of an IF part and a THEN part (also called a condition/antecedent and an action/consequent). When the consequents of a rule are executed, the rule is said to have been fired which affect the environment or the knowledge base.

(c) *Inference engine:* The inference engine tries to derive new information about a given problem using the rules in the rule base and the situation-specific knowledge in the WM. It determines the set of rules which can be fired. The set of rules which can be fired is called the conflict set. Out of the rules in the conflict set, the inference engine selects one rule based on some predefined criteria. This process is called conflict resolution.

This problem solving model involves chaining of IF-THEN rules to form a line of reasoning. If the chaining starts from a set of conditions and moves toward some conclusion, the method is called forward chaining. If the conclusion is known but the path to that conclusion is not known, then reasoning backwards is called for, and the method is backward chaining. These problem-solving methods are built into inference engines that manipulate and use knowledge in the knowledge base to form a line of reasoning. The inference engine shall be built with suitable search control strategy in order to pass through the various phases like matching rules, conflict resolution etc**.**

5. IMC ARCHITECTURE – COOPERATIVE EXPERT SYSTEMS

The functional architecture of the IMC is depicted in Fig. 4. The basic mission functions of IMC providing various kinds of assistance to the pilot are as follows[5]:

- *System Status Reporting:* This subsystem monitors the status of on-board aircraft components. It attempts to identify, diagnose, and verify systems which are malfunctioning or may malfunction during the mission.
- *Situation Assessment:* It makes use of data gathered from on-board sensors, such as radar, and information from external sources. This information formation is used to develop a comprehensive understanding of threat activity, estimates of threat intentions, and predictions of future action.
- *Tactical Mission Planner:* This subsystem provides the pilot with appropriate information and responses such as defensive threat reaction, use of countermeasures, allocation of weapons, and coordination of wingman roles. It also provides alternative mission plans for the pilot based on the current situation.
- *Pilot Vehicle Interface:* This subsystem establishes a means of communication between the pilot and the other functional systems of the IMC. It provides the intelligent computing functions necessary to control the content and timing of the cockpit displays to improve the two way flow of information between the pilot and his associate.

On the top of these functionalities of IMC, the mission manager module serves as the common communication link between the functional subsystems and acts as a central repository for active plans and goals. It performs the main executive function that controls the activities of IMC

The basic philosophy of the expert system development in IMC will follow the principles of cognitive, human-centered automation[4] where the behavior and assistance of IMC will be authorized by the crew. The cognitive sub-processes are theoretically referred to as:

- Data acquisition from the external world
- Situation interpretation

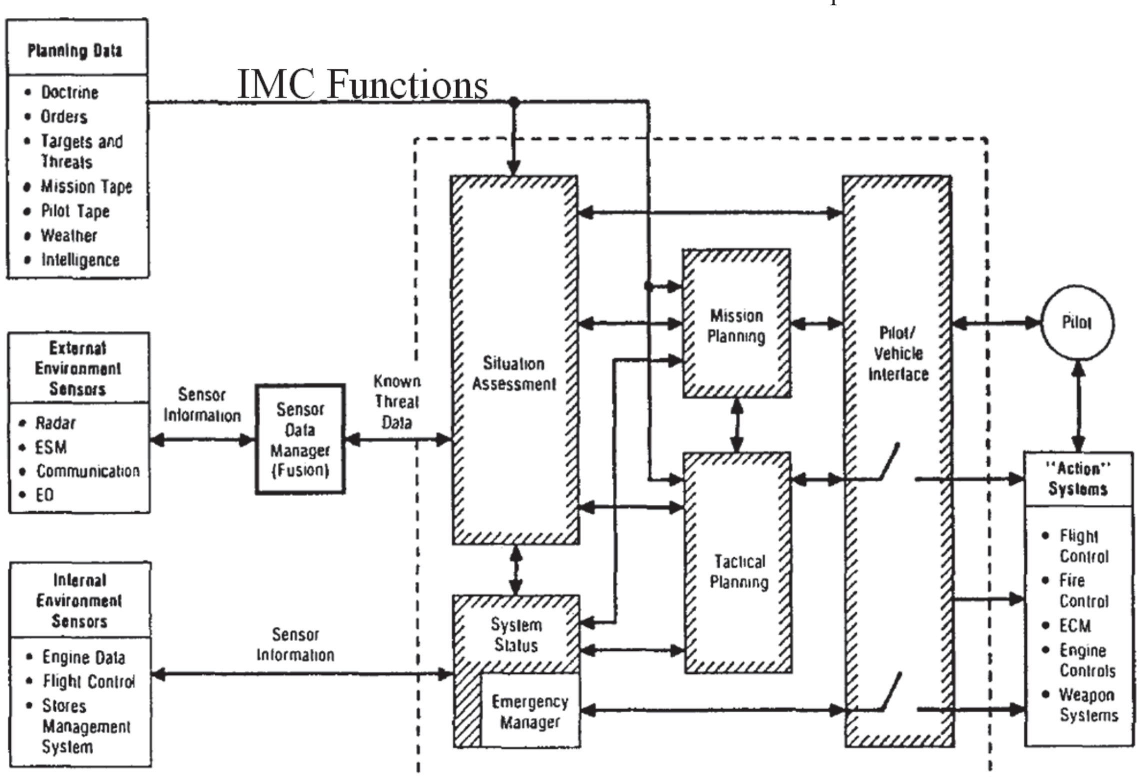

Figure 4. IMC functional architecture.

- Goal activation (i.e. situation diagnosis)
- Planning and decision making
- Scheduling of the tasks to be performed, and
- Control and execution of the derived actions.

The cognitive processing in IMC is depicted as follows:

In IMC, the above explained cognitive process is operating with the following main blocks as shown in Fig. 5.

- Working memory, which contains static, and dynamic database containing navigational data, terrain data, feature data, aircraft sensory data, ATC data, and current situation data etc and
- Rule base, which contains the motives and goals, models of aircraft, environment and pilot.
- Inference engine, which generates the appropriate proposal for any situation related to the functions of IMC[5].

Figure 6 details the AI based functional components of IMC to perform its mission functions.

To ensure situation awareness for the mission, all

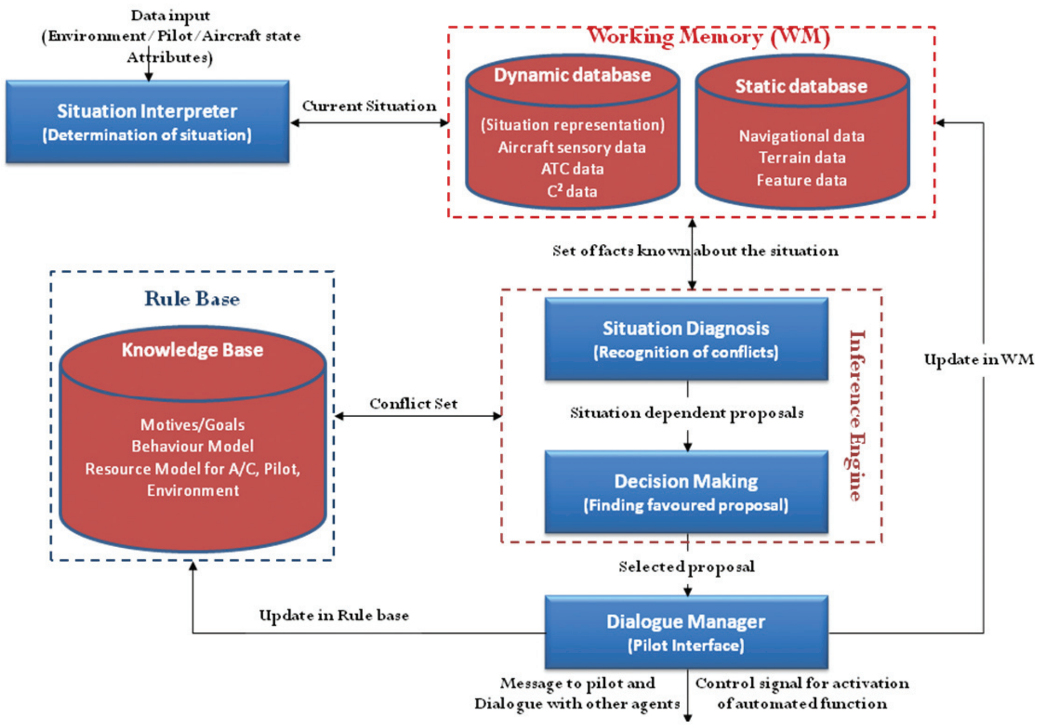

Figure 5. Cognitive processing in IMC.

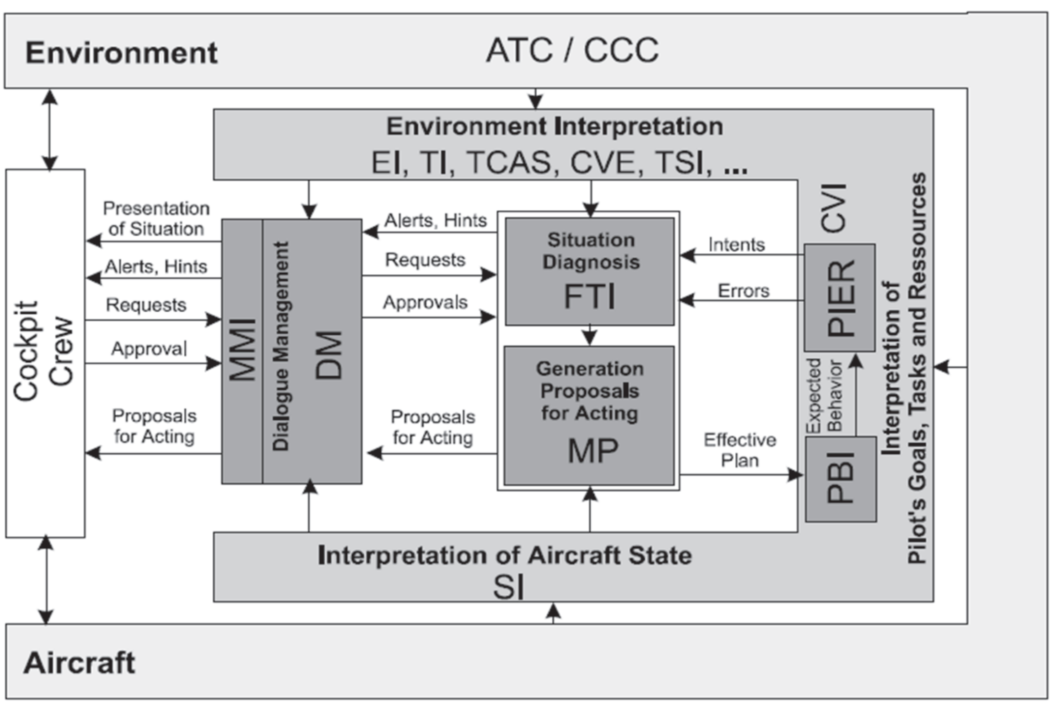

Figure 6. IMC – Functional flow.

information produced by the modules is assembled in a central situation representation (CSR) which provides a complete dynamic database of the current situation. This can be seen as an analogue to the pilot's own mental representation of the actual situation. Static databases contain information such as navigational, terrain and feature data. Dynamic external data such as aircraft sensory data, air traffic control and C^2 instructions as well as environmental information are gathered via an external communication interface. This part represents the cognitive sub-process (1) of data acquisition from the external world.

Various modules such as aircraft systems interpreter (SI), environmental interpreter (EI), provide crucial information on health status of aircraft systems and environment, and the flight progress. The tactical situation interpreter (TSI) calculates the local threat distribution along the mission plan. Ground proximity is detected by the terrain interpreter (TI). The computer vision internal (CVI) provides information concerning the pilot's point of gaze. The computer vision external (CVE) serves the interpretation of the surrounding environment using its computer vision capabilities. In this way IMC is able to perform conflict detection with respect to local changes in the tactical situation. The modules pilot behavior interpreter (PBI) as well as pilot intent and error recognition (PIER) serve mainly for the monitoring of pilot behavior[6]. All of these modules establish the cognitive sub-process (2) of situation interpretation within the cognitive loop.

On the basis of situation knowledge, possible conflicts ahead can be identified (e.g. threats, weather) by the flight situation and threat interpreter (FTI). Here the impact on the current flight is assessed, conflicts are detected, and resolution activities are initiated. The module FTI is the implementation of the cognitive sub-process (3) of situation diagnosis.

The mission planner (MP) generates a complete 3D/4D mission plan either on demand by the crew or autonomously, where the crew does not have the resources to interact. The mission plan consists of both IFR and low-level flight segments. The module MP can be seen as the representation of the cognitive sub-process (4) of planning and decision making.

The interface between IMC and the crew is controlled by the module dialogue manager (DM). Speech output is being used for focusing the pilot's attention on the important aspects. More complex information is transmitted using graphical displays. Information input is realized utilizing speech recognition to a large extent[7]. The DM-related functions cover comprehensive parts of the cognitive sub-processes (1) data acquisition from the cockpit crew as part of the machine-external world and (6) control and execution of the derived actions with respect to the pilots and implemented in the mission manager

The above explained cognitive behavior of the MC with the human-centered automation increases the aircraft performance and its mission capabilities.

The IMC behavior in assisting the pilot during an air-to-air mission is explained with following events as shown in Fig. 7.

A group of fighter aircraft is assigned the mission. They fly to point in friendly territory and wait there until they receive a target assignment – enemy bomber in this case. When the target is assigned:

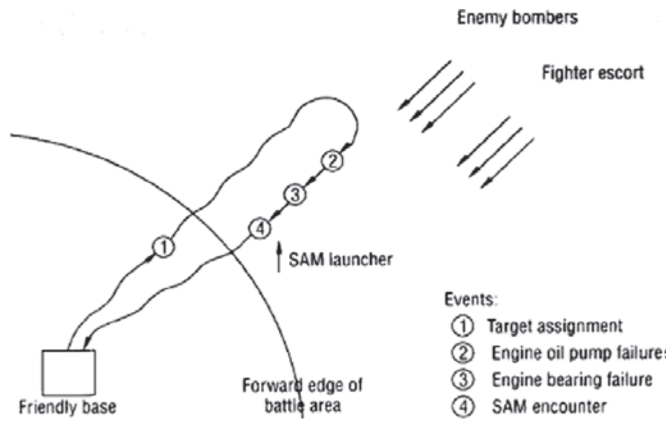

Figure 7. Example of an air-to-air mission.

Event 1 – The mission planner evaluates and selects the ingress and egress routes through enemy defence. System Status supplies performance data to the mission planner during the process to assure that the route is within the aircraft's capabilities. After attacking the target, say, one of the aircraft experiences an oil pump failure in one of its two engines.

Event 2 – System Status detects the failure, alerts the pilot and recommends that the engine be shut down because bearing failure is imminent. Anxious to leave enemy territory as soon as possible pilot rejects engine shut down. System Status proposes an alternate plan for running the faulty engine at 80% power to maximize bearing life. The pilot implements this plan. Two minutes later engine bearings fail.

Event 3 – System Status alerts the pilot to the failure and alerts the mission planner that mission route's outbound leg is no longer feasible because the fighter cannot achieve supersonic cruising speed as originally planned.

Shortly after engine failure, say, an enemy surface-to-air-missile launcher starts tracking the fighter.

Event 4 – The tactical planner evaluates the SAM threat and begins planning evasion options. One option is to maneuver using fighter's superior turning ability to break the missile's radar lock. Another option is to deceive the radar by dispersing chaffs. Normally pilots would avoid the second option because using a decoy is likely to make the fighter visible to other SAM radars that had not seen it previously.

However, estimates of single engine performance provided by system status it forces the tactical planner to select a decoy turn maneuver, because the fighter cannot sustain a tight turn long enough for it to be effective against the SAM. During the decoy turn, system status provides turn limits data to the pilot to optimize the fighter's remaining maneuverability and defeat the SAM.

Behaviour of conventional MC for the same four events described in above example:

Event 1 – MC cannot re-evaluate the stored mission plans to generate new routes through enemy defence and it totally depends on the pilot which mission plan to execute in certain situation.

Event 2 – MC will not give any kind of proposal to the pilot to increase the mission effectiveness and safety.

Event 3 – MC will not calculate the feasibility of outbound leg. Pilot has to fly according to the planned mission plan.

Event 4 – MC will not propose any evasion option. Pilot himself has to think and execute evasion option.

The above illustrated example shows how IMC performs the system status role which goes beyond detecting equipment failure. In this scenario, the system status plays an active partner in helping the pilot and other planners such as mission planner, tactical planner, etc., through the mission manager module. It also provides options to the pilot for correcting faults or at least mitigates their effects.

The above illustration in both the cases of conventional MC and the intelligent MC clearly brings out the fact that IMC is a major decision support system in the cockpit and thereby increases the mission effectiveness and safety of the pilot.

The following paragraphs explains the cognitive process of IMC for the 'event 2', at each sub-process

(a) *Data acquisition*: Data is constantly gathered from all the sensors and subsystems.

(b) *Situation interpretation:* By conducting predefined tests on the acquired data to detect equipment failures, Oil pump failure is detected and interpreted as malfunctioning in one engine and the situation/results is represented in working memory as problem statement.

(c) *Situation diagnosis*: Solutions are searched in the knowledge base (Rule base) based on the problem statement and generates appropriate hypothesis or plans and the related constraints. In this case two plans are found. One is to shut down the engine and other one to reduce the power of engine.

(d) *Decision making*: Prioritizing the effectiveness of the plans appropriate one is chosen as the favoured proposal. Since failure is imminent system chooses engine shut down as favoured proposal.

(e) *Dialogue manager*: Engine shut down proposal is presented to the pilot through dialogue manager.

(f) *Plan execution*: Pilot rejects the current proposal and since the proposal is continuously monitored during execution, the system status is providing the corrective action/ proposal, which is in this case, the proposal of reducing the engine power which pilot accepts satisfactorily and execute as shown in Table 1.

Data – Input from bus
Result – Database assertion
Message – I/O with PVI

Thus the IMC performs the role of crew assistant in reducing the pilot's workload in midst of the Modern cockpit environments covering highly integrated and complex automatic functions.

6. IMC DEVELOPEMNT APPROACH

All of the above modules for each of the mission functions shall be concurrently developed as these expert systems development approach can be easily modularized as mentioned in the Fig. 8.

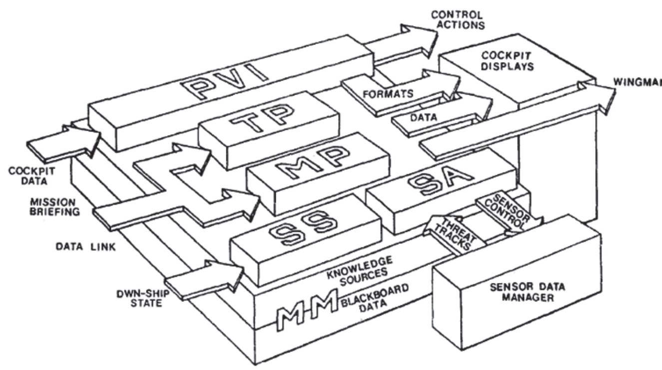

Figure 8. IMC modular approach.

Further, as all the models shall be prototyped in the simulated environment, the real-time performance of the IMC shall be verified before and after porting on the target hardware.

7. IMC CERTIFICATION

Testing the effectiveness of the integration of human and machine intelligence is an important emerging concern for fielding AI-based tactical decision aids. The emphasis falls in three important areas such as the real-time performance of the IMC, demonstration of operational utility of the aiding provided by the IMC, i.e. the inference capability for its functions like flight guidance, mission planning etc. and the knowledge base

Table 1. System status logic type and I/O

Process	Logic type	Input	Output
Situation interpretation • Fault detection • Limit estimation	Kalman filters models	Data	Result
Situation diagnosis • Plan generation • Constraints generation	Constraint propagation models Forward chaining	Result	Result message
Decision making • Favoured plan selection	Forward chaining and models	Result	Result message
Dialogue manager • Presentation to pilot	Forward chaining and models	Data result	Data message
Plan execution • Pilot response	Models	Message	
Plan monitoring • Corrective action	Backward chaining and models	Data result	Data message

component of IMC. The key methods for verifying expert system[8]:

- Rules verification for structure and weights
- Cross reference verification
- Line of reasoning
- Empirical testing and categorical testing

The testing of inference engine associated with real-time performance testing as well it has high association with the sensitivity of the system for its operational capability.

As the IMC development approach is highly modularized, the philosophy of incremental qualification can be adopted, where functionality of a subsystem can be developed and tested in incremental way.

8. FUTURE GROWTH

Currently Defense Avionics Research Establishment, Bangalore is in the process of developing the proposed IMC architecture. The functions are prototyped in a simulated environment. Further in general, the adaptability of IMC into the mission management systems for unmanned air combat system shall be explored as the artificial intelligence which has been emerging out as the key to improve the efficiency of UAV mission management.

9. CONCLUSION

The cognitive behavior of the MC with the human-centered automation increases the aircraft performance and its mission capabilities as the modern cockpit environments are covering highly integrated and complex automatic functions, pose various demands on the crew and in unusual situations the crew often is overtaxed and acts erroneously. 'Clumsy automation' is considered to be a major reason for deficiencies concerning the interaction between cockpit crew and aircraft systems. In this scenario, the role of IMC is crucial in reducing the pilot's workload by acting as crew assistant. Figure 9 illustrates the strength of cognitive automation.

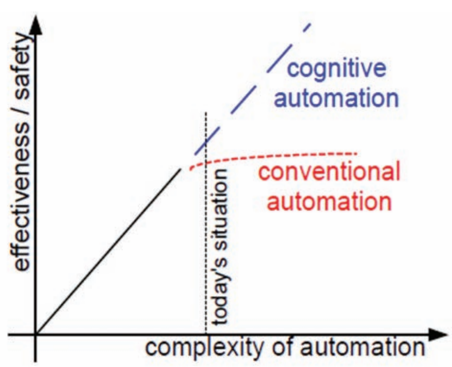

Figure 9. Expected benefit of conventional and cognitive automation.

Artificial intelligence techniques have become a natural evolution based on the availability of rapidly accelerating raw computer power. In fact, AI techniques are becoming so ubiquitous that the computers that now bear the label 'Intel inside' could well be labeled 'AI inside', says Alan Meyrowitz, Director, Navy Center for Applied Research in Artificial Intelligence, Naval Research Laboratory, Washington.

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REFERENCES

1. Sutterfield, Brian; Hoschette, John A. & Anton, Paul. Future for the jet fighter mission computers. *In* the Digital Avionics Systems Conference, 2008. DASC '08. IEEE/AIAA, 26 Oct. 2008. pp.1.A.4-1-11
2. Krishnamoorthy, C.S. & Rajeev, S. Artificial intelligence and expert systems for engineers. CRC Press LLC,
3. Smith, Reid G. Knowledge-based systems, concepts, techniques, examples. Presented at the Canadian High Technology Show. Lansdowne Park, Ottawa, ON, 8 May 1985 .
4. Billings, Charles E. Aviation automation. The search for a human-centered approach. Lawrence Erlbaum Associates: Mahwah, NJ. 1997.
5. The pilot's associate: A forum for the integration of knowledge based systems and avionics. Capt. Carl Lizza, Air Force Wright Aeronautical Laboratories, Wright-Patterson Air Force Base, Ohio. pp. 1252-1258.
6. Putzer, Henrik & Onken, Reiner. COSA – A generic approach towards a cognitive system architecture. *In* the Cognitive Work Process: Automation and Interaction. *In* the 8th European Conference on Cognitive Science Applications in Process Control, CSAPC'01. Munich, Germany. 24 -26 Sept. 2001, pp. 140-151
7. Flemisch, Frank & Onken, Reiner. The cognitive assistant system and its contribution to effective man/machine interaction. The Application of Information Technology (Computer Science) in Mission Systems. NATO RTA SCI. Monterey, USA. 1998. pp4-1to 4-18
8. Tsai, Wei-Tek; Vishnuvajjala, Rama & Zhang, Du. Verification and validation of knowledge system. *IEEE Trans. Knowledge Eng.,* 1999, **1**(1). 202-211

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