2010: THE SYMBIONIC COCKPIT

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ABSTRACT

The cockpit of the year 2010 is described in terms of both the capabilities and systems it contains and how the pilot interacts with it. A brief mission narrative is provided describing seveal hours in the life of the Manta air superiority fighter. This is followed by a discussion of the pilot interface components employed in the cockpit including hueristic voice, instrument panel display, canopy display, and holographic display systems. The concept of a "symbionic" system is then introduced, describing in some detail the capabilities and features of a cockpit system that senses the physiological and mental state of the pilot and responds accordingly. Finally, conclusions and predictions are made that summarize and emphasize the points made in the paper.

INTRODUCTION

Predicting the technology which will be on the shelf a quarter century from now is, to say the least, a difficult challenge. Picture, for example, telling someone in 1960 that in 1985 there would be aircraft made of composites, possessing digital, fly by wire flight control systems, and containing color cathode ray tubes in the crewstation. The acceleration in technological development continues to be overwhelming. As one small example, the main computer in NASA's Space Lab had 128K of internal memory (ref. 1); now, most home computers contain this amount and many have double this capacity.

There are two factors, however, which aid our prognostications considerably. The first is that nearer term predictions have already been made (ref. 2,3,4,5). The year 2000 is the main target of these efforts, but they can serve as a jumping off point for ten years beyond. The second factor is the state of the art in production or near-production crewstations. The F-18 and the soon to be produced F-15E present an inkling of things to come. The F-18 contains such technologies as cathode ray tubes (CRTs), multifunction controls and voice warning systems. The F-15E is slated to have color CRTs and flat panel displays. If this is the state of the art now, what will the crewstation be 25 years from now and what will the pilot's job be in that crewstation? The purpose of this paper is to describe the 2010 cockpit and discuss how the pilot might interact with it.

THE 2010 MISSION

Before discussing the cockpit of the future, we must develop an understanding of the kinds of jobs the aircraft will be asked to perform. This section of the paper characterizes, in broad terms, several hours in the life of the mythical F-1 Manta, our fifth generation multi-role fighter.

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The Manta is sitting ground alert at Boxcar Air Force Base when data link reports four low-level cruise missiles inbound; the suspected target is the supply depot at Port Station. Through data link the Manta receives latest missile position, altitude and heading information, and launches on a best approximation intercept course. Projected fuel requirements, alternate air fields, weapon launch envelope, netted resources, and airborne refueling capabilities are automatically displayed on the lower left portion of the forward display surface. The pilot reviews the data for reasonableness and decides that the route planner is functioning as needed. After reaching altitude and simultaneously crossing Point Bravo, the aircraft navigation and guidance systems trigger an avionics remode to air-to-air covert intercept and performs necessary system status checks. Long range sensors operating in a covert, passive mode are set to scan for Red forces' cruise missile support aircraft (CMSA) in the airspace along the projected missile route.

Just prior to crossing the Forward Edge of the Battle Area (FEBA), satellite intelligence data is received reporting current missile heading and altitude information, and confirmation that the missiles are hostile. Upon receipt of intelligence data, the on-board route planner computes an updated intercept heading, arms four Multi-role Attack Missiles (MAM's) and assigns missiles to targets. Time to optimum launch, along with soonest 50% probability of kill (Pk) launch zones are displayed as both digital time-to-go and graphic situation awareness template overlays. (Yes, there will still be numeric data in order to convey quantitative information to the pilot.)

Simultaneously with arriving at the 50% Pk location, passive sensors detect one CMSA at maximum range, bearing 012 degrees. The route planner immediately generates a missile attack sequence in order to deal with the new threat. The option to initiate the immediate attack sequence is declined (overriden) by the pilot, resulting in a forced "Pk desired" selection by the pilot. Routing and computed Manta probability of survival (Ps) are displayed as a function of alternative cruise missile Pk options. The pilot selects 80% Pk for the missiles, accepting the probable need for close in particle beam engagement with the CMSA.

MAM launch occurs after pilot consent, and immediate BVR air-to-air moding occurs, placing sensors in an active mode, with two more MAM's becoming armed. Synthetic target symbology showing relative target position, velocity vector and altitude is holographically projected in front of the pilot for review and modification of the planned attack profile. Although out of MAM launch envelope, the pilot overrides the MAM disable function and mentally commands a single launch at the CMSA. Missile miss is indicated as the Manta configures for maneuvering combat. Previously unused direct lift surfaces are deployed and air-to-air combat algorithms are engaged to provide optimum attack trajectories.

As additional sensor data is accumulated and analyzed, the cruise missile support aircraft is classified as to type, top speed, maneuver capability, likely armament, and possible netted support assets. This data is displayed alpha-numerically as both feedback to the pilot that the system is functioning normally, and as tactics support data permitting pilot modification to attack profiles. As the range and time to optimum beam firing decrease, the synthetic target changes color and finally begins to blink indicating within the shoot with impunity zone. The pilot mentally commands a pulse discharge (previously known as shooting), observes the target aircraft disintegrate and tolerates an automatic 12"G" turn to avoid debris.

Because the pilot had overriden the original missile launch opportunity, the Manta is now operating below bingo fuel for the planned recovery base. This data was withheld from the pilot as it was not prioritized high enough during the previous segment to become an active display parameter. Now, the pilot is presented with a recommended routing to the number one priority alternate. The pilot, aware of runway damage incurred since departure, changes the alternate, consents to the new routing, and the return-to-base mode is engaged.

THE CREW SYSTEM

Overview

The mission previously discussed gives a good indication of what the 2010 crew system has to perform. What are the characteristics of the crew system which will allow the Manta to successfully complete its mission? The unique feature required in this system is symbionics. The term symbionics combines key elements from the words symbiosis, biology and electronics. *Sym* is from the Greek syn, a prefix meaning "with, together with"; *bi* is derived from the Greek bios meaning "life, of living things", and *onic*, from electronic meaning "operated . . . or done by the action of electrons". (ref. 6) Hence symbionics as an adjective refers to a system in which a biological organism (the pilot for our purposes) and intelligently controlled electronic components (an "electronic crewmember" [EC]) are combined to produce a composite whole, the successful operation of which is dependent upon the interaction of the two. In the context of a future military aircraft, symbionics refers to the manner in which the vehicle, as a system, senses and processes incoming information and, in response, determines and carries out specific actions. Such a system is characterized by a human operator, blended with a computer-based, electronic subsystem so as to make one indistinguishable from the other in the realm of information processing and control. Further, a symbionic system is one in which neither the human element nor the electronic subsystem can, by itself, complete all functions necessary for optimum system performance; there is a synergistic relationship between them.

This section of the paper describes, in some detail, the key features of the symbionic cockpit. These features range from systems to provide physiological comfort and protection to the pilot to information monitoring and control systems that treat the pilot as an integral component with executive program type supervision and control over all other systems and subsystems on the vehicle. Three areas are discussed: Life Support, Active Pilot Monitor and Control, and Symbionic Special Features.

Life Support

The Manta fighter has a completely self-contained environmental control system capable of filtering or neutralizing chemical, biological and radiological agents from the air used to pressurize the cockpit. Cockpit purification systems employing ultraviolet light baths and radiation absorbing molecular aerosols are installed to cleanse contaminated surfaces resulting from unavoidable exposures. "G" protection is provided through a combination of on-body equipment including pulsed-wave bladders and restraints, and a fully gimbaled, pilot posture and support system. This system provides full-body support while maintaining the optimum body position for "G" tolerance. Escape from the aircraft, while either airborne or on the ground, is provided for through separation of the crew capsule from the main vehicle air frame. Provisions are contained in the crew capsule for five days survival, emergency location, exterior surveillance, communications, water survival, and anti-personnel response. An on-board, throttleable escape engine and fuel supply provide sufficient propulsive power for two hours flight, while a deployable air cushion or parachute recovery system provides safe return-to-earth capability. Solar/nuclear power cells contained in the capsule and activated upon capsule separation from the air vehicle provide electrical energy to monitor and control all capsule systems, including displays, survival computer, laser self-protection weapon and surveillance systems. For capsule abandonment, full-body protection from chemical, biological or radiological agents is provided for through pilot application of "plasti-skin" a spray-applied, semi-permeable membrane. Finally, additional protection from nuclear flash is provided for through PLZT transparancies used in the canopy and direct view ports located in the sides and bottom of the crew capsule.

Active Pilot Monitor and Control

Pilot command input to and monitoring of the air vehicle is provided for through several interface systems. These include the following:

Stick and Throttle Control—The stick and throttle control system provides for pilot manual input to those systems and functions on the vehicle to which the pilot has access. In general, only outer-loop control functions are permitted, dealing primarily with the accomplishment of mission level goals such as specifying target class, identifying mandatory waypoints, or overriding assigned target priorities. Limited inner-loop control authority is provided for thrust or attitude management, but only as back-up to the computer driven system.

Heuristic Interactive Voice—The interactive voice system provides natural language interaction between the pilot and the vehicle. Most pilot inputs can be made using the voice system, including weapons arming, destination selection, navigation profiles, target priorities and data link message creation and transmission. The heuristic aspects of the voice system imply a level of learning far beyond that contemplated for current voice recognition systems. Not only will the Manta's voice recognizer be able to distinguish between different forms of the same word, e.g., two-niner-niner-two versus twenty-nine ninety-two, but it will also be able to learn the pilot's emotional state. Through voice templates built up during stressful portions of training missions and prior combat sorties, and by comparing voice characteristics to other physiological measures of stress gathered from the pilot at the same time, the EC's voice system will learn when the pilot's emotional state may be so high as to indicate information processing overload. If this condition is reached, the EC will automatically offload the pilot through dynamic task allocation.

Electronic Instrument Panel—Located within the crew capsule below the canopy sill line and encompassing the forward hemisphere is an electronic display surface on which is presented unprocessed sensor imagery, computer generated graphics imagery or alpha-numeric text data for consideration by the pilot. The system is self-tailoring such that degraded sensor imagery is detected and automatically replaced with a synthetic, computer generated alternative. Default parameters determine where on the display surface information is first presented, but pilot override, either manually thorugh touch control, orally through verbal control, or mentally through brain wave control, can reposition the data on the display surface. In addition to repositioning, data can be expanded (for example, sensor imagery can be blown-up), condensed or deleted using the same interface techniques mentioned above. Since the display surface is touch sensitive, it may also be a system controller and serve as backup input medium for pilot control of the aircraft.

Canopy Display System—The canopy is also used for display presentation and transitions from a totally opaque surface to prevent flash blindness and/or serve as a display surface, to total transparency for out-of-the-cockpit, direct viewing of the real world. Transition from opacity to transparency is under computer control and occurs as a function of weather condition, sensor data accuracy, ambient light level, mission condition, or, if desired, direct pilot intervention. In the case of sensor imagery presentations, the system will automatically vary the opaqueness level in order to obtain the best information content out of the system, and blend as necessary, computer generated graphics with the real world scene. Display resolution matches the real world and the transition to computer generated scene enhancement is below the pilot's perceptual threshold.

Holographic Display System—The holographic realtime projection system projects computer generated holographic imagery into the cockpit space to present a true, three-dimensional view for maintaining pilot situational awareness. Imagery is computer generated, based on sensor, data link or pilot input, but as was the case with the electronic display surfaces or canopy display system, transition from one to the other is not discernable by the pilot. Thus, the system provides the best information possible on a continuous basis by subtly blending computer generated data with the real world as seen through the canopy.

Symbionic Special Features

Physiological Monitoring and Control System—Many of the concepts embodied in the definition of a symbionic system could be applied to today's aircraft, and, for that matter, are the essence of all human-machine systems. So how will the 2010 symbionic crewstation differ from those in current aircraft? The crucial distinction centers on how intimately the pilot and the EC are tied together. In the book *North Cape* (ref. 7) such a relationship is described. The pilot, Joseph Teleman, is flying the AR-17, a reconnaissance aircraft a generation or two beyond the SR-71. The AR-17, among other things, can remain aloft unrefueled for a week.

> Teleman's physiological and biochemical status was monitored constantly during the mission through a specially tailored system of instruments blended together to form the Physiological Control and Monitoring System [PCMS]. At the start of the mission, an intravenous catheter was inserted into the superior vena cava vein through a plug implanted surgically in his shoulder. A glass electrode was brought into intimate contact with his bloodstream at this nearest acceptable point to the heart. Through the electrode a series of minute pulses, set up by an electrochemical reaction with his blood, informed the computer continually of his body status. The computer was programmed to receive inputs directly from various parts of the aircraft's controlling instrumentation that, coupled with the *in vivo* status reports, determined the time and dosage of the drugs he received. If the instrumentation, directed by the flight plan or by instructions from Teleman, called for a state of physiologically alert and expanded consciousness, proper drugs were fed into his bloodstream through the catheter and his body responded accordingly. Because of the duration of the flights, often lasting six to seven days, when Teleman was not needed to respond to specific tasks, the computer instructed the PCMS to feed in barbiturate derivatives and he slept. Teleman had once calculated that at least 65 per cent of all his missions were spent sleeping. (pp. 31–32).

The degree of interaction between Teleman and the AR-17 is quite obviously a radical departure from any serious proposal that might be advocated today. Nevertheless, it is certain that the pilot's "plant dynamics" will be monitored in real time and that the data will be used to dynamically allocate tasks between the pilot and the EC.

Thought Control—*North Cape* gives some insight into one communication link in the symbionic crewstation—an automatic and unconscious transmission of data based on physiological indices; however, there must also be a means for the pilot to put direct commands into the system. The book *Firefox* (ref. 8) previews a key way this communication will occur in the 2010 cockpit. Major Mitchell Gant, the pilot of the MiG-31, gave his commands directly to the avionics subsystem by means of thought control (although he had some difficulty in that the commands had to be thought in Russian). This thought controlled, biocybernetic communication loop has been described elsewhere (ref. 9). The reason for including it here is that it provides an example of a very effective means of interaction with the EC; other means might include voice control. The key point is that it is these natural communication channels that let the pilot and the avionics work together so effectively. The result is a sharing of tasks in a way never before heard of.

Dynamic Task Allocation—One reason that the pilot has a workload problem in certain situations is that so many tasks have to be performed in such a short period of time that he loses sight of his priority scheme. If he knew which task to start with, many times the others would fall into place. In the symbionic crewstation prioritization will not be a problem for the pilot when complex situations arise; he will pick the task that he feels is the top priority, and the EC will automatically, in real time, handle the others—this is the essense of dymanic task allocation. Throughout the mission the crewmembers, human and electronic, will have such intimate knowledge of how to work with each other that they will function as smoothly as an olympic figure skating pair, each anticipating the moves of the other while striving for the same goal. The tasks, therefore, will be dynamically allocated to each partner as a function of mission segment and their health. If for example, the pilot were to sustain injury, the PMCS would detect it immediately and assign tasks to the EC depending on the state of the injuries. Conversely, if through battle damage for example, the EC were to become partially disabled, it would inform the pilot of its injuries and tell him the tasks it was no longer able to perform.

Levels of Automation—At what level will the pilot and the EC interact? In a previous paper (ref. 10), the authors discussed three categories of pilot-computer interface (pilot-only, blended, and computer-only) and three types of weapon system goals (mission, functional, and task). Of the nine possible computer interface/weapon system goal combinations created, the blended/mission pairing is the one of most interest for the symbionic crewstation. In this condition, pilot involvement in decisions occurs at his option. Pilot-only decisions will occur rarely in this crewstation. Because of the unique capabilities the EC can bring to the table, the pilot by himself will, for the great majority of cases, perform less efficiently than when blended with the EC. Similarly, most of the computer-only decisions will deal with relatively mundane factors such as monitoring systems, diagnosing faults or handling high data rate sensor fusion. The key mission decisions will involve the talents of both crewmembers. These decisions are related to the broad, overall objectives of the weapon system. For example, in the mission discussed previously, the mission goal was to destroy the Red force cruise missles. This was a blended decision, one which the computer (EC) may not change on its own. The computer may advise the pilot that accomplishment of this mission is no longer feasible and recommend an altenative, but pilot consent is required to act. The lower level functions and tasks needed to attain this mission goal will be handled by the EC. For example, the functions of navigating to the intercept point, selecting and arming the proper weapons, and computing defensive strategies against threats all would be the EC's responsibility—unless the pilot chooses to intervene.

SUMMARY

The cockpit of the year 2010 will be very different from those in today's aircraft. By far the biggest difference will lie in the crew's composition. All fighters of this era will have two crewmembers—one human and one electronic. Advancements in computer technology will have taken such strides that the electronic back seater will be able to perform the tasks previously assigned to his human counterpart. Examples of these are navigation, communications, weapons management, and sensor data fusion.

The electronic crewmember will also possess unprecedented knowledge of the pilot. The normal reaction time and flying behavior of the pilot will be stored, and a template of average performance will be used as a reference pattern to know when the pilot is performing in a non-optimum manner (because of injury, for example). Communication from the pilot will be through natural and very efficient links such as thought control, eye control, or voice control. The communication between the two partners will be so complete that one will react to the moves of the other in a manner that is second nature. Because of this symbionic relationship, they will achieve weapon system performance unheard of in present fighter aircraft.

CONCLUSIONS/PREDICTIONS

1. For manned aircraft of the year 2010, the crew station will contain no windows per se; the composite structure will become transparent when required.
2. The capsule cockpit will provide for essentially unlimited "G" tolerance.
3. The capsule, upon ejection, will have its own power and self protection weapons.
4. The level of communication between the human and electronic crewmembers will be so intimate that dynamic task allocation and blended automation will occur easily.
5. All decisions will be automated except those related to mission goals—they will be blended.

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