TOWARD THE PANORAMIC COCKPIT, AND 3-D COCKPIT DISPLAYS

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ABSTRACT

"Situational awareness" has been identified as the single most critical factor in improving mission effectiveness in fighter aircraft. Situational awareness can be described as having knowledge of the current and near-term disposition of both friendly and enemy forces within a volume of space. This knowledge or information in future military aircraft will be presented in the cockpit using computer or electro-optically generated displays. Thus, display technologies are critical for providing a pilot the situational awareness necessary to fly, fight, and survive in the future combat environment.

This paper will present ongoing research at the Cockpit Integration Directorate to develop and mature large area (panoramic) cockpit technology for transition to current and future military aircraft, and to evolve this technology into a three-dimensional (3-D) cockpit display for providing an optimum man-machine interface in future aircraft cockpits. A review of the Panoramic Cockpit Control and Display System (PCCADS) study and final results, and current extensions to that effort will be discussed. An assessment of display hardware technology, and progress toward realizing a panoramic cockpit display will be presented. Finally, related efforts to extend panoramic display technology to 3-D will be examined.

INTRODUCTION

A pilot's success and survival in the air combat arena is highly dependent upon his ability to rapidly formulate and act upon an accurate mental model of the surrounding environment. This requires an understanding of friendly, enemy, and unknown aircraft movements, target and threat locations, topographical layout, safe flight corridors, etc. State-of-the-art for displaying this information to a pilot uses two-dimensional (2-D) pictorial formats, displayed on multiple cathode ray tube displays of limited size (i.e., 6" x 6"), as depicted in Figure 1. In order to develop situational awareness, many pilots of current fighter aircraft assimilate and integrate information from several 2-D displays and cognitively fuse them into a single, coherent 3-D mental image. Integrating information in this manner requires pilot cognitive processing resources and valuable decision making time, both of which will be at a premium in future cockpits.

As situational information becomes more complex, multiple displays with limited size 2-D formats may not be sufficient to present the pilot critical information in an easily understood manner. Large area panoramic displays coupled with stereoscopic 3-D separation may provide the pilot with situational information which could be far superior to current technology. Emerging flat panel display technologies will enable these larger displays to be fabricated for cockpit applications. These new display capabilities will enable the pilot to better cope with the increasingly demanding workload associated with future missions.

REVIEW OF PCCADS STUDY

Current tactical fighter cockpit display systems present problems for gaining and maintaining situational awareness. This is a difficult task since the limited size displays on current fighter aircraft become too cluttered as the tactical situation gets more complex. A potential solution to this problem is to integrate the available data and information and present it on a single display. The main objective of the PCCADS study was to evaluate the improvements to situational awareness if a single, large area color display were used to handle the clutter problem and provide the display surface area required to fuse all sensor data into a single picture of the tactical situation (1,2). In the initial PCCADS study, the Head Down Display (HDD) essentially occupied the entire instrument panel of the cockpit, as shown in Figure 2.

The McDonnell Aircraft Company (MCAIR) was contracted by the Wright Research and Development Center (WRDC) to test and validate the PCCADS concept. MCAIR designed and built a cockpit simulator with a 15" x 20" (300 square inch) HDD using two rear projectors to present information on the display surface. One projector provided the background display, usually a moving map, while the other projector provided all of the overlay information, such as ownship, friendly, and other aircraft positions, threat and target locations, route-of-flight and other information required to perform various mission tasks. Windowed inserts for systems status or sensor display were always available, but only displayed at the pilot's command. The pilot had the option of enlarging, reducing or completely removing the inserts from the PCCADS display at his discretion. This large area display was coupled with a Helmet Mounted Sight/Display (HMS/D) that projected limited HUD symbology and targeting cues to the pilot, and a narrow field of view HUD was projected on the out-the-window scene.

The key elements of the graphics system designed to generate the required display information were the Map Image Generation System (MIGS), a Compuscene IV, a Silicon Graphics IRIS, a graphics processor, and the projection system. A functional block diagram depicting the PCCADS simulator is shown in Figure 3.

The PCCADS cockpit was operated using four different control methods:

(1) Hands on Throttle and Stick (HOTAS)
(2) Touch control
(3) Helmet Mounted Sight (HMS)
(4) Voice control

Flight control was provided by dual throttles and a limited movement deflection sidestick, both incorporating numerous HOTAS switches to select and control avionics functions. The entire panoramic HDD surface had a touch sensitive overlay and employed pull down menus as a means of designating information to be displayed on the HDD. The helmet mounted sight used a Polhemus head tracking device to detect when the pilot was looking into the cockpit, and drove a cursor on the HDD. Finally, a Votan VPC-2000 Voice Recognition Card provided voice control.

PCCADS TESTING AND RESULTS

Ten pilots assisted MCAIR in the evaluation of the PCCADS cockpit and its utility in tactical fighter operations. Four of these were senior USAF pilots with F-15 experience, while the remaining six were MCAIR engineering pilots. Extensive training consisting of eight hours of academics and six hours of hands-on familiarization in the PCCADS cockpit was given to all the pilots.

The PCCADS crew station was evaluated in 80 hours of piloted simulation. The 80 hours of simulation was divided between 40 hours in a dome simulation facility with complete 360 degrees out-the-window scene, and 40 hours in a part task simulator with a 40 degree out-of-the-window scene. The Air Force pilots participated only in the dome facility evaluations. Each pilot flew both an air-to-air and air-to-ground scenario, with each scenario divided into segments for the purpose of data collection. Performance data were collected in real-time during the test scenarios, and subjective situational awareness and workload data were collected using questionnaires during breaks, and between mission segments during simulations. In the questionnaires, the pilots were asked to compare the situational awareness provided by the PCCADS display relative to the displays in the aircraft they were most familiar with, e.g., F-15. The results showed that the pilots were overwhelmingly in favor of the PCCADS concept as a means of providing better situational awareness in the cockpit.

It is one thing to demonstrate the potential effectiveness of a 300 square inch HDD for the cockpit, but quite another to actually build such a flight capable display. Due to current size limitations on display technology, a more prudent approach is to apply the PCCADS concept to a display size (100 square inches) that is more realizable in the near future. This is the objective of current efforts within the Cockpit Integration Directorate.

PCCADS 2000

The PCCADS 2000 program is a jointly sponsored effort by the Cockpit Integration Directorate (WRDC/KT) and the Armstrong Aerospace Medical Research Laboratory (AAMRL/HEA). Both organizations are involved in the development of technologies and techniques for improving the pilot-vehicle interface. The objective of this extension to the original PCCADS study is to reconfigure the PCCADS cockpit to demonstrate and evaluate, in a real-time piloted simulation, the benefits of the PCCADS display concept using a smaller 100 square inch panoramic display with full color and touch capabilities. In this revised display configuration, a 100 square inch, full color "integrated situation display" is flanked on either side with 5 X 5 inch monochrome displays for systems status or other display functions, as depicted in Figure 4. This display configuration is more realizable in the near term, and is in accord with a 100 square inch flat panel display development effort currently sponsored by WRDC/KTD. The PCCADS 2000 program will use the same four control mechanisms as the original PCCADS study, and will also demonstrate and evaluate the HMS/D in conjunction with this new display configuration.

The current PCCADS cockpit will be modified to provide realistic F-15E and augmented F-15 avionics capabilities expected for the mid 1990s. For the augmented F-15 avionics, an electronic terrain map and JTIDS system with sensor fusion will be integrated into the avionics suite, and will be used as an integral avionics capability for providing situation information in the battle area. Test comparisons of the F-15C, F-15E, and the PCCADS 2000 display systems, both with and without the HMS/D system, will be made. It is expected that pilot situational awareness and fighter aircraft performance will be significantly enhanced by implementing the PCCADS on a 100 square inch integrated situation display, which is a display size realizable for early 1990s applications.

DISPLAY TECHNOLOGY ASSESSMENT

At present, there is no single technology that can satisfactorily provide reliable, sunlight readable, full color large area displays for the military aircraft cockpit environment. Consider that a 100 square inch display would require a display surface nearly three times the size of current fighter cockpit display technology. While presenting an opportunity to provide the pilot additional situational awareness information in a fused manner, large area cockpit displays also present a challenge to the display designer.

The future cockpit display will require improved sunlight readability, color capability with increased resolution, and possibly night vision compatibility, while minimizing display weight, power, and space requirements. Emerging flat panel display technologies offer a solution to meeting these stringent requirements. The current leading technology for a sunlight readable, full color, video capable flat panel display is Active Matrix Liquid Crystal Display (AMLCD) technology. Unlike the multiplexed liquid crystal displays currently popular in portable computers, AMLCDs use an active thin film device (usually a transistor or diode) to individually control each picture element (pixel). This provides increased contrast and wider viewing angle, resulting in a more readable display. It also allows good gray scale capability for display of video information, since the voltage on each pixel can be controlled individually. Because liquid crystal displays are nonemissive, the contrast ratio is not greatly affected by ambient illumination, which gives these displays improved sunlight readability compared to cathode ray tubes. For avionics applications, a compact backlighting system is used for improved daylight and nighttime viewing. To obtain a color display, an array of color filters is aligned over the thin film array of pixels.

AMLCD technology and applications have grown dramatically over the past few years (3,4). WRDC/KTD has previously funded efforts to investigate the use of this technology for both head-up and multi-function display applications, in the High Reliability Head-Up Display and Color Matrix Display efforts. Current state-of-the-art for avionics applications is demonstrated by full color AMLCD prototypes up to the 6" x 6" size range (5,6) [Figure 5]. This is comparable to the sizes of CRT based displays used in fighter cockpits today. AMLCDs for avionics applications, in sizes up to 100 square inches, will be available in the early 1990s. WRDC/KTD is currently pursuing development of a 100 square inch, full color, sunlight readable AMLCD demonstrator under the Color Head Down Display program.

Similar technology developments for commercial applications have already demonstrated flat color AMLCD TV prototypes up to 14 inches in diagonal, as shown by Sharp Corporation at the 1988 International Display Research Conference in San Diego (7). More significantly, the recent announcement by the Japanese Ministry of International Trade and Industry for a multi-million dollar R&D effort to develop up to 1 meter square color AMLCDs for High Definition TV and other commercial applications is indicative of the future growth in size expected for this developing flat panel technology.

Once large area (100 square inch or greater) displays for cockpits are built, a logical next step is to combine this technology with stereo 3-D technology. There are indications from current research using stereo 3-D that there may be a significant increase in situational awareness in selected cases when a large area display is combined with stereo 3-D pictorial formats.

3-D DISPLAY FORMAT EVALUATION

3-D PAYS OFF

As more of the information the pilot utilizes is presented synthetically through computer graphics, the display formats have continued to get more complex. Some of the display formats created to give the pilot an awareness of his situation are particularly challenging to design in a clear, uncluttered manner. This is especially true in the case of an Air Battle Situation Display (ABSD) [Figure 6] because of the inability to present the depth cues needed to locate the different aircraft in their proper position in the sky (8). The purpose of this study was to compare the relative effectiveness of presenting the ABSD in a stereo 3-D display versus a 2-D display format. The effectiveness of each display type was evaluated in terms of its ability to convey spatial location information about friendly, enemy, and unknown aircraft in a given volume of space relative to an ownship symbol.

The subject's task was to search a spatial quadrant of the ABSD relative to the ownship symbol and identify the number of aircraft symbols in a given target group in that quadrant. When the results were analyzed, the data showed that when the subjects used the 3-D version of the ABSD, they were significantly more accurate (approximately 20%) in identifying the location of the aircraft than when they used the 2-D version.

In another study (9) examining 2-D vs 3-D versions of display formats, the format of interest depicted sensor coverage around an aircraft and consisted of a green, wire frame globe encompassing the aircraft. The task was to identify different segments (colored amber) of the globe that indicated a malfunction of the sensors in that area. Both 2-D and 3-D versions of the display were evaluated.

The results showed that there were nearly four times as many errors with the 2-D version as with the 3-D version. (39 errors for the 2-D version vs 11 errors for the 3-D version).

3-D DOESN'T PAY OFF

Another study was conducted to examine a new flight display, called the Pathway in the Sky, which would provide the pilot with additional situational awareness. The idea behind the Pathway is that the pilot will be able to preview the path ahead and, therefore, anticipate changes in altitude and/or heading. Adding 3-D depth cues to the path should further aid the pilot in obtaining situational awareness by showing how far out in space the path will turn or change altitude. Previewing is not possible with a head up display using a velocity vector and a flight director because the pilot sees only an instantaneous view of the path and cannot see ahead.

The purpose of this study was to evaluate the effectiveness of a two-dimensional pathway, a three-dimensional pathway, and a two-dimensional HUD when flying a pre-programmed route. Eighteen pilots from the US Air Force, US Air Force Reserve, Air National Guard, and other organizations at Wright Patterson AFB participated in this study. All pilots had previous HUD experience.

The results showed that pilots performed significantly better [$F(1,17) = 3.40$ $p < .006$] when using either the 2-D or the 3-D pathway than they did when using the HUD. However, there was no difference in performance between the two versions of the pathway.

WHY 3-D PAYS OFF SOMETIMES

Based on the research discussed in this paper, stereo 3-D seems to be most effective in display formats which are attempting to portray spatial relationships and lack inherent, strong monocular depth cues. This was true in the Air Battle Situation Display just discussed. It was also true of the sensor coverage display format. However, it was not true in the case of the Pathway.

The 3-D path did not do **significantly** better than the 2-D path because the 2-D path provided sufficient monocular depth cues through the use of perspective, relative motion, and interposition. For instance, the pathway seen in the distance appeared smaller and seemed to converge at the horizon. Also, the path blocks closer to the pilot moved faster than the ones viewed in the distance. Because the 2-D path used these monocular depth cues, it was as intuitive as the 3-D path.

SUMMARY

The increasingly complex aerial battle scenarios of tomorrow will require new methods for presenting pilots the information they need to gain and maintain situational awareness. Large area panoramic cockpit displays will allow the needed information to be presented on a single display surface in an integrated and fused manner that will reduce pilot workload requirements. Innovative control mechanisms will allow the pilot to manipulate the information displayed to suit his immediate needs in a given segment of a mission. These panoramic displays will allow the pilot to intuitively understand the tactical situation and take appropriate actions quickly.

The enabling technology to realize these large area displays will be flat panel display technology. Currently, AMLCDs for avionics applications have demonstrated full color and video capability, improved sunlight readability, and sizes up to 9 inches diagonal. This technology is currently undergoing qualification testing for military cockpit applications. AMLCD technology appears scalable to the large sizes needed for panoramic cockpit displays, and will be driven to sizes up to a meter square by commercial applications in the 1990s.

Research into the area of 3-D technologies is providing Air Force experts with better information regarding potential benefits of stereo 3-D displays for future fighter cockpits. One area of current interest focusses on helping the pilot more accurately and quickly build situational awareness in the 3-D aerial environment using true 3-D displays. Other possibilities include increasing target detection in low resolution sensor imagery, creating format declutter options without losing data, and assisting the air traffic controller in safely directing flight paths within the air corridors.

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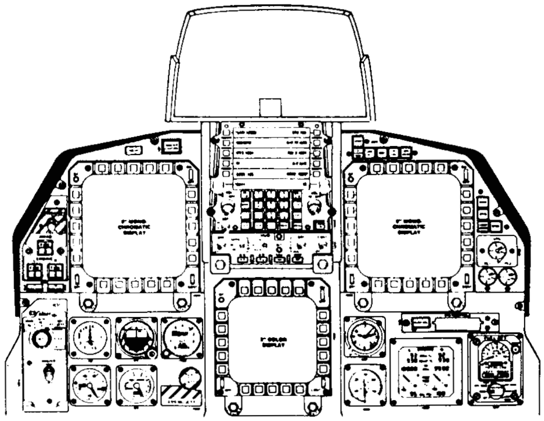

Figure 1. Example of Current Fighter Cockpit Display Layout

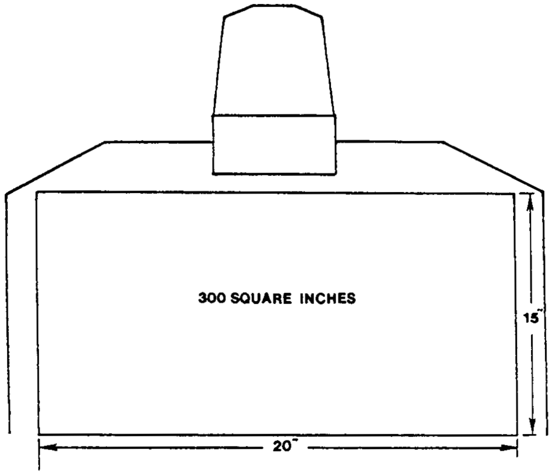

Figure 2. PCCADS Display Layout

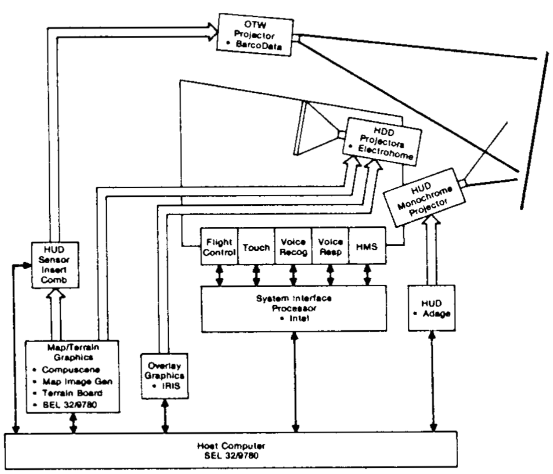

Figure 3. PCCADS Simulator

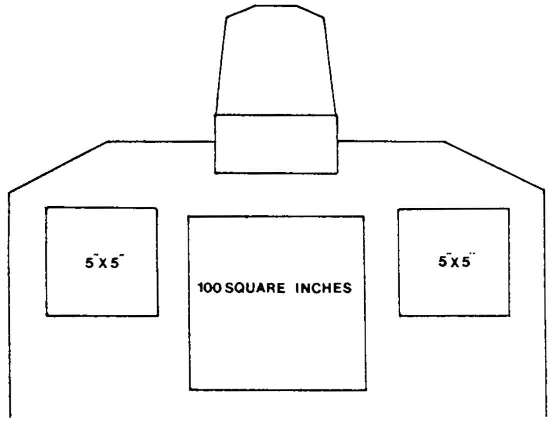

Figure 4. PCCADS 2000 Displays Layout

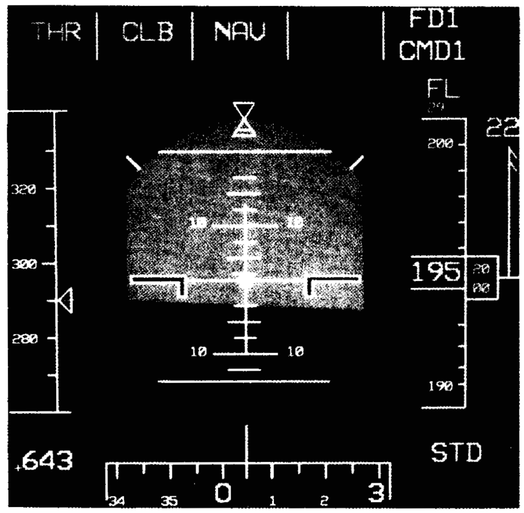

Figure 5. 6.25" x 6.25" Full Color AMLCD Prototype (GE)

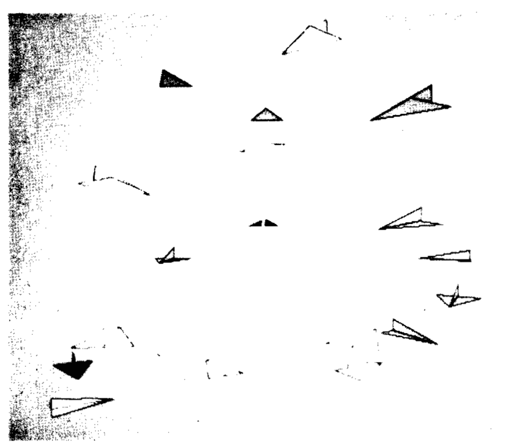

Figure 6. Air Battle Situation Display