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ADVANCE DISPLAYS AND CONTROLS

**AN ASSESSMENT OF ADVANCED DISPLAYS AND CONTROLS
TECHNOLOGY APPLICABLE TO FUTURE
SPACE TRANSPORTATION SYSTEMS**

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INTRODUCTION

This paper addresses the topic of advanced display and control (D&C) technology, covering the major objectives of this technology, the current state-of-the-art, major accomplishments, research programs and facilities, future trends, technology issues, space transportation systems applications and projected technology readiness for these applications. It will also address the holes that may exist between the technology needs of the transportation systems versus the research that is currently under way, and will recommend cultural changes that might facilitate the incorporation of these advanced technologies into future space transportation systems.

OBJECTIVES

Some of the objectives of advanced D&C are synonymous with those of most other advanced avionics technology concepts for space transportation systems. These include reduced life cycle cost, improved reliability and fault tolerance, use of standards for the

incorporation of advancing technology, and, of course, reduced weight, volume, and power. Additional objectives of advanced D&C are to reduce the pilot's workload and improve the pilot's situational awareness, resulting in improved flight safety and operating efficiency. This will partially be accomplished through the use of integrated, electronic pictorial displays, consolidated controls, artificial intelligence and human-centered automation tools. Another objective is to reduce or eliminate paper/manual clutter, such as the Shuttle flight data file, through the use of interactive optical disk technology. The proposed Orbiter Glass Cockpit Display Upgrade Program is an example of a system which attempts to implement some of these objectives. This program will be discussed in a later paragraph.

CURRENT STATE-OF-THE-ART

The current state-of the-art, as well as a potential future direction, in advanced D&C technology is indicated in Figure 1. Representing the state of current D&C technology is

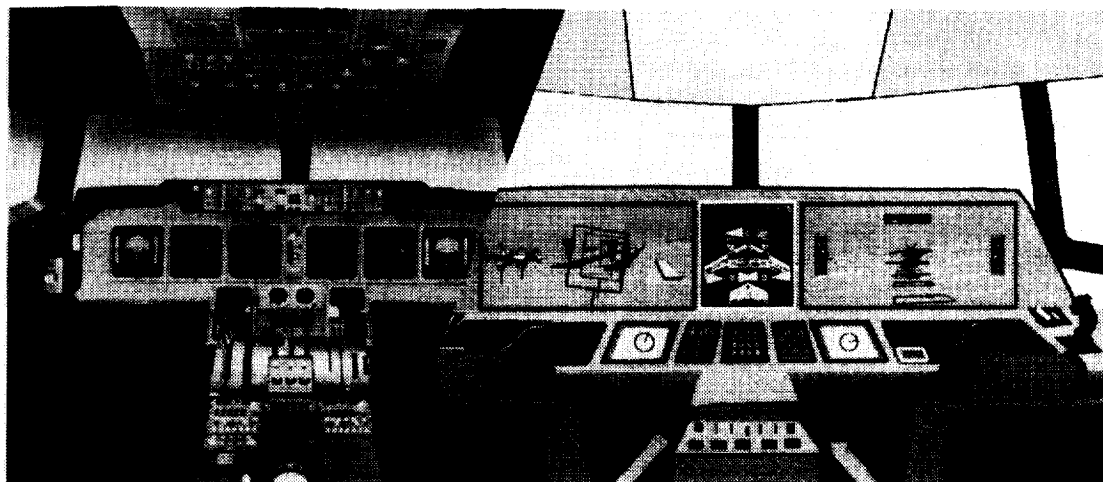


Figure 1.- State-of-the-art transport cockpit (MD 11) and a vision for future cockpits.

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the McDonnell Douglas MD11 transport aircraft cockpit. Here, a clean, uncluttered pilot interface is provided by an "all-glass" cockpit configuration. Display information is computer-generated on full-color cathode ray tube (CRT) displays. The displays are six side-by-side form-factor "D" units, having a 6.25" x 6.25" display surface. Even though the displays are electronic, the format of the presentations are largely renditions of earlier electromechanical displays, such as those presently used in the Space Shuttle. Flight control and engine status information is presented on the two outside primary flight displays (PFD's) and the two inside engine-monitoring/systems status displays. Navigational information, in the form of navigational charts (maps) or horizontal situation indicators (compass rose), is presented on the two inside displays that are between the PFD's and the two center displays. Pilots interface with the aircraft control system and the navigational system primarily via the glare-shield control panel and the navigation control/display units (keyboard/display units shown in the center console). The MD 11 employs extensive use of reliable digital avionics and automation to aid the pilots in flight management, aircraft control, and on-board systems monitoring.

A vision for the future cockpit is shown also by Figure 1, an advanced cockpit technology concept emanating from the aero human factors R&T base program at Langley Research Center (LaRC). Depicted here is an advanced, "all-glass" flight deck which is unusually clean and uncluttered and which makes use of large-screen, integrated, pictorial display technology and human-centered automation. This concept and the technology which it embodies will be discussed in a paragraph below.

A major thrust that is underway in the research and development community is the replacement of the color CRT display technology with flat-panel display technology. The main thrust of these flat panel display devices is to minimize depth, weight, and power consumption, as well as to improve reliability and sunlight viewability. The potential advantages of flat-panel technology vs. CRT technology are presented in Figure 2.

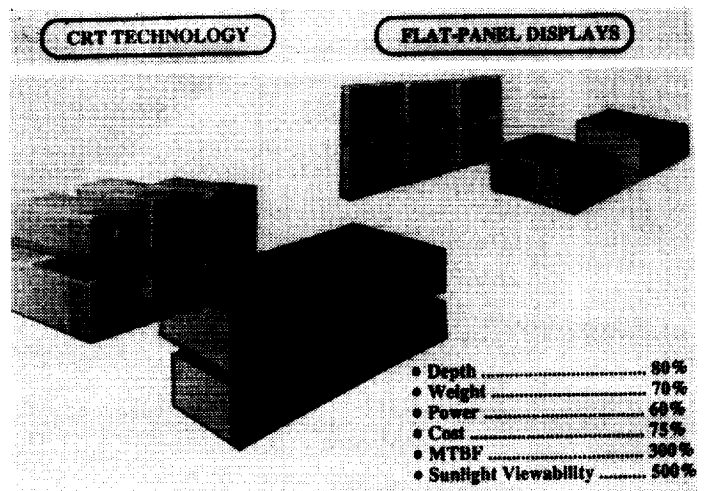


Figure 2-. Potential advantages of flat-panel display technology over the CRT.

Currently, the most promising full-color flat-panel technology is the Active-Matrix Liquid Crystal Display (LCD). One such device, made by General Electric, is currently undergoing bench testing in the Advanced Systems Development Laboratory at Johnson Space Center (JSC). It has a 6.25" x 6.25" usable screen area, and is capable of high-resolution (1024 X 1024 picture elements) graphics and/or video with 16 gray scale levels. An example of a this display is shown in Figure 3, which illustrates a typical primary flight display (PFD) format.

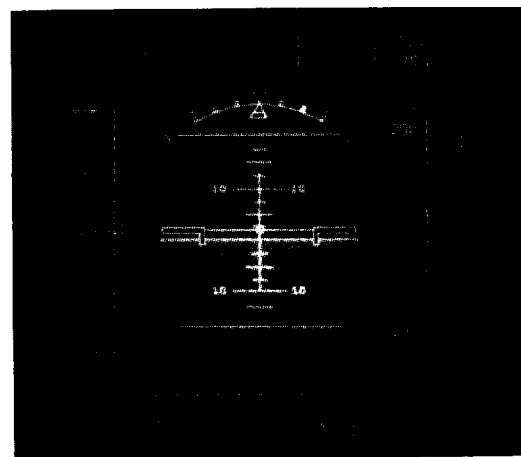


Figure 3.- State-of-the-art color LCD.

Such a device is typical of what might be installed in Shuttle, as part of the proposed Orbiter Glass Cockpit Upgrade Program, to achieve the advantages indicated by Figure 2.

MAJOR ACCOMPLISHMENTS

Some of the major accomplishments which have occurred in the area of advanced D&C during this decade will be discussed next.

The most notable accomplishment is the emergence of several glass cockpits in commercial and military aircraft such as the Boeing 747-400, the Gulfstream G IV, and the McDonnell Douglas MD11. In these cockpits, the conventional electromechanical flight instruments have been replaced with color CRT's driven by modern processors. Since the displays and processors are on a bus, the system can be readily reconfigured in the event of hardware failures. Additionally, these cockpits have made extensive use of built-in-test-equipment (BITE) to ease the maintenance task. This allows the rapid identification and replacement of the particular hardware device that failed without the need for extensive ground-support equipment.

Other notable accomplishments have occurred in the area of flat-panel displays. Five of the leading candidates for color, electronic display in flight are: the CRT; active-matrix LCD; thin-film electroluminescent (TFEL) display; light-emitting diode (LED) display; and plasma panel display (PDP). Of these candidates, the latter four are flat-panel technologies. The potential advantages of flat-panel technologies have already been provided in Figure 2. However, Figure 4 provides the key advantages and limitations of each technology as compared to the CRT. Although PDP technology is not represented in Figure 4, its advantages and limitations will be discussed below.


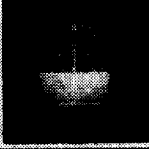
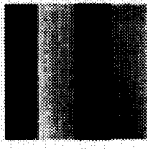
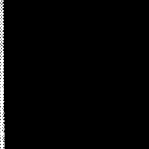
CRT	LCD
 <p>ADVANTAGES</p> <ul style="list-style-type: none"> ● Low Cost ● Resolution <p>LIMITATIONS</p> <ul style="list-style-type: none"> ● Large Depth ● Non-Graceful Degradation 	 <p>ADVANTAGES</p> <ul style="list-style-type: none"> ● Low-Voltage ● Brightness <p>LIMITATIONS</p> <ul style="list-style-type: none"> ● Viewing-Cone ● Environmental Tolerance
TFEL	LED
 <p>ADVANTAGES</p> <ul style="list-style-type: none"> ● Small Depth ● Environmental Tolerance <p>LIMITATIONS</p> <ul style="list-style-type: none"> ● Brightness ● Blue Phosphor 	 <p>ADVANTAGES</p> <ul style="list-style-type: none"> ● Reliability ● Brightness <p>LIMITATIONS</p> <ul style="list-style-type: none"> ● Partial-Color ● Power Consumption

Figure 4. Four leading candidates for color, electronic flight display.

The color CRT provides the advantages of low cost (because of its maturity) and high resolution display. However, it has the disadvantages of large depth and non-graceful degradation. Further, it is susceptible to "washout" under high levels of ambient light. TFEL flat-panel technology has made great strides through research supported by the Army and LaRC. It has achieved full-color capability with small depth and environmental tolerance, however, its brightness limits its present use to low-ambient light environments. The color LED flat-panel technology has the advantages of very high reliability and brightness, but it is achieved at the cost of high power consumption. Further, full-color has not been achieved because of the lack of a bright blue LED capability. The color active-matrix LCD technology, described in the above section and shown in Figures 3 and 4, has the additional advantages of low-voltage operation and high brightness in conjunction with high resistance to "washout" in high-ambient light environments. Color PDP technology has the advantage of large screen size, however, it is achieved at the cost of additional weight in comparison with the other flat-panel technologies. Clearly, the color LCD technology is the leading flat-panel display candidate and has gained much confidence for potential use in both the Space Station MPAC and the Orbiter Glass Cockpit Upgrade, and will undoubtedly be a prime candidate for future advanced space transportation systems.

Another area of major accomplishment during the 1980's is the remarkable advancement in real-time graphics computers/generators. Laboratory-based graphics generators are now available that provide the following high-performance characteristics:

- RESOLUTION: 1280X1024 Pixels
- REFRESH: 30 or 60 Hz
- 3-D TRANSFORM: 500K/Sec.
- POLYGONS/SEC.: 100K (4-Sided)
- COLORS: 16M
- OTHER FEATURES: Hidden Surfaces; Light Sources for Shading

Such generators are being employed in the Aero Human Factors R&T base efforts at LaRC since they offer, for the first time (in a package that might be considered small enough to ruggedize

for flight applications), the opportunity to present pilots flight control information in a high-fidelity, 3-D, "real-world" format that is easier for a pilot to assimilate and act upon. Figure 5, for example, shows one of the "real-world" formats that has been studied at LaRC.

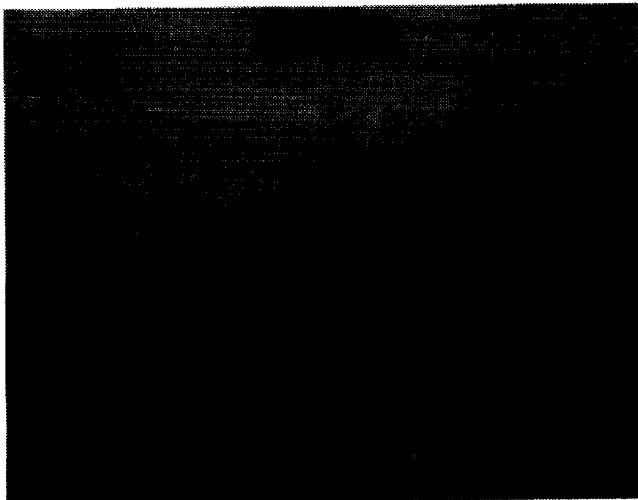


Figure 5.- Example of a "real-world" 3-D display format studied at LaRC.

The most prominent feature of this flight display is the "pathway-in-the-sky" symbology. This type of "real-world symbology" has been shown, in both DOD and NASA research, to enable highly-precise flightpath control, especially for vehicles requiring complex curved flight paths.

The generation equipment described above also permits the real-time generation of displays, such as the format shown in Figure 5, in stereo, thus, enabling the exploitation of "stereopsis" or true-depth in "real-world" pictorial displays. Figure 6 shows the technique being used at LaRC for generating pictorial flight displays in stereo 3-D. Separate left- and right-eye views of the 3-D flight display are provided to the pilot through time-multi-plexing using liquid-crystal goggles, as indicated by Figure 6. The pilot's brain fuses the disparate views into a 3-D image having true depth. Since each eye is shuttered at a 60 Hz rate (overall display frame rate is 120 Hz), there is no flicker. The technique does result in a reduction of vertical resolution by one-half, thus, providing a stereo display having 512 X 1280 picture elements (Pixels). Research at LaRC has shown that presenting pictorial

displays in stereo can provide increased pilot performance and situational awareness.

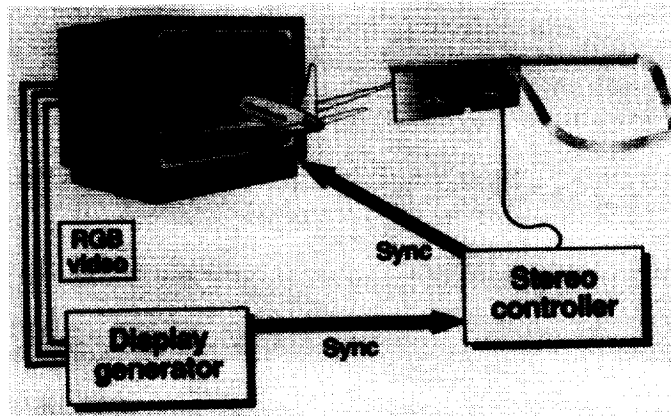


Figure 6.- Technique for generating real-time pictorial flight displays in stereo.

RESEARCH PROGRAMS AND FACILITIES

Several government and industry research programs around the United States are furthering the state-of-the-art in advanced D&C technology or are evaluating the products of advanced development. At NASA/JSC, flat-panel displays and hand controllers are evaluated in the D&C portion of the Advanced Systems Development Laboratory which is headed by Andrew Farkas. In addition to the color active-matrix LCD evaluations mentioned in the above section on Current State-of-the-Art, NASA/JSC will be evaluating a 17" full-color plasma flat-panel display to be received within the next year. This device is being developed under a Phase II Small Business Innovative Research grant from NASA. Another effort under way in this laboratory is the development of a hand controller test bed. Several examples of commercially available hand controllers have been procured and will be evaluated in this test bed, with a special emphasis on determining which hand controllers are best suited to perform robotics tasks with systems such as the Mobile Servicing Center, the Shuttle Remote Manipulator System, and the Flight Telerobotic Servicer. In addition to these activities, this laboratory has developed a simulated Flight Telerobotic Servicer Aft Orbiter Workstation, and a Space Station Multi-Purpose Applications Console (MPAC). These facilities are intended to be used for the determination of requirements for the actual systems.

NASA/JSC also has the Systems Engineering Simulator which is used to perform real-time man-in-the-loop simulations of most Shuttle and Space Station tasks. Functional mockups of the Shuttle Forward and Aft station cockpits, and of the Space Station Cupola are among the simulated systems.

NASA/LaRC and NASA/ARC have several interrelated research programs that have resulted or will result in advances in D&C technology. These programs and their relationships are shown in Figure 7.

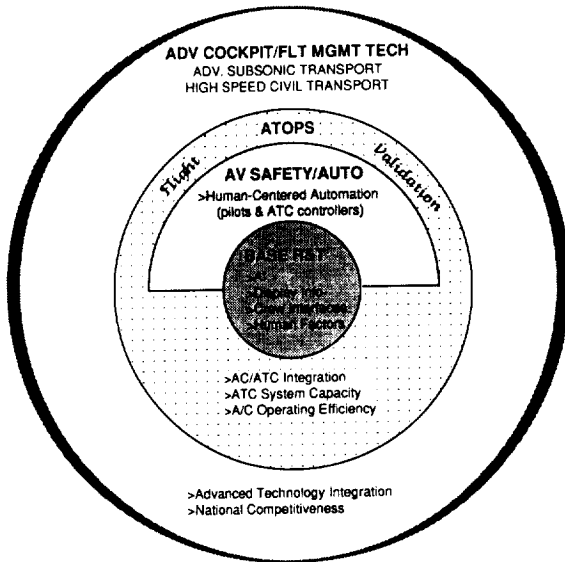


Figure 7.- Research programs at LaRC and ARC related to advanced D&C technology.

The Aero R&T Base program has primary thrusts in the areas of artificial intelligence (knowledge-based systems for pilot aiding), in integration of display information, in advanced crew interface technology, and in human factors methodologies and guidelines for the application of these new technologies. The Aviation Safety/Automation program is a joint program with Ames Research Center (ARC) which has the thrust of providing advanced human-centered automation technologies and application guidelines for both pilots and air traffic controllers. The ATOPS (Advanced Transport OPERating Systems) program has the research thrusts of improving aircraft/ATC systems integration, increasing ATC system capacity, and enhancing aircraft operating efficiency. The ATOPS program, which employs an advanced

B-737 Transport Systems Research Vehicle (TSRV), to be discussed in more detail below, provides a testbed for flight validation of advanced concepts and technology. The Advanced Cockpit/Flight Management Technology program (also a joint effort between LaRC and ARC) is a proposed new initiative which would emphasize both advanced subsonic transports and high-speed civil transport applications and would provide the mechanism for integration of advanced concepts and technologies emanating from the other programs and for providing an advanced technology base which would enhance national competitiveness. Much of this technology base, in the area of advanced D&C, will be applicable to future space systems.

NASA/LaRC and NASA/ARC have extensive cockpit simulation facilities which support the above and other research programs. At LaRC the facilities include a Visual Motion Simulator (VMS), a DC-9 Simulator, an "all glass" Advanced Concepts Simulator (ACS), a Transport Systems Research Vehicle (TSRV) Simulator and companion TSRV B-737 research aircraft, and a Crew Station Systems Research Lab with associated Advanced Display Evaluation Cockpit (ADEC) simulator and Aircraft Cockpit Ambient Lighting Simulation System (ACALSS). At ARC the facilities include a Flight Simulation Complex and a Man Vehicle Systems Research Facility. Two of the major tools within these facilities are the Vertical Motion Simulator and the Advanced Concepts Simulator (ACS). The ACS at ARC is a companion simulator to the ACS (mentioned above) at LaRC (see Figure 8) and



Figure 8.- LaRC Advanced Concepts Simulator

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will be used for joint studies with LaRC, particularly in the area of the Aviation Safety/Automation program. The ACS at LaRC is shown in Figure 8 along with an example of bioinstrumentation used by the Human Engineering Methods group to assess the physiological impact of new automation and D&C technology on humans.

The TSRV B-737 aircraft facility at LaRC is quite unusual in that the research cockpit, a full-color, "all glass," electronic flight deck, is located aft of the standard cockpit and can be utilized to fly the aircraft in a variety of research studies, including approach and landing maneuvers. The airborne TSRV Aft Flight Deck is shown in Figure 9.

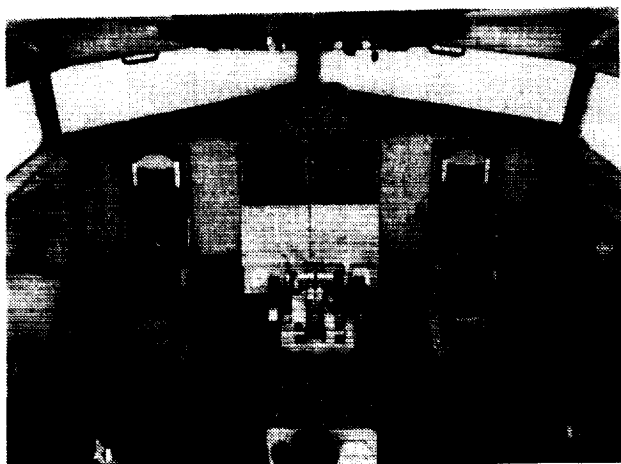


Figure 9.- The LaRC TSRV Aft Flight Deck onboard the B-737 aircraft.

The TSRV aircraft represents a unique flying testbed that has already been used extensively in studies investigating methods for improving the safety, efficiency, and capacity of the National Airspace System, as well as for landing studies, investigating helmet-mounted display (HMD) technology, in support of the National AeroSpace Plane (NASP) program.

Other research programs and associated facilities of interest to this assessment include the Super Cockpit Program, headed by Dean Kocian of the Air Force Wright Research and Development Center (WRDC), and the Cockpit Integration Directorate program, headed by Terry Emerson of WRDC. The former program has the thrust of providing the technology for an integrated, "virtual cockpit" through use of advanced display generation and HMD

technologies. The virtual interface of the Super Cockpit Program is depicted by Figure 10.

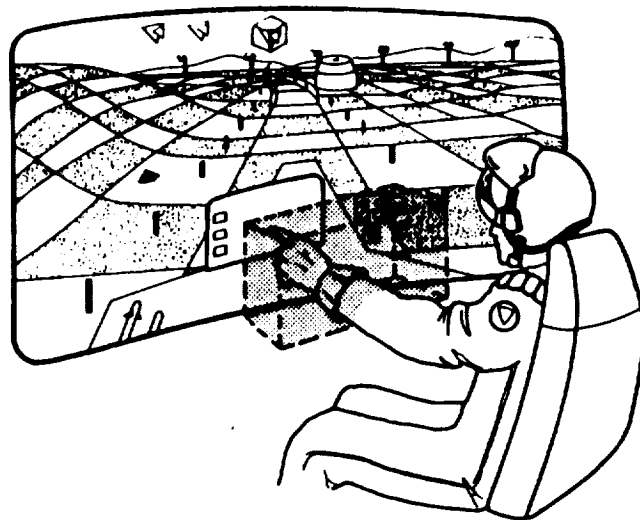


Figure 10.- "Virtual Cockpit" provided by HMD technology in the Super Cockpit Program.

The latter program (Cockpit Integration Directorate) is doing research on pictorial flight display formats for integration of information, on stereo 3-D displays, and on color LCD technology for military applications. A major facility used for this research is their "Magic Cockpit," an "all-glass" fighter cockpit with rapidly reconfigurable display capability. WRDC has also supported "Big Picture" research at McDonnell Aircraft, under Gene Adam, the thrust of which is to study the benefits of providing enhanced situational awareness and planning information to pilots of tactical aircraft via HMD's and large-screen electronic displays. Another important government research program is the Pilot's Associate Program, headed by Doc Dougherty at DARPA. This program is investigating the extensive application of artificial intelligence to future military cockpits in the form of an "electronic associate."

FUTURE TRENDS

The 1990's will undoubtedly bring further advancements in the the fields of voice, touch, and hand-controller input technologies, in flat panel technologies, in HMD's, in artificial intelligence techniques, and in flight worthy graphics generators capable of integrated, "real-world" pictorial display formats.

In voice technology, for example, the 1990's should see further enhancement in continuous-speech, speaker-independent voice recognition technology which will result in systems that allow the operator to keep his/her hands on the controls during critical or dangerous operations. Human factors research has found that voice recognition systems are much more effective when the operator is allowed to speak in a continuous, comfortable manner with commonly used expressions rather than speaking with isolated words, as is required in older voice recognition systems.

Large-screen flat-panel or projection display technology, coupled with advances in real-time graphics generators, may enable the type of advanced-concept future cockpit depicted in Figure 1, wherein total integration of the crew's information requirements is achieved through panoramic, wide-field-of-view, integrated pictorial displays. Already, LaRC is developing a flexible panoramic display research system (depicted in Figure 11) employing dual, full-color, CRT projectors in conjunction with rapid display prototyping graphics systems and software to explore the advantages and limitations of panoramic and large-screen, reconfigurable display concepts. More extensive R&D will be enabled in these areas by the proposed ARC/LaRC Advanced Cockpit/Flight Management Technology program.



Figure 11.- Large-screen/panoramic display research system being developed at LaRC.

The Human Factors R&T base and Aviation Safety/Automation programs at LaRC and ARC should produce significant advances in appli-

cation of human-centered automation and knowledge-based systems in aiding crews of future vehicles. Already, the efforts have produced important advances in intelligent cockpit aids for fault management, flight planning and replanning, flight phase management, and check-list and advisory systems.

Also, DARPA has launched an effort to get the U.S. up to speed in the area of High-Definition Television (HDTV), a field which has undergone extensive development in Japan and Europe. DARPA has funded several commercial sources to do research in this area which will most likely result in further advancements in large-screen projection and flat-panel technologies. Further, the HDTV technology is indicated for many applications which require live video images, such as teleoperations and telerobotics.

TECHNOLOGY ISSUES

This next section will attempt to address technology issues specific to the area of advanced D&C for space transportation systems. The first issue is the maturity of advanced display media. CRT's have for many years been the basic display device for image generation, including computer-generated raster graphics. The CRT and its associated raster-scan generators have evolved dramatically throughout their lifetime to provide a high level of reliability, photographic clarity, high-speed animation, and an unlimited range of colors. However, functional requirements have also evolved, and these changes have had effects on display device technology. As indicated above, various technologies for producing visual images have emerged that may eventually replace the CRT.

For most of the space transportation systems, such as the Orbiter Glass Cockpit and the Space Station MPAC, it is necessary to include displays which consume very little power and are sunlight legible in approximately 10K ft-candles of ambient light. Currently, the active-matrix LCD is the front runner in the flat panel display race, with TFEL and plasma lagging somewhat behind. However, it is expected that one or more of these technologies will be ready to meet the needs of advanced transportation systems of the 1990's.

Another key technological issue is the method by which the human interacts with the displays and controls system. In the past such methods required the use of, for the most part, dedicated controls and switches for man-machine operation. Meaningful research has already been performed on how multi-functional controls, such as keyboards, touch overlays, voice recognition, and programmable, variable-legend switches, may decrease the number of dedicated items, without affecting operator efficiency, to provide a clean and uncluttered work area. However, care must be taken to avoid man-machine interaction techniques which result in an unreasonable amount of heads-down time during critical operations such as aircraft take-off and landing. For example, some pilots have criticized the Control Display Units (CDU) flown in modern cockpits for this reason. These devices consist of a small scratch-pad display and a multi-function keyboard which at times require several keystrokes to initiate certain operations should changes occur in the flight plan. An additional concern is the inevitable impact that electronic displays and controls (i.e. all-glass cockpits) will have on crew training. Flight crews will obviously have to be re-trained to become proficient with these new systems.

Another area which requires further study is the area of advanced display symbology. The goal is to give the pilot or operator an easily interpreted indication of the vehicle state and onboard systems status. Visual and auditory means are used to provide information to the human operator. Visual images, however, have the highest content of information that may be interpreted within the shortest amount of time. This characteristic is even further enhanced when such information is preprocessed into a form in which the human brain can grasp the information content with minimal mental interpretation. This processing is done with a graphics processor, which consists of some sort of display generator driven by a computer designed to generate graphical and alphanumeric output. Graphics generators range in capabilities from mere text information displays to high-end, real-time 3-D computer image generators (as described above). To achieve maximum capabilities with minimal

hardware, a flexible graphics system must be incorporated into the man-machine system architecture which will be capable of meeting present needs, yet will be adaptable for more advanced needs.

The area of artificial intelligence for cockpit automation is one which requires further research. The goal is to develop techniques to monitor and assist the operator rather than to replace him/her and to anticipate future problems rather than giving a warning once a fault or error has occurred. The danger of making the crew bored or mere machine-minders must be avoided through the judicious selection of tasks to be automated. Clearly, computers lack the creative ability and cognitive characteristics which permit humans to interpret and integrate relationships between data for working around faults or problems which may not have been foreseen. However, properly designed expert systems could offer capabilities for safety and efficiency unmatched by today's systems.

Before artificial intelligence can be successfully utilized in space transportation systems, a cultural change will be required at NASA to overcome the resistance to this technology. The advent of advanced D&C coupled with expert systems technology could produce more autonomous vehicles and greatly reduce requirements for large ground facilities with "marching armies" to support them.

SPACE TRANSPORTATION SYSTEM APPLICATIONS

The following paragraphs will attempt to identify the space transportation systems which could benefit from the advanced display and control concepts previously discussed. First is the proposed Orbiter Glass Cockpit Display Upgrade Program, which is a candidate for Assured Shuttle Availability (ASA) funding for 1991. Today's Shuttle cockpit consists of electromechanical flight instruments which were designed in the early 1970's and have been operating for over ten years. As a result of their age and extensive use, these mechanical devices have gradually begun to show signs of wearout and have become an increasing maintenance problem. They are experiencing an increasing number of failures, and the

problem is further complicated due to parts and skills obsolescence and limited availability of spares. In addition to these problems, the Multipurpose CRT Display System (MCDS), which consists of four monochrome 5" x 7" displays and four Display Electronics Units (DEU) has had a history of extremely high failure rates. The baseline design of the proposed Orbiter Glass Cockpit Display Upgrade

program attempts to eliminate the problems of both of these sets of hardware by evolving to an advanced display system which utilizes state-of-the-art flat panel flight displays and modern processors integrated on a high speed data bus. Similar systems are already flying in several commercial and military aircraft cockpits. The proposed panel layouts and architecture are shown in Figures 12 and 13, respectively.

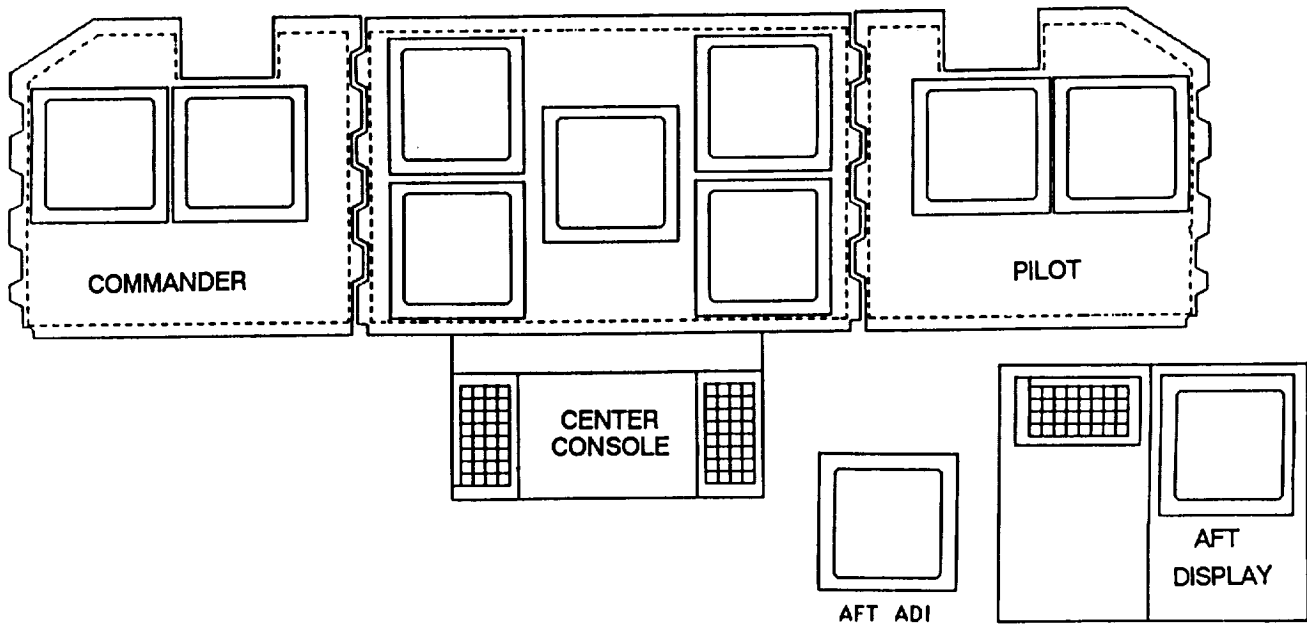


Figure 12.- Orbiter conceptual glass cockpit layout.

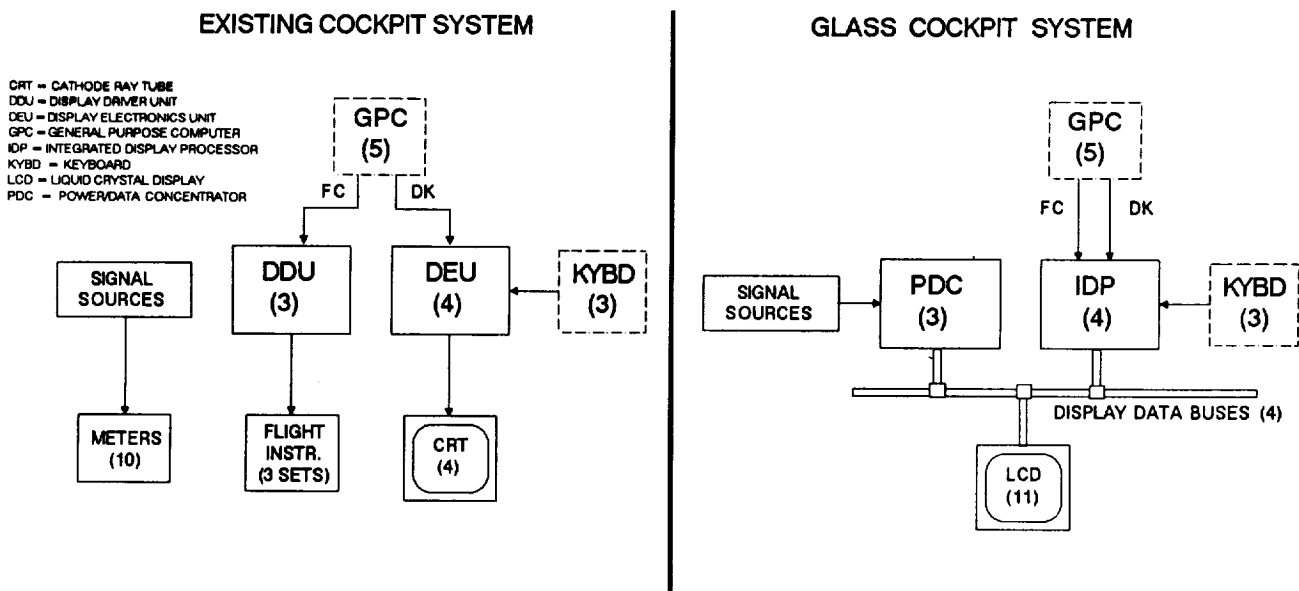


Figure 13.- Orbiter glass cockpit conceptual baseline architecture.

Some of the goals of the new system are that it be transparent to the orbiter General Purpose Computer (GPC) hardware and software, that it exhibit improved reliability and fault tolerance and reduced life cycle costs, and that it employ standard interfaces for subsequent incorporation of advancing technology. It should also have sufficient growth margins to support new functions which may arise in the future. One potential upgrade to this proposed system which has received some discussion is the implementation of a combined aft cockpit manipulator workstation. When one considers that the Shuttle Remote Manipulator System (RMS), the Space Station Freedom (SSF) RMS, the Flight Telerobotic Servicer, the Canadian Special Purpose Dexterous Manipulator, the Satellite Servicer, and the OMV must all be controlled from the orbiter, it is quite apparent that insufficient real-estate exists for the use of special-purpose displays and controls for all these systems. It would be quite feasible to install additional hardware on the Glass Cockpit data buses to implement a workstation capable of handling all these devices.

The SSF Multi-Purpose Applications Console (MPAC) and the Assured Crew Return Vehicle - Crew Emergency Return Vehicle (ACRV - CERV) are other near-term programs which are benefiting from research and accomplishments in the area of advanced D&C. The current MPAC design employs modern processors, three 15" color flat panel displays, a QWERTY keyboard, a trackball, and two six degree-of-freedom force-reflecting hand controllers. The ASRC - CERV design employs 2 flat panel displays, a keyboard, modern processors, and other dedicated displays and controls.

Although conceptual designs for the displays and controls which may be needed for far-term programs such as the manned Lunar and manned Mars missions have not yet been defined, it is certain that they will incorporate advances made during the next several years. The

authors envision very large multi-function flat panel pictorial displays driven by real-time 3-dimensional graphics processors, multifunction controls (i.e. minimal use of hard-wired single function switches), and extensive use of human-centered automation and expert systems technology.

RECOMMENDATIONS

Two "holes" were identified during the STATS proceedings. The first one is that present funding levels in the research and technology base and in advanced development programs do not provide the timely capability to influence or adapt commercial D&C technology to the specialized needs of space. The problem is further compounded by the fact that NASA only procures a relatively small quantity of the end-product. The second hole is the need for a focused technology program to integrate advances being made in display devices, graphics engines and pictorial formats, expert systems, and human-centered automation to provide technology readiness and validate projected gains in safety and operational efficiency for future space transportation systems. To fill the first "hole," it is recommended that funding levels for advanced D&C research and development be increased. To fill the second "hole," it is recommended that early development be undertaken at JSC on a "next generation" orbiter experimental cockpit facility.

SUMMARY

An attempt has been made in this paper to discuss the current state-of-the-art of D&C technology, to identify key issues and accomplishments, and to show where the technology is headed. In addition, cultural changes that would facilitate the migration to advanced D&C technology in advanced programs and the general applicability of advanced D&C to specific near-term and far-term space transportation systems have been discussed.