A FLEXIBLE FLIGHT DISPLAY RESEARCH SYSTEM

USING A GROUND-BASED INTERACTIVE GRAPHICS TERMINAL

Jack J. Hatfield, Henry C. Elkins,
Vernon M. Batson, and William L. Poole

NASA Langley Research Center

SUMMARY

Requirements and research areas for the air transportation system of the 1980 to 1990's are reviewed briefly to establish the need for a flexible flight display generation research tool. Specific display capabilities required by aeronautical researchers are listed and a conceptual system for providing these capabilities is described. The conceptual system uses a ground-based interactive graphics terminal driven by real-time radar and telemetry data to generate dynamic, experimental flight displays. These displays are scan converted to television format, processed, and transmitted to the cockpits of evaluation aircraft. The attendant advantages of a Flight Display Research System (FDRS) designed to employ this concept are presented. The detailed implementation of an FDRS, under development at Langley Research Center (LaRC), is described. The basic characteristics of the interactive graphics terminal and supporting display electronic subsystems are presented and the resulting system capability is summarized. Finally, the system status and utilization are reviewed.

INTRODUCTION

Aircraft in the air transportation system of the 1980 to 1990's must be capable of operating in a wide range of weather conditions and in congested airspace. These aircraft will be navigated and controlled with a greater precision, both in position and time, than is presently required. Advanced electronics technology is becoming available for implementation of avionics meeting these requirements. For example, advancements have been made in the areas of computer-generated electronic displays, computers for navigation and control, pilot input-output devices, and data link transceivers. Before this technology can be applied, however, much research is required to define the characteristics of a fully integrated system and the pilot's role as controller and system's manager. (See ref. 1.) The research must define the required pilot-vehicle interface, piloting procedures, avionic systems capabilities, and pilot-system task allocations.

An informal survey of personnel involved in vertical take-off and landing (VTOL) and fixed-wing aeronautical display research at LaRC indicated the need for a flexible display generation system to support flight projects in these areas. To provide the desired cockpit display research support, the following capabilities are required:

1. Rapid development of displays, with minimal turn-around time for format modifications

2. Efficient generation of a wide spectrum of displays, from basic formats, such as conventional electro-mechanical indicators, through advanced formats, such as aeronautical chart and electronic attitude director indicator (EADI) displays, including true-perspective landing scenes

3. Simultaneous generation of multiple, independent displays

4. Generation of interactive, multi-mode displays, with automatic or pilot-initiated data entry and mode selection

5. Utilization of monochrome and color electronic display media

6. Mixing of display symbology with background scenes, such as those produced by airborne imaging sensors

7. Real-time generation of dynamic displays, with update rates from 0 to 30 hertz and refresh rates of 40 to 60 hertz.

A Flight Display Research System (FDRS) with these characteristics is being developed at LaRC to support both fixed-wing and VTOL aircraft display research. When its development is complete, the FDRS will enable researchers to have flight-test integrated, real-world pictorial, and symbolic displays which have the potential to declutter the cockpit and minimize the pilot's assimilation time. (See, for example, refs. 2 and 3.) In the following sections, the design concept for and the implementation of the FDRS are described and the resulting system capability is demonstrated. Finally, the developmental status, results of system testing, and utilization of the system are reviewed.

DISPLAY EVALUATION SYSTEM

Concept

Through an analysis of the preceding requirements and a survey of available computer-generated display systems, it was determined that an FDRS, using a ground-based interactive graphics terminal (IGT), could be developed to provide the required display generation capability. An IGT was chosen as the major FDRS subsystem for several reasons. In particular, interactive graphics display systems were judged to be more flexible, more easily programed (using higher order language), more capable of producing multiple, complex displays, and more readily accessible to interactive devices than were special-purpose, airborne, computer-generated display systems. The increasing use of interactive graphics display systems for ground-based cockpit simulator display research supports this conclusion. (See, for example, refs. 4 and 5.)

A flight display testing method using the concept of ground-based display generation by an IGT is illustrated in figure 1. To evaluate a display using this concept, the evaluation aircraft would fly in the environment of the Wallops Flight Center (WFC) Experimental Runway Facility which would provide aircraft tracking, telemetry, and communications capability from an aeronautical radar research complex (ARRC). Prior to flight testing, the experimenters would prepare applications programs for generation of candidate display formats. An IGT, located within the FDRS, would provide the basis for rapid development and modification of these applications programs. During flight testing operations, real-time dynamics would be imparted to candidate flight displays by position, velocity, and simulated guidance data obtained from the ARRC and by aircraft sensor data telemetered from the evaluation aircraft via digital data link. The ground-generated flight displays would be converted into TV format, processed, and transmitted by video link to the evaluation aircraft where they would be displayed on high-performance TV monitors. Television was chosen as the method for remoting the visual capability of the IGT into the research cockpit because of many potential advantages. Processing, recording, transmitting, and displaying visual data in television format would result in standardized components which are less expensive than graphics format devices. Converting graphics displays to television format would permit simplified mixing of symbology with background scene generators which also use television formats. Processing images using sophisticated television video techniques would offer the potential for generation of advanced-format displays. Pilot interaction with the ground-based IGT would be provided functionally via the extensive up and down digital telemetry link and visually by the video uplink which closes the real-time in-flight simulation loop. The evaluation aircraft would also be capable of interacting with a simulated air traffic control (ATC) system via a Wallops and Langley data link.

Feasibility of the ground-generated, televised display concept was proven through prior flight research on graphic displays for steep, noise-abating approaches to landing (ref. 6). The display generation in this prior effort was provided by an analog computer and the displays investigated were necessarily very simple. Implementation of the concept using an IGT and correspondingly more sophisticated television processing techniques provides a method for satisfying the requirements of advanced aeronautical display research. This method has the following attendant advantages:

1. Generating the displays on the ground will permit the use of laboratory-quality equipment within the FDRS and simple airborne equipment within the evaluation aircraft.

2. Using an IGT in the ground-based configuration will make computer-generated display capability available to many aircraft research projects.

3. Basing the FDRS capability around an IGT will permit automation of pre-flight system checkout and post-flight data processing of quick-look performance data.

4. Matching the characteristics of the IGT used at WFC for flight research to those used at LaRC for research simulation support will provide software compatibility to smooth the transition from ground-based to in-flight display evaluation.

These are potential advantages which cannot be achieved without a detailed system design and development of components with appropriate performance characteristics. The characteristics of the IGT, the television subsystem, and the data telemetry subsystem are particularly important. In addition, extensive systems integration and interfacing are required. The following section describes the FDRS which resulted from such a detailed design, development, and systems integration process.

System Design

The design and development challenge presented by the preceding display evaluation concept is to visually and functionally remote the capability of an IGT and its supporting display electronics, operating in real time, from the ground into the research aircraft. The design approach selected to accomplish these objectives is illustrated schematically in figure 2. Three basic communications paths are required between the ground-based equipment and the research aircraft. These paths are the radar tracking, the uplink and downlink data telemetry, and the television uplink.

The ARRC facility uses an FPS-16 radar, which can track aircraft accurately from 64.4 kilometers (45 miles) to touchdown, with telemetry coverage, and a laser tracker, which supplements the radar from 16.1 kilometers (10 miles) to touchdown. ARRC data processing is provided by two computers. A Honeywell 316 computer is used for processing radar/laser azimuth, elevation, and slant-range data to derive aircraft position, velocity, and simulated Instrument Landing System (ILS) guidance signals relative to user-selected runways and/or touchdown pads. A Honeywell 716 computer is used for management of digital communications between the Honeywell 316 computer, the LaRC/Wallops data link, the uplink and downlink telemetry, and the FDRS. The Honeywell 716 can also be utilized to derive simulated Microwave Landing System (MLS) guidance signals.

The telemetry system provides a means for transmitting both aircraft sensor outputs and pilot interactive commands to the ground. It also provides a means for transmitting computed data and ATC commands from the ground to the aircraft. This uplink and downlink telemetry system, known as the Transponder Data System (TDS), was developed specifically to LaRC and WFC specifications to support the FDRS. Data accuracy, capacity, and rate characteristics for the TDS were specified in response to requirements for aircraft data input and output to and from the FDRS. For example, it was specified that the TDS contain both proportional and discrete (digital on/off status) telemetry channel capacity to provide data for real-time animation of graphics displays and pilot interaction via airborne switch array and/or keyboard. The TDS operates through the FPS-16 transmitter/receiver and the aircraft transponder using the dead-time between ranging pulses to provide a cost-effective pulse-position-modulated (PPM) digital data link. A summary of the TDS characteristics is contained in table I.

Figure 3 illustrates the ARRC facility's radar tracking, data processing, and telemetry subsystems in greater detail than figure 2. In addition, the general configuration, major components, and signal flow from and to the FDRS are shown in greater detail. Illustrated are extensive digital, analog, and discrete signal interfaces between the ARRC facility's subsystems, the IGT, and the hybrid interface and patching subsystem within the FDRS. These interfaces support the flow of radar-derived, telemetry, and LaRC/Wallops data link signals through primary and backup data paths.

Primary data flow between the ARRC and the FDRS is via digital data path between the Honeywell 716 and the IGT. This high-speed parallel digital interface is capable of 60 000 16-bit word transfers per second in a half-duplex mode. All transfers are initiated by the Honeywell 716. The IGT interface includes hardware packing and unpacking of two 16-bit Honeywell 716 words into one 30-bit IGT word.

Backup data flow between the ARRC and the FDRS is via analog and discrete data paths between the Honeywell 316 computer, the TDS, and the hybrid interface and patching subsystem of the FDRS. In the backup operational mode, high-accuracy proportional data (16 to 26 bits, binary) will be encoded in a coarse/fine two-channel analog data format, whereas standard-accuracy proportional data (10 to 13 bits, binary) will be encoded in a single-channel analog data format. This backup operational mode will permit many flight operations to continue in the event of failure of digital interfaces between the HW 316 and HW 716, the HW 716 and TDS, and/or the HW 716 and the IGT. The formats and the interface requirements for input and output of data to and from the IGT and its hybrid interface and patching subsystem are summarized by table II.

Figure 3 delineates and illustrates the two major subsystems of the FDRS in greater detail than in figure 2. These two subsystems are the interactive graphics terminal and the supporting display electronics. These subsystems and their associated interfaces are contained in the mobile instrument van shown in figure 4. Developing the FDRS in a van permits its use at WFC for flight research support and at LaRC for simulator research support. The van is equipped with an air-ride suspension system, equipment shock mounting, and an air conditioning system for appropriate environmental control of the IGT and the supporting display electronic subsystems.

The IGT subsystem forms the basis for:

1. Programing and modifying advanced flight display formats

2. Processing radar-derived and telemetry data inputs for real-time display animation

3. Generation of the dynamic graphics displays

4. Automating control of static and dynamic background image generators represented in figures 2 and 3.

The static and dynamic background images as well as the dynamic graphic images are converted into television format as represented by figures 2 and 3. Once these images are in television format, they can be easily processed and mixed using television studio equipment. This processing and mixing can be designed to achieve advanced-format display generation capability, such as grey-scale or color encoding of symbology and prioritizing or windowing of symbology.

The processed television video can be recorded and transmitted to the aircraft via a microwave uplink which has dual, independent, high-resolution channels. This television uplink has the capacity to handle both monochrome and color-encoded video. Resolution capability for each independent channel is variable from a low of 350 x 300 TV lines for National Television Standards Committee (NTSC) color-encoded channels (at a scanning standard of 525 TV lines per frame) to 850 x 1,000 TV lines for monochrome channels (at a scanning standard of 1225 TV lines per frame). The projected transmission range for the television link is 32.2 kilometers (20 miles). Display of the dual independent video channels in the research aircraft is via high-performance monochrome or color television monitors. When used to support ground-based cockpit simulation at LaRC, the television uplink of the FDRS need not be used, since the video output channels from the TV processing and mixing electronics illustrated in figure 3 can be used to drive high-performance television monitors directly.

This section has emphasized the general systems configuration of the FDRS, the description of the ARRC facility, and signal flow between the ARRC, the FDRS, and the research aircraft. The capability of the FDRS within the configuration described is critically dependent on the characteristics of its two major subsystems. The salient features of these subsystems and their effect on system capabilities are described in the next section.

FLIGHT DISPLAY RESEARCH SYSTEM

Interactive Graphics Terminal

As related in the previous section on design approach, the FDRS is configured around the capabilities of the IGT, its associated peripheral devices and interfaces, and its graphics displays. These components are illustrated in simplified form in figure 3 and in detail in the IGT block diagram of figure 5. Figures 6(a) and 6(b) show the actual IGT in the FDRS mobile equipment van. The IGT is an Adage AGT/130 Graphics Terminal System. The major components are its DPR-4 digital processor, disk memory subsystems, digital/hybrid interfaces with associated transformation array, vector and character generators, interactive devices, and multiple graphics displays.

Location of the IGT at a remote site, such as the WFC Experimental Runway Facility, required that it have real-time, dynamic display generation capability without dependence on a large host computer. This capability is provided by the graphics-oriented processor in conjunction with the hybrid coordinate transformation array of figure 5. The 30-bit word length of the digital processor speeds up image manipulations by using one-word and two-word formats to define two-dimensional and three-dimensional vectors, respectively, in its outputs to the coordinate transformation array. This array has the capability to scale, translate, and rotate these vectors at a rate of 4 microseconds per vector. This speed is attained through utilization of hybrid electronics operating in parallel to solve the direction-cosine matrix. The coordinate transformation array drives graphics displays through the vector generator and character generator. The character generator is capable of producing alphanumeric elements in four sizes.

The digital processor has 16K words of storage and is programable in Fortran IV and/or assembly language. The processor and disk memory are software-compatible with computer graphics terminals presently being used at LaRC to support real-time cockpit display simulations (ref. 7). Thus, applications programs for flight display research, as well as for simulator display research, can be written in Fortran IV and minimal software modifications will be required to translate a display evaluation program from the cockpit simulator environment to the flight environment.

The disk memory subsystems provide a basis for storage of source and relocatable object programs as well as a monitor and operating system which automates programing and system control. The operating system permits use of the console display and keyboard/teletypewriter to manage disk files, edit, and compile and assemble programs, and to monitor and evaluate displays. Disk packs used on the 80M-bit disk memory of figures 5 and 6(b) are interchangeable with LaRC units. The second memory (40M-bit) of figures 5 and 6(b) provides a backup operational capability in the event of failure of the primary disk drive.

Interactive capability is provided at the IGT console by discrete interrupt function switches, alphanumeric keyboard, variable analog voltage control dials, analog data tablet, light pen, and a joy stick illustrated in figure 5 and shown in figure 6(a). Much of this interactive capability can be remoted to the aircraft cockpit via the digital, discrete, and analog interfaces illustrated in figures 3 and 5 and shown in figure 7. Figure 7 shows the portion of the hybrid interface and patching subsystem which is implemented outside of the IGT main frame. This subsystem comprises the FDRS input and output signal interfacing rack (utilizing differential buffering techniques on both analog and discrete signals), an analog computer (for special buffering and subsystem testing), and analog and discrete signal patch panels (for routing of signals to, from, and within the FDRS). In addition, an analog tape recorder is available for recording signals selected at the analog patch panel. The IGT drives or receives signals from all remote devices, either internal or external to the FDRS, through these interfaces. For example, they provide the path for IGT programatic control of FDRS image sources, such as the static image files and moving maps (backgrounds) illustrated in figure 3. Since the characteristics of these interfaces are summarized in table II, they will not be repeated here.

The graphics displays available to the IGT user include the graphics console display and three precision graphics displays as illustrated in figure 5. Four independent displays can be created simultaneously and refresh and update rates are software selectable. This capability includes the programatic segregation of symbology intended for a single composite display onto multiple graphics displays. In this manner, the scan-converted symbology from each graphics display can be subjected to individual video processing techniques. This capability is a key factor in attaining the required special effects for advanced-format display generation. Figure 6(a) shows a three-dimensional test pattern displayed on the graphics console display and that same test pattern displayed on the television monitor at the left, after having been scan converted to television format. The scan-conversion process is described in the next section on the supporting display electronics subsystem. A summary of the hardware and software characteristics of the IGT is contained in table III.

Supporting Display Electronics Subsystem

Graphics-to-TV scan conversion. - The graphics-to-TV scan-conversion technique used in the FDRS is illustrated in figures 2 and 3 and shown in figure 8(a). This latter figure shows two of the IGT precision graphics displays being viewed by two high-resolution television cameras and thereby forming electro-optical, graphics-to-TV scan-conversion channels. The graphics displays shown are precision, flat-faced, stroke-drawn displays having a minimum of 2000 resolvable picture elements (equivalent of 2000 TV scan lines) per display diameter. The clarity of the precision displays is illustrated by the photographic insets in figure 8(a) showing an EADI flight display on the left cathode ray tube (CRT) and an aeronautical chart flight display on the right CRT. This figure demonstrates the IGT capability to generate dual, independent, complex displays simultaneously. In the scan conversion process, the photoconductive surface of the vidicon imaging tube provides short-term storage of graphics images (for one TV frame), until erased by the TV scanning raster in the readout process. This method provides flicker-free scan conversion of the graphics images into television format (provided that the graphics images are refreshed at a 40- to 60-hertz rate). The television rendition of the graphics display loses some clarity and edge sharpness; however, much of this clarity and edge sharpness can be recovered by scanning the television cameras at a high line rate (from 875 to 1225 TV lines per frame) or by television image enhancement. The FDRS television subsystem has both of these capabilities.

Background scene generation. - Figure 3 illustrates the image sources controlled by the IGT. In addition to the graphics displays discussed above, the static and dynamic background scene generators shown are programatically controlled. These background scene generators will consist of future image sources, such as a rastergraphic display generator and a visual landing scene generator presently under development, static image files, and moving-map image sources. The static image files and moving-map image sources, as well as television video recording components, are shown in figure 8(b). The static image files comprise two dual-drum projectors, operating under IGT programatic control and imaging into two high-resolution vidicon TV cameras. The moving-image sources (moving maps) comprise two back-lighted, motion-base transparency tables imaging through pechan (roll) prisms and zoom lenses, all of which are under IGT programatic control, into two high-resolution vidicon TV cameras. The video recording subsystem comprises two helical-scan tape recorders, which can record independent displays at variable scan standards, and a video hard copy unit which can record displays at 525 scan lines/frame.

Video processing and mixing techniques. - Since television processing and mixing technology must provide all required capabilities not inherent in the IGT, much effort has been devoted to implementing a flexible, high-performance processing and mixing subsystem. In particular, video processing techniques are key factors in generating advanced-concept displays having simulated rastergraphic, color-coded, and prioritized or windowed symbology. Flexibility is achieved through use of components which can operate at TV scanning standards from 525 lines/TV frame to 1225 lines/TV frame, and by video patching which can reconfigure subsystem architecture and signal flow. High performance is achieved through use of wide-bandwidth, temperature-stabilized components which produce high-resolution images for transmission.

Typical video processing which has been implemented within the FDRS for generation of advanced-format displays is illustrated in figures 9(a) and 9(b). The video processing of figure 9(a) produces two independent displays -- a simulated rastergraphic/stroke-drawn EADI on the upper high-resolution TV monitor and a stroke-drawn aeronautical chart display on the lower high-resolution TV monitor.

The video processing of figure 9(b) produces a single color-coded display -- a simulated EADI, which can be displayed as illustrated in figure 9(b) in red-green-blue (primary colors) format on the upper color TV monitor or in NTSC encoded format on the lower color TV monitor. The latter format is more suitable for transmission because both luminance and chromanance information are encoded onto one video channel, as opposed to the red-green-blue format which requires three video channels. The red-green-blue format is preferable for applications requiring high-resolution display because the NTSC encoding process limits the horizontal resolution.

As illustrated in figure 9(a), an EADI typically requires white symbology, black or grey-scale encoded symbology, prioritized or windowed symbology, and sky/ground shading. The processing technique for generation of a simulated rastergraphic/stroke-drawn EADI display is shown by figure 9(a) to require presentation of white symbology, black symbology (white symbology to be grey-scale encoded), and priority symbology on separate graphics scopes. In addition, image sources defining priority windows and sky/ground shading are presented on the FDRS background image generators. All image sources are converted into TV format. The nonadditive mixer combines the white symbology with sky/ground shading. Then the black symbology is matted into this composite image by using special effects generator number 1. The composite image output is fed to special effects generator number 2 where the priority window symbology is inserted by using an external key mode, and thereby forming the final, composite image. The processing technique for generation of the simulated stroke-drawn aeronautical chart display is shown by figure 9(a) to require only scan conversion of the display, generated on one graphics scope, into TV format for presentation on a high-resolution TV monitor.

The processing technique of figure 9(b) produces multiple colors through treating the symbology or background image from each source as a different color. Therefore, the symbology on graphics scope 1 can be assigned color A, the symbology on graphics scope 2 can be assigned color B, etc. TV format renditions of the symbology on each graphics scope are processed by a switch and gain matrix. This matrix can assign any color to the symbology from a given scope through adjustment of the levels of three output signals from that scope into the red-green-blue, first-stage nonadditive mixer. Color coding is assigned to the sky/ground shading from the moving-map source of figure 9(b) by the same encoding process at the second-stage nonadditive video mixer. By using the described encoding process, the FDRS can generate four-color displays using the graphics scopes as image sources, and eight-color displays, using static and dynamic background image sources in addition to the graphics scopes.

System Capability

To demonstrate the advanced-concept display generation capability of the FDRS, a number of candidate simulator and/or flight displays have been programed in Fortran. For example, the EADI and aeronautical chart displays of figures 10(a) and 10(b) are important new concepts for integrated display of vertical and horizontal situation and command information in cruise and terminal phases of aircraft missions. They are presented here only to be illustrative of the complexity of simultaneous, dynamic displays which the FDRS is capable of generating and the video processing techniques which are used. Therefore, the display formats and their utilization by the pilot will not be described in detail. The simulated rastergraphic/stroke-drawn EADI display of figure 10(a) was generated by using the video processing techniques of figure 9(a). It is typical of formats being studied by researchers to present aircraft vertical situation and command information to pilots. It can contain from 10 to 20 symbolic and pictorial indications including an aircraft reference symbol, ILS deviation box, potential flight path symbol, artificial horizon, roll/pitch grid (simulated stroke-drawn, white symbology), sky/ground shading (simulated rastergraphic symbology), roll scale/pointer and flight director bars (prioritized, grey-scale encoded symbology), and alphanumeric presentations of altitude and navigational waypoints (priority-window symbology). The techniques of shading, grey-scale encoding and prioritizing of symbology provide a less cluttered and more easily interpreted display. For example, the use of sky/ground shading (ref. 1) has produced fewer control reversals by pilots.

The aeronautical chart display of figure 10(b) was generated by using the video processing techniques of figure 9(a). It is an example of a simulated stroke display (all white symbology) employing no rastergraphic techniques. It is typical of formats being studied by researchers to present aircraft horizontal situation information to pilots. It can contain from 20 to over 100 symbolic and pictorial indications to present a plan-view map of radio navigation aids, airport symbols, range circles, holding patterns, and waypoints.

By using the interactive capability of the FDRS, evaluation pilots can add or delete symbology in the EADI display of figure 10(a) and change map scales or change from north-up to heading-up presentations in the aeronautical chart display of figure 10(b).

The EADI displays of figures 11(a) to 12(b) are presented to show the FDRS capability for color-coded display generation. Color coding of displays is of interest to aeronautical researchers as a means of decluttering displays and providing faster data identification. Reference 8, for example, has shown that color coding has an advantage over shape coding of symbology for target identification and counting.

Figures 11(a) and 11(b) provide a comparison of the monochrome presentation and the color-coded presentation of the EADI display. (Although these figures were presented in color at the conference, consideration of time and expense preclude their reproduction in color here). In these two displays, the sky/ground shading was produced by stroke-drawn vectors from the IGT. Figures 12(a) and 12(b) show the same EADI display with and without rastergraphic sky/ground shading produced by the processing technique of figure 9(b). The FDRS can change color coding either interactively or programatically. Thus, a color change can be provided to suit pilot preference or to signify an error or an alarm status indication. The color-coded displays of figures 11(b) and 12(a) are more suitable for presentation in a head-down cockpit display, whereas the color-coded display of figure 12(b) is more suitable for presentation in a head-up display (HUD) where the pilot must view an out-the-window scene through the symbology set.

The displays of figures 10(a) to 12(b) are illustrative of the broad-based display generation capability of the FDRS. These displays illustrate the clarity of a television format of 525 scan lines per television frame. Higher clarity can be achieved in the monochrome displays by using higher line rates, such as the 875 to 1225 scan lines per television frame, which the system has available.

System Status

The FDRS, as described above, is in the final stages of development; however, the system as presently configured has broad-based cockpit display generation capability. In fact, the system has been used to support three research simulation projects at LaRC. To provide dynamic, real-time displays to both motion-base and fixed-base cockpits, the FDRS was interfaced to a CDC 6600 simulator computer by data lines and to the cockpits by video lines. The display formats produced by the FDRS for these simulations are indicative of the wide spectrum of display generation capability. The display formats are shown in figure 13 and are discussed briefly.

The top display is an EADI which was generated for LaRC's Terminal Configured Vehicles (TCV) project for display in the 737 motion-base simulator. Interactive capability was also remoted to the simulator to allow the pilot to change from cruise mode to landing mode and to add or delete symbology. The display shown is the landing mode which contains a perspective runway. The middle displays of figure 13 are a Helicopter Attitude Director Indicator and an Integrated Horizontal/Vertical Situation display which were generated for the LaRC VTOL Approach and Landing Technology (VALT) program for display in a CH-46 fixed-base simulator. The display on the left contains situation and command information and the display on the right contains situation and predictive information. The bottom display of figure 13 is a vertical scale, dial, and drift meter format which was generated for the VALT program for display in the SH-3A simulator. These conventional instrument renditions were video mixed with a color visual landing scene to provide situation information during helicopter approach, hover, and landing. All these user programs were written in Fortran.

To provide for the smooth integration of the FDRS with the Wallops facility, including the radar, the telemetry (TDS) and the research aircraft, operational testing was performed at WFC using a C-54 aircraft in early 1975. The status of the FDRS at the time of this testing was as follows:

1. All interfaces with ARRC were implemented with the exception of the digital interface between the interactive graphics terminal and the WFC HW 716. (See fig. 3.)

2. The video subsystem was used in an interim configuration which did not afford the full design capabilities.

3. The television uplink telemetry contained only a single channel capability as compared with the dual channel capability illustrated in figure 3.

The data flow concept, utilized for system checkout, was to loop uplink data telemetry, received on the test aircraft, back around into downlink data telemetry using all TDS uplink and downlink proportional and discrete channels. The interactive graphics terminal and television subsystem within the FDRS played key roles in that (1) the interactive graphics display system was the (a) source of telemetry test signals, (b) destination of looped-around telemetry test signals, (c) means of calculation and display of diagnostic presentations comparing uplink and downlink test signals, and (2) the television subsystem was the means for scan converting the diagnostic graphics displays and remoting them to ARRC and the test aircraft.

The operational testing at WFC verified anticipated data rates, delays, accuracy, transmission range, and imaging performance for the entire ARRC/FDRS/research aircraft system operating in a closed-loop, dynamic fashion. The tests demonstrated the feasibility of the ground-based interactive graphics terminal televised display concept, and its use in a diagnostic pre-flight and flight checkout mode. Examples of three diagnostic displays for presenting and analyzing telemetry system performance are shown in figures 14(a) to 14(c), as reproduced on the FDRS television hard-copy unit.

In the diagnostic bargraph display of figure 14(a), a failed or an out-of-tolerance telemetry channel is readily identified. For example, note the simulated failure of the top nine downlink channels. In the diagnostic alphanumeric display of figure 14(b), values of uplink test signals and looped-around downlink signals can easily be compared and the IGT can calculate and display system loop-errors for each channel. This latter display mode is shown in figure 14(c).

Since the authors' return to LaRC from WFC, the planned development of the FDRS, primarily in the areas of the digital communications between the FDRS and the ARRC, the television processing subsystem, the television uplink system, and the operator's console, has been continued. In the spring of 1976, the completed system will begin operational support of TCV and VALT flight research projects at the WFC Experimental Runway Facility.

CONCLUDING REMARKS

A Flight Display Research System is being developed to support in-flight evaluation of proposed aeronautical displays. The system uses a ground-based interactive graphics terminal to achieve a general capability for producing complex displays. A telemetry data subsystem and a television processing and transmission subsystem are used to functionally and visually remote the capability of the graphics terminal from the ground into the research aircraft.

This technique has many advantages:

1. In-flight evaluation of cockpit display concepts can be accomplished without developing costly computer-based airborne systems. Generating the displays on the ground permits the use of laboratory quality equipment within the FDRS and simple airborne equipment within the evaluation aircraft.

2. Use of an IGT in the ground-based FDRS makes computer-generated display capability available to many aircraft research projects. This capability permits evaluation of a wide spectrum of displays -- from basic formats such as conventional electro-mechanical indicators, through advanced formats such as aeronautical charts and electronic attitude director indicator (EADI) displays, including true-perspective landing scenes. The graphics software required to develop these displays can be written in a high-level language to permit rapid program development and display format modification.

3. Matching the characteristics of the IGT used at WFC for flight research to those used at LaRC for research simulation support will provide software compatibility to smooth the transition from ground-based to in-flight display evaluation.

4. The processing and mixing of the images prior to transmission to the aircraft can be designed to enhance the inherent capability of the IGT in achieving advanced-format display generation capability. Specific capabilities afforded by this processing include color and grey-scale encoding of symbology, mixing symbology with rastergraphic or continuous tone scenes, prioritizing and windowing symbology, and providing a standard format for recording, transmission, and display.

The system design and component development effort required to achieve these advantages has been described. Display formats demonstrating system capability and the interim use of the system to support ground-based simulation have been presented. Operational testing at WFC has verified anticipated data rates, delays, accuracy, transmission range, and imaging performance for the entire ARRC/FDRS/research aircraft system operating in closed-loop, dynamic fashion. After this testing, system development has continued and the system is scheduled to commence support of flight research projects in the spring of 1976.

REFERENCES

1. Wempe, T.: Flight Management - Pilot Procedures and System Interfaces for the 1980-1990's. AIAA Paper No. 74-1297, Nov. 1974.

2. Warner, John D.: Advanced Controls and Displays for Future Commercial Aircraft Operations. AIAA Paper No. 70-938, July 1970.

3. Mulley, William G.: Instrumentation Displays for Future Naval Aircraft. AIAA Paper No. 75-599, Apr. 1975.

4. Imrich, Thomas: Concept Development and Evaluation of Airborne Traffic Displays. FTL Rep. R71-2, Mass. Inst. Technol., June 1971.

5. Palmer, E. A.; and Cronn, F. W.: Touchdown Performance With a Computer Graphics Night Visual Attachment. AIAA Paper No. 73-927, Sept. 1973.

6. Elkins, Henry C.; and Hatfield, Jack J.: Televised Graphic Displays for Steep Approach-to-Landing Research. NASA paper presented at 11th National Symposium on Information Display (New York, N.Y.), May 1970.

7. Leavitt, John B.; Tarig, Syed I.; and Steinmetz, George G.: The Design and Implementation of CRT Displays in the TCV Real-Time Simulation. Applications of Computer Graphics in Engineering, NASA SP-390, 1975.

8. Smith, Sidney L., and Thomas, Donald W.: Color Versus Shape Coding in Information Displays. J. Appl. Psych., vol. 48, no. 3, June 1964.

TABLE I. - TRANSPONDER DATA SYSTEM CHARACTERISTICS SUMMARY

I. GROUND-BASED TRANSMITTER/RECEIVER: C-BAND RADAR, RCA AN/FPS-16

II. AIRBORNE TRANSMITTER/RECEIVER: C-BAND TRANSPONDER, VEGA MODEL 302C-2

III. MODULATION TECHNIQUE: DIGITAL PPM: CODING INTERSPERSED BETWEEN RADAR/TRANSPONDER RANGE PULSES

IV. TELEMETRY LINK DATA RATES:
- 1.2 KILOBITS α 120 PRF
- 6.4 KILOBITS α 160 PRF
- 10.2 KILOBITS α 1024 PRF

V. TYPE OF DATA TRANSMITTED: PROPORTIONAL AND DISCRETE CHANNELS

VI. CHANNEL CAPACITY: SELECTABLE;

UPLINK	DOWNLINK
0 TO 16 PROPORTIONAL CHS. AND 0 TO 64 DISCRETE CHS.	0 TO 48 PROPORTIONAL CHS. AND 0 TO 64 DISCRETE CHS.

VII. ENCODER CHANNEL SIGNAL CHARACTERISTICS:

	UPLINK	DOWNLINK
PROPORTIONAL:	± 10 VOLTS ANALOG OR 10-BITS TTL PARALLEL DIGITAL MUXED, EACH CHANNEL SELECTABLE.	± 5 VOLTS ANALOG OR 10-BITS TTL PARALLEL DIGITAL MUXED, SELECTABLE IN GROUPS OF 4 CHS.
DISCRETE:	TTL INDIVIDUAL LINES OR TTL PARALLEL DIGITAL MUXED, SELECTABLE IN GROUPS OF 4 CHS.	TTL INDIVIDUAL LINES OR TTL PARALLEL DIGITAL MUXED, SELECTABLE IN GROUPS OF 4 CHS.

VIII. ACCURACY AND RESOLUTION:

	ANALOG I/O	DIGITAL I/O
ACCURACY:	0.5% OF FULL SCALE	0.3% OF FULL SCALE
RESOLUTION:	0.1% OF FULL SCALE	0.1% OF FULL SCALE

IX. ERROR DETECTION CODES EMPLOYED:
- PROPORTIONAL CHANNELS: 2-BIT PARITY CODE
- DISCRETE CHANNELS: YII CODE
- ENTIRE FRAME: BCH CODE

X. SECURITY MODES:
- MAXIMUM SECURITY: FRAMES WITH ERRORS IDENTIFIED BUT REJECTED
- MINIMUM SECURITY: FRAMES WITH ERRORS IDENTIFIED BUT ACCEPTED
- NORMAL SECURITY: INDIVIDUAL CHANNEL ERRORS IDENTIFIED BUT ACCEPTED OR REJECTED BY SWITCH SELECTION

XI. SPECIAL FEATURES:
- PROPORTIONAL CHANNEL STRAPPING FOR INCREASED SAMPLING RATE (2 TO 8 CHS/STRAPPED CH.)
- PROPORTIONAL CHANNEL PAIRING FOR INCREASED ACCURACY (16- TO 20- BITS)
- HIGHER UPDATE RATES FOR SELECTED DISCRETES

TABLE II. - INTERACTIVE GRAPHICS DISPLAY SYSTEM MAJOR INTERFACES

#	ROUTING FROM	ROUTING TO	DATA TRANSMITTED	DATA TYPE	PATH TYPE	WFC	FDRS	CHANNEL CAPACITY
(1)	HW 316 (D-to-A)	DPR4 (A-to-D)	A/C Position, Velocity, and Guidance Info.	ANALOG	BACKUP	±20 volts	±10 volts	10
(2)	DPR4 (D-to-A)	TDS Uplink Encoder	Computed Guidance and Control Info.	ANALOG	BACKUP	±10 volts	±10 volts	16
(3)	TDS Downlink Decoder	DPR4 (A-to-D)	A/C Air-Mass and Inertial Referenced Info.	ANALOG	BACKUP	±10 volts	±10 volts	48
(4)	DPR4 (D-to-A)	FDRS Television Subsystem	Control of Background Scene Dynamics	ANALOG	PRIMARY	NA	±10 volts	24
(5)	TDS Downlink Decoder	DPR4 (Discrete Interface)	Pilot Mode Selection and Data Entry	DISCRETE	PRIMARY	Differential Driver/Receiver	TTL (0 - 3.5 volts)	64
(6)	DPR-4 (Discrete Interface)	TDS Uplink	Annunciator Response and Mode Switch LTS	DISCRETE	PRIMARY	Differential Driver/ Receiver	TTL (0 - 3.5 volts)	64
(7)	DPR-4 (Discrete Interface)	FDRS Television Subsystem	Pilot or Auto Selection of Background Scenes	DISCRETE	PRIMARY	NA	TTL (0 - 3.5 volts)	26
(8)	HW 716 (High Speed)	DPR-4 (High Speed)	Same as (1), (3), and (5) above	DIGITAL	PRIMARY for Proportional Data Backup for Discrete Data	Differential Driver/Receiver	TTL (o - 3.5 volts)	60K words/sec. 16-bit words
(9)	DPR-4 (High Speed)	HW 716 (High Speed)	Same as (2) and (6) Above	DIGITAL	PRIMARY for Proportional Data Backup for Discrete Data	Differential Driver/Receiver	TTL (0 - 3.5 volts)	30K words/sec. 30-bit words

TABLE III. - CHARACTERISTICS SUMMARY OF THE INTERACTIVE GRAPHICS SYSTEM

HARDWARE CHARACTERISTICS

- GRAPHICS-ORIENTED GENERAL PURPOSE CENTRAL PROCESSOR
  - 30 BIT WORD LENGTH
  - 1 u SEC CYCLE TIME
  - 32 K MEMORY ADDRESSING
  - 1 WORD FORMAT FOR 2-D VECTORS
  - 2 WORD FORMAT FOR 3-D VECTORS
  - INTERRUPT STRUCTURE
  - 15, 30, AND 60 BIT ARITHMETIC AND DATA MANIPULATION CAPABILITY
- DISK MEMORY SUBSYSTEMS
  - 40 AND 80 MILLION BIT STORAGE
  - STORES MONITOR AND OPERATING SYSTEM
- INTERACTIVE INPUTS
  - TABLET
  - LIGHT PEN
  - FUNCTIONS SWITCHES
  - KEYBOARD
  - VARIABLE DIALS
  - FOOT PEDALS
- 4 x 3 HYBRID COORDINATE TRANSFORMATION ARRAY
  - 3-D VECTOR CALCULATIONS in 4 u SEC - ACCURACY 0.1%
- GRAPHICS DISPLAY CAPABILITY
  - 3,570 CHARACTERS @ 40 FPS
  - 8,300½" VECTORS @ 40 FPS
  - UP TO 4 INDEPENDENT DISPLAYS
  - 4,160 1" VECTORS @ 40 FPS
  - 1,190 10" VECTORS @ 40 FPS
  - 32K x 32K POSITION GRID
  - INDEPENDENTLY ADJUSTABLE REFRESH AND FRAME RATES

SOFTWARE CHARACTERISTICS

- DISK RESIDENT OPERATING SYSTEM
  - FOREGROUND/BACKGROUND OPERATION
  - HIGH SPEED OVERLAY CAPABILITY
  - MACRO ASSEMBLY CAPABILITY
- SOFTWARE SUPPORT SYSTEM
  - FORTRAN IV COMPILER
  - GRAPHICS DISPLAY OPERATORS
  - ASSEMBLY LANGUAGE CAPABILITY
- GENERAL LIBRARY SUBROUTINES
  - FORTRAN OBJECT TIME SUPPORT
  - GENERAL MATH PACKAGE
  - INTERFACE I/O DRIVERS
- UTILITY AND SERVICE ROUTINES
  - SOURCE LANGUAGE TEXT EDITOR
  - SYSTEM SELF-TEST AND DIAGNOSTIC ROUTINES
  - DISK FILE MANAGEMENT PROGRAMS

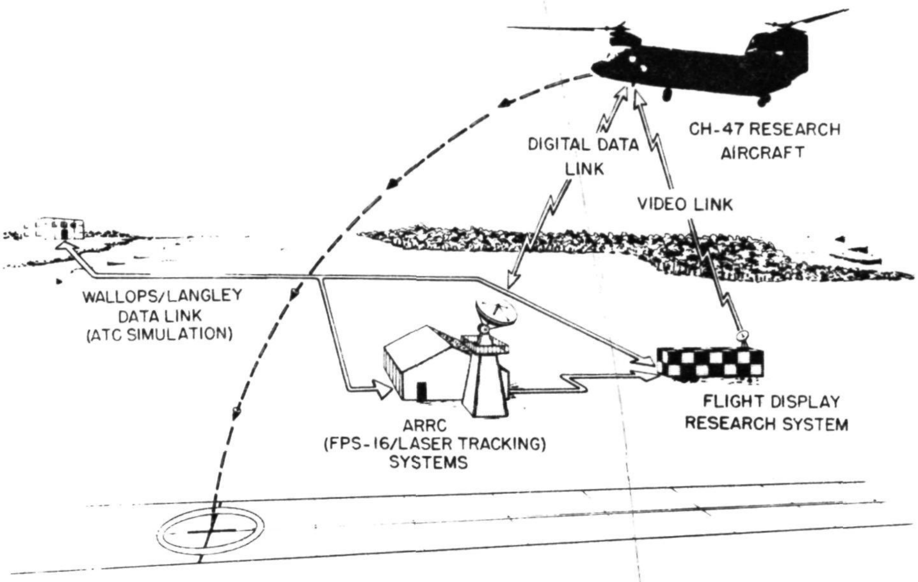


Figure 1.- Conceptual method of flight display testing.

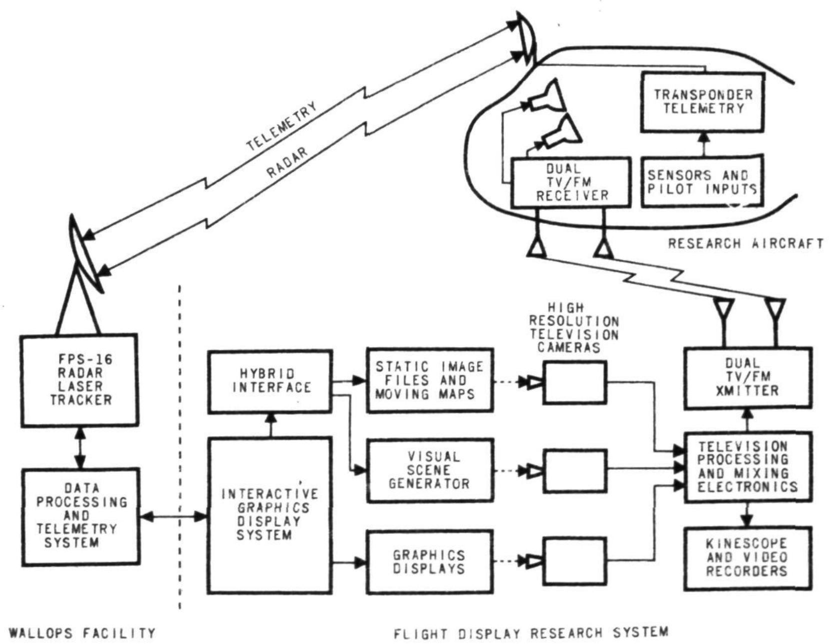


Figure 2.- Schematic diagram of flight display evaluation system.

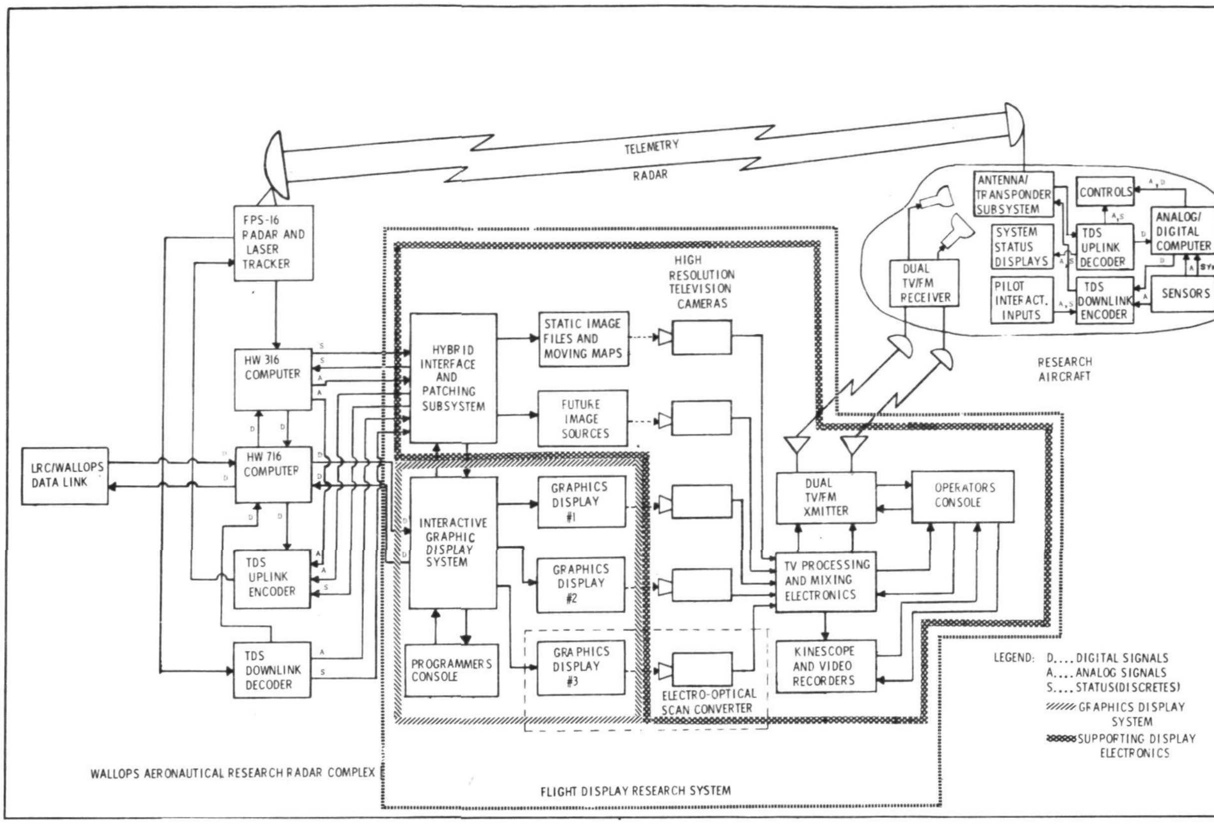


Figure 3.- Architecture and signal flow in the flight display evaluation system.

Figure 4.- Flight Display Research System.

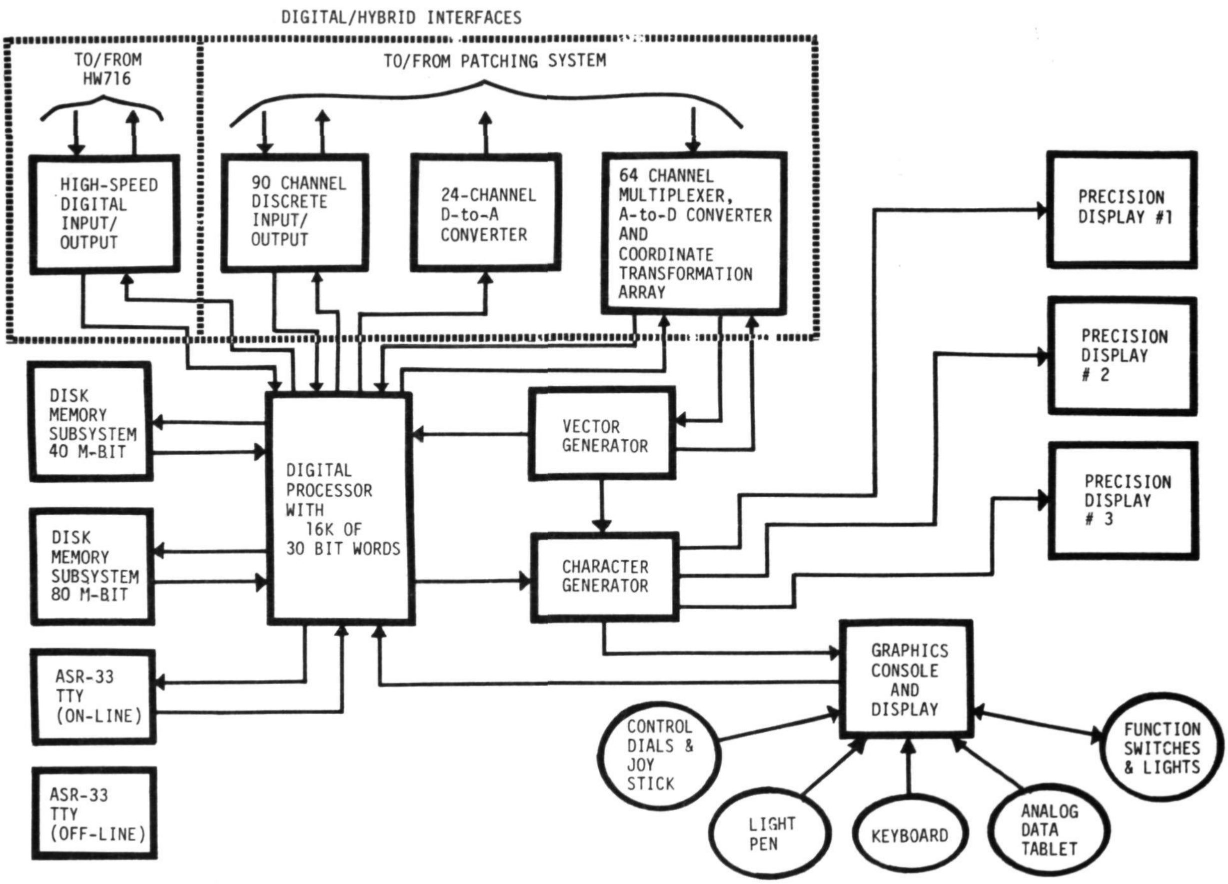
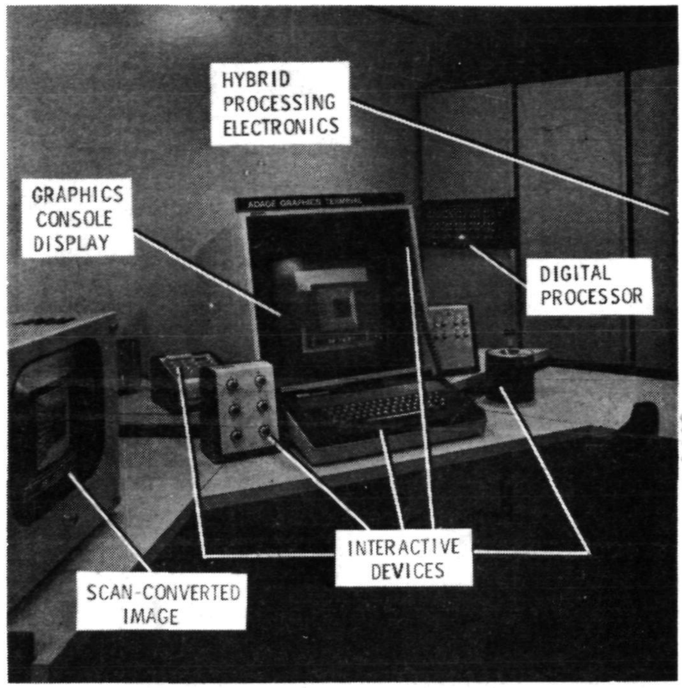
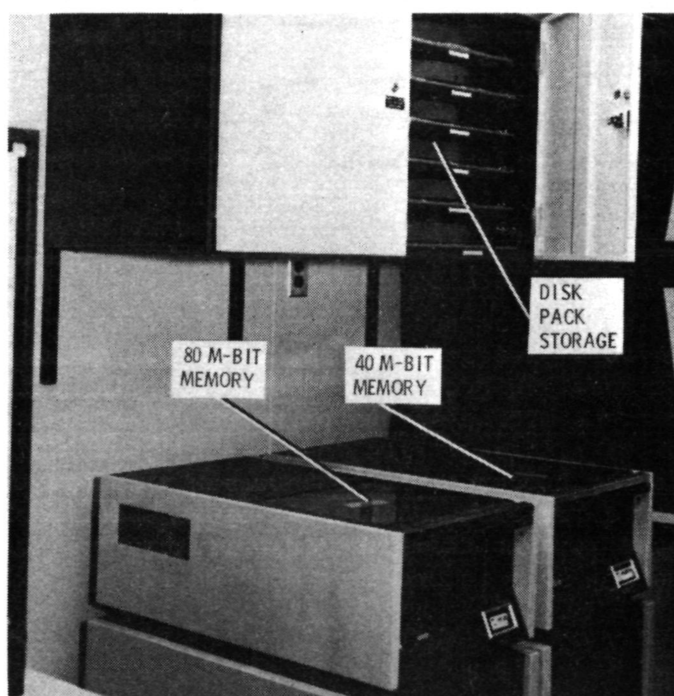


Figure 5.- Interactive graphics terminal schematic diagram.



(a) Interactive graphics terminal.



(b) Disk memory subsystem.

Figure 6.- Terminal and memory subsystem

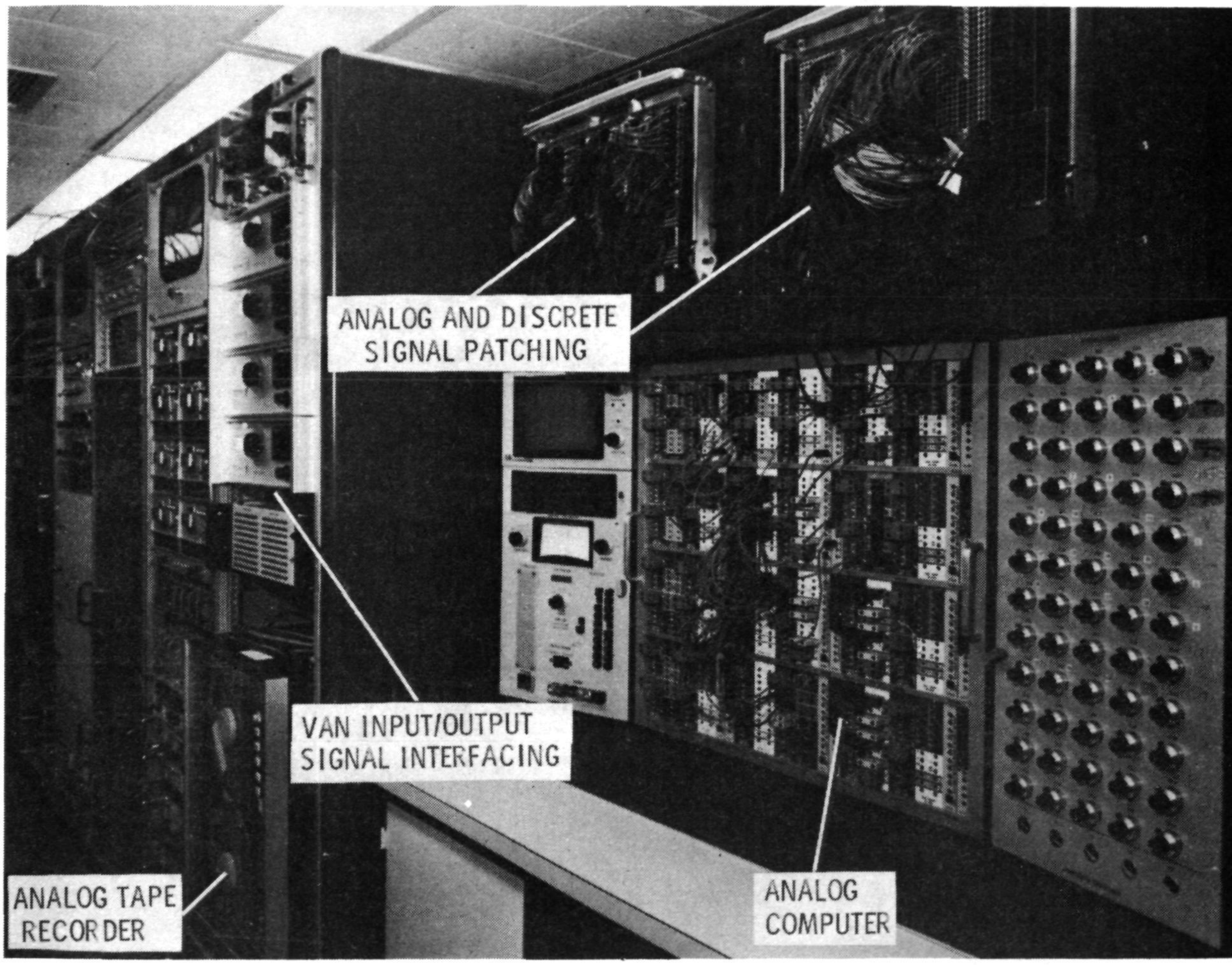
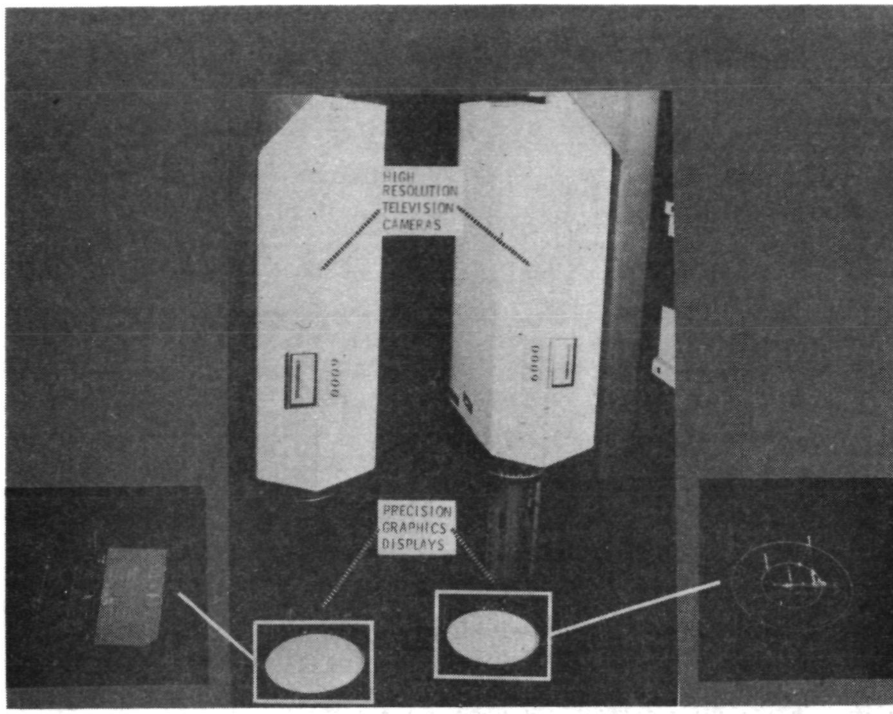
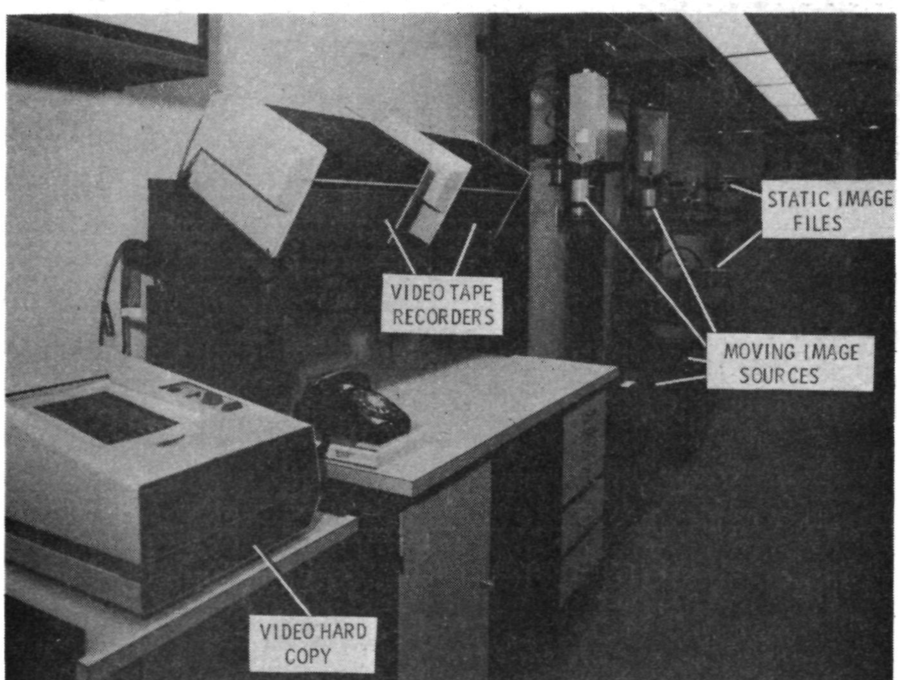


Figure 7.- Hybrid interface and patching subsystem components.

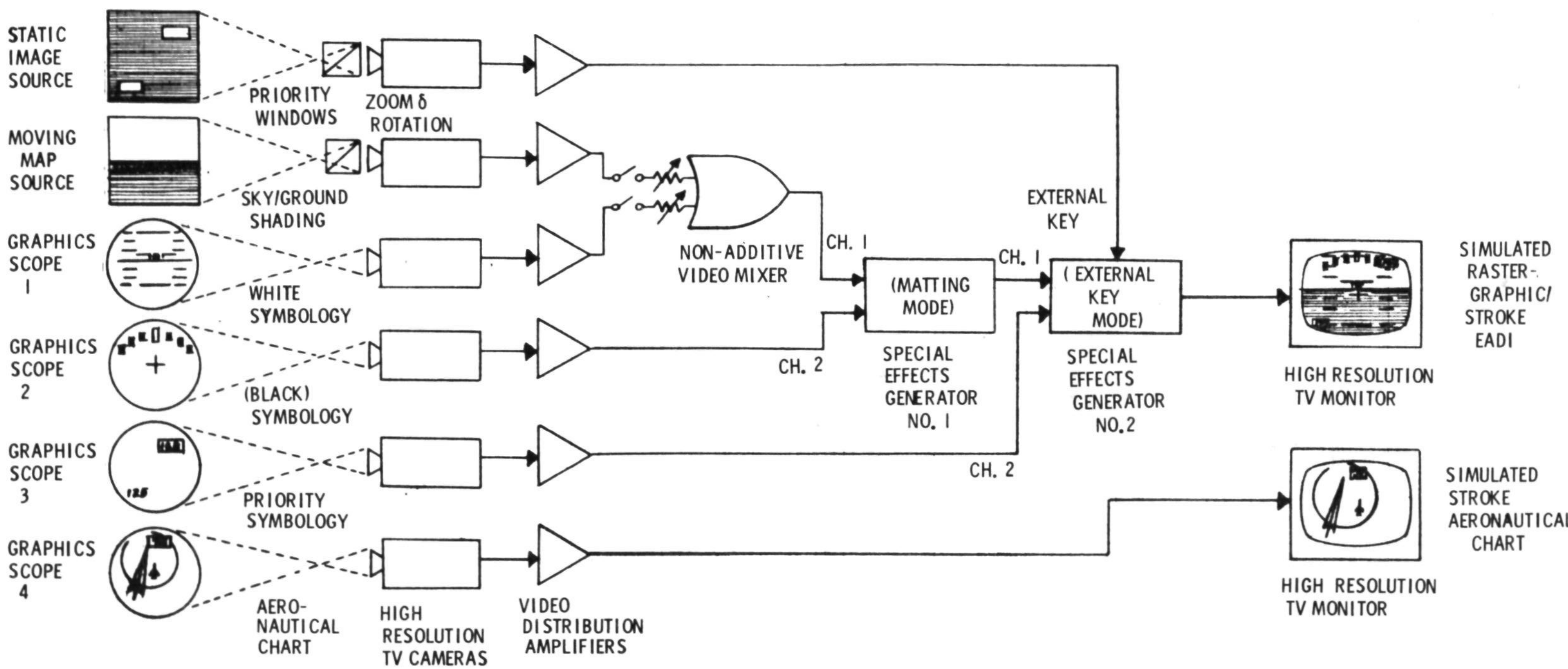


(a) Graphics-to-TV scan converters.



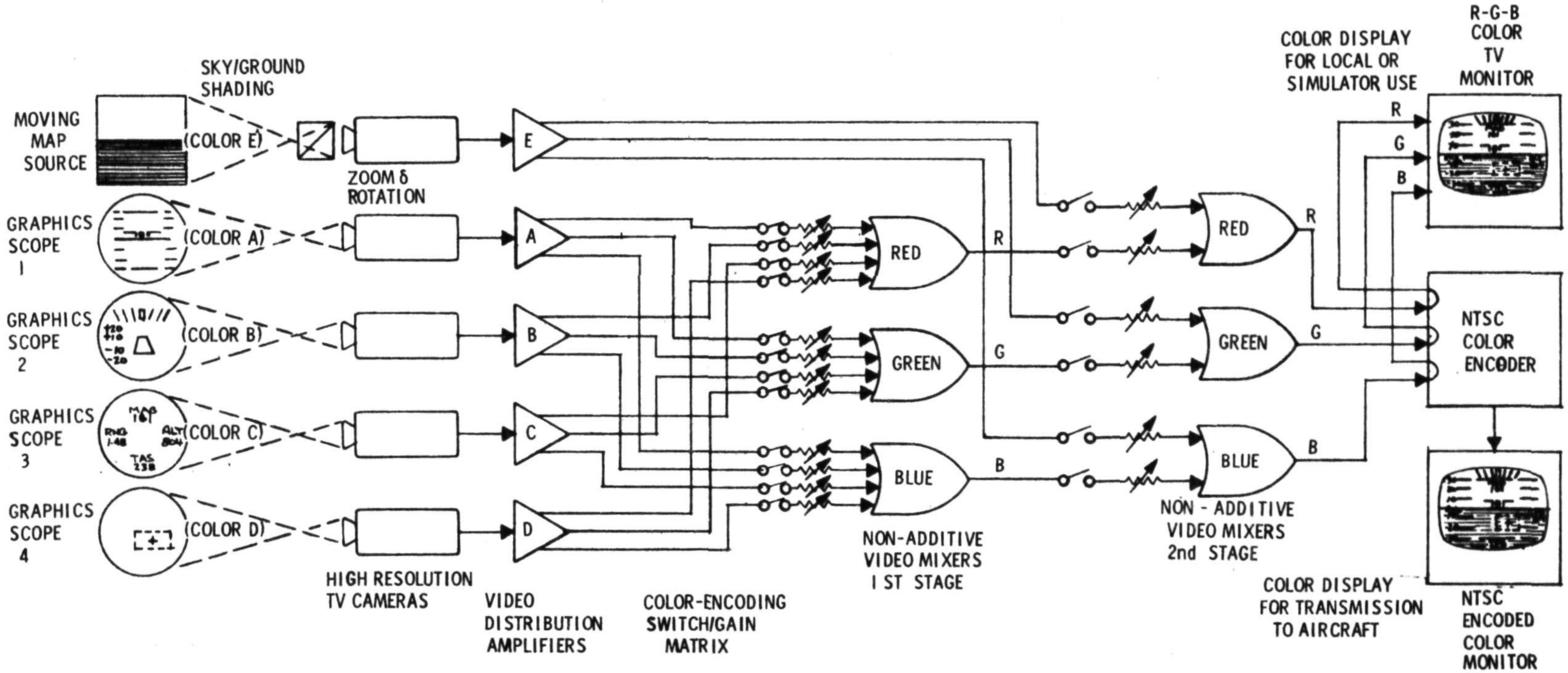
(b) Video imaging and recording components.

Figure 8.- Scan converters and video components.



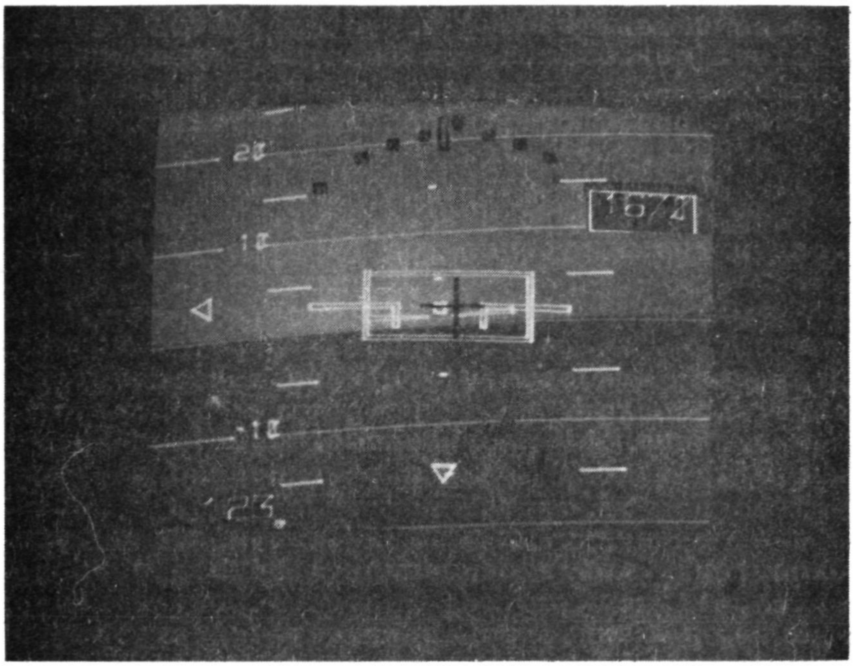
(a) Generation of a simulated rastergraphic/stroke-drawn EADI and a simulated stroke-drawn aeronautical chart, simultaneously.

Figure 9.- Video processing.

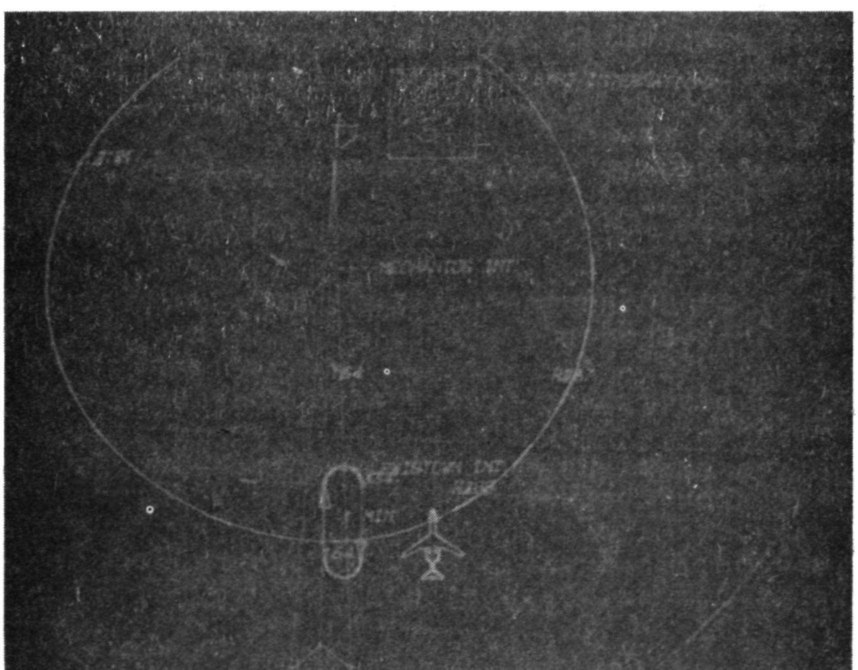


(b) Generation of a color-coded EADI display, with or without simulated rastergraphic sky/ground shading.

Figure 9.- Concluded.

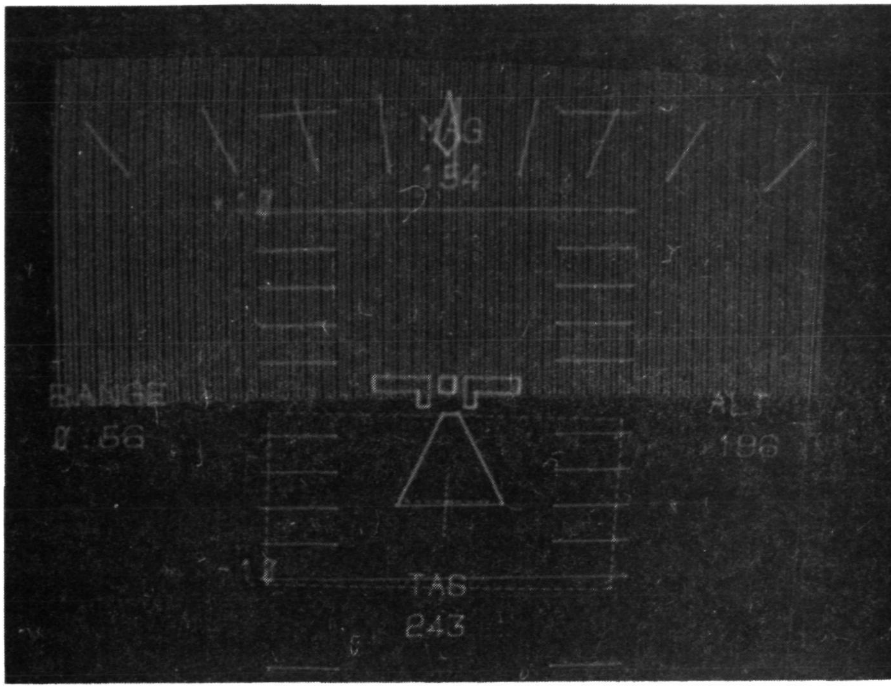


(a) Simulated rastergraphic/stroke-drawn EADI display, with sky/ground shading grey-scale encoded symbology, and priority-window symbology.

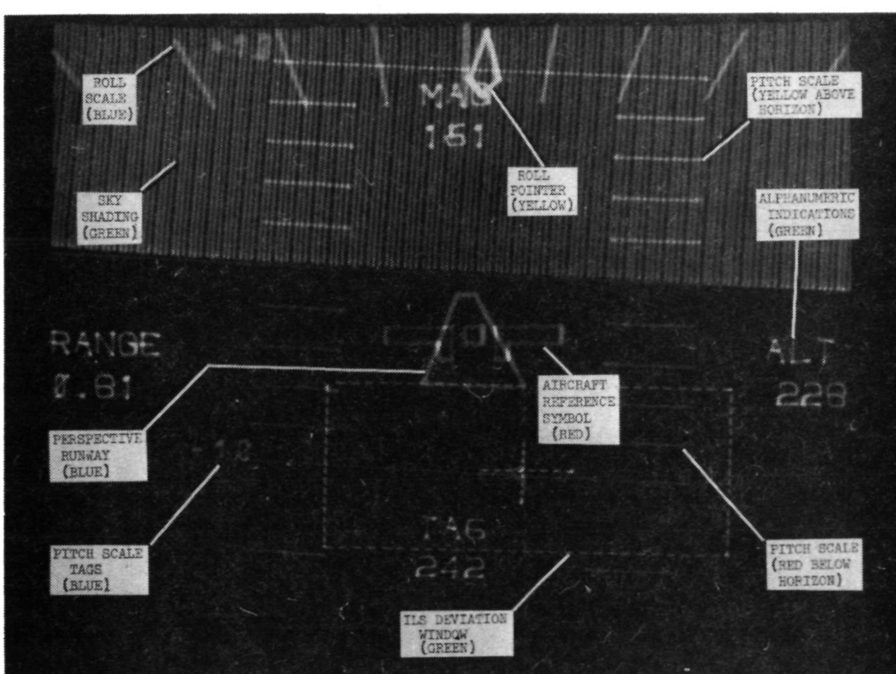


(b) Simulated stroke-drawn aeronautical chart display.

Figure 10.- Simulated displays.

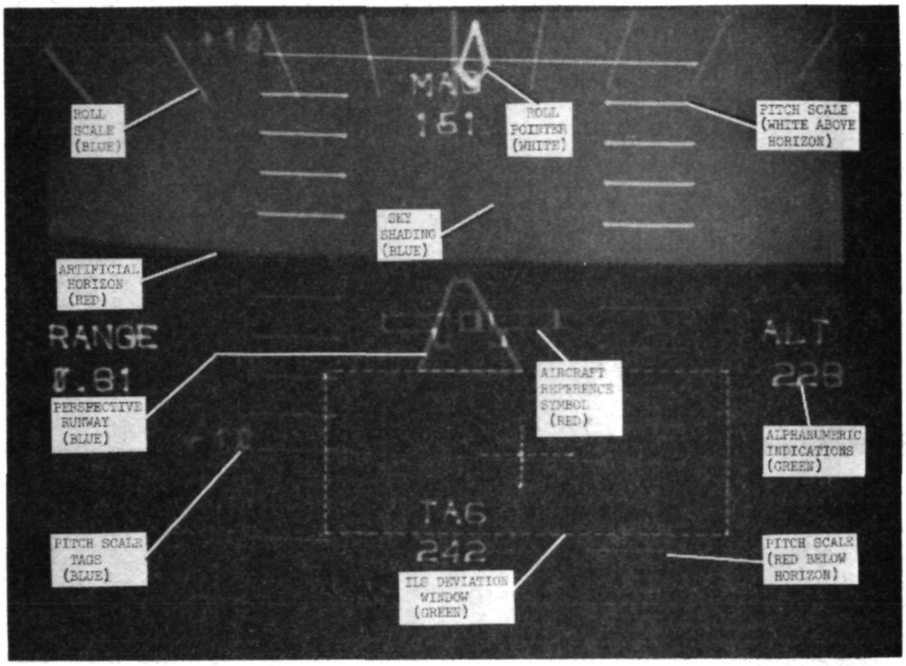


(a) Monochrome EADI display.

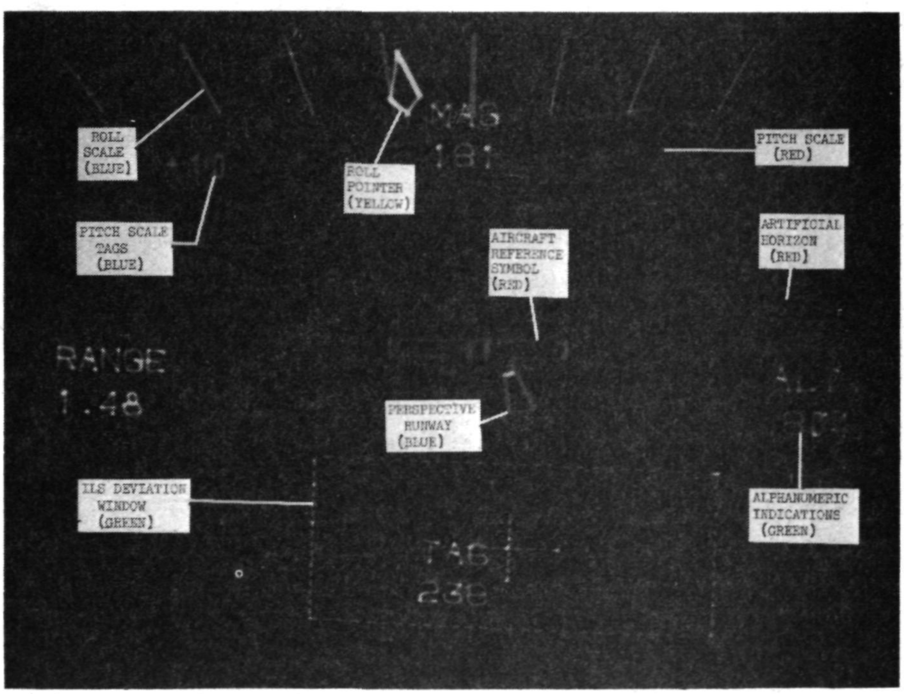


(b) Color-coded EADI display.

Figure 11.- EADI displays with stroke-drawn sky shading.



(a) With simulated rastergraphic sky shading.



(b) Without sky shading.

Figure 12.- Color-coded EADI display.

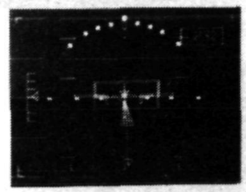
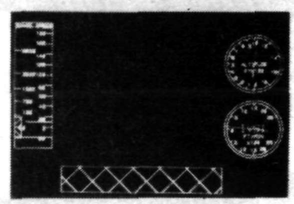
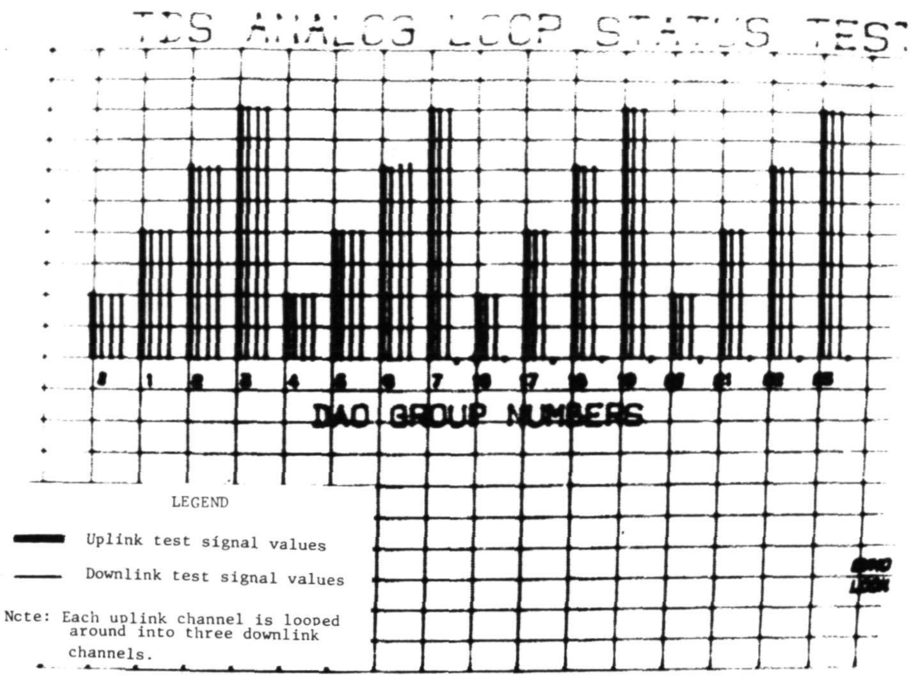
TYPE OF DISPLAY	PROJECT	IMAGE
ELECTRONIC ATTITUDE DIRECTOR INDICATOR (EADI)	TCV (737 SIMULATOR)	
ATTITUDE DIRECTOR INDICATOR AND INTIGRATED HORIZ./ VERTICAL SITUATION	VALT (CH-46/47 SIMULATOR/ AC)	 
VERTICAL SCALE, DIAL AND DRIFT-METER INDICATOR	VALT (SH-3A SIMULATOR/ AC)	

Figure 13.- Displays generated by the FDRS for research simulation support.



(a) Diagnostic bargraph display of TDS data in the analog loop-around test.

TDS/ANALOG SYSTEM
LOOP ACCURACY TEST

DAO CHS OUTPUT	MUX GRP #1 IN	MUX GRP #2 IN	MUX GRP #3 IN
TEST VOLTAGE	LOOP VALUES, VOLTS		
DAO 0- 6.00	MUX16- 5.98	MUX32- 5.96	MUX48- 5.96
DAO 1- 6.00	MUX17- 6.00	MUX33- 6.00	MUX49- 5.96
DAO 2- 6.00	MUX18- 5.98	MUX34- 5.96	MUX50- 6.00
DAO 3- 6.00	MUX19- 6.01	MUX35- 6.00	MUX51- 6.01
DAO 4- 6.00	MUX20- 5.98	MUX36- 5.96	MUX52- 6.02
DAO 5- 6.00	MUX21- 6.05	MUX37- 6.05	MUX53- 6.05
DAO 6- 6.00	MUX22- 5.98	MUX38- 6.00	MUX54- 5.99
DAO 7- 6.00	MUX23- 5.96	MUX39- 5.97	MUX55- 5.96
DAO16- -6.00	MUX24- -5.96	MUX40- -6.05	MUX56- -5.90
DAO17- -6.00	MUX25- -5.96	MUX41- -5.96	MUX57- -5.94
DAO18- -6.00	MUX26- -5.96	MUX42- -5.96	MUX58- -5.95
DAO19- -6.00	MUX27- -6.01	MUX43- -5.96	MUX59- -5.94
DAO20- -6.00	MUX28- -6.01	MUX44- -6.02	MUX60- -6.03
DAO21- -6.00	MUX29- -5.96	MUX45- -5.96	MUX61- -5.95
DAO22- -6.00	MUX30- -6.01	MUX46- -5.96	MUX62- -5.94
DAO23- -6.00	MUX31- -5.96	MUX47- -5.96	MUX63- -5.96

Note: (1) Each uplink channel is looped around into three downlink channels.
(2) Left column shows values of uplink channels 0 to 15.
(3) Right three columns show values of downlink channels 0 to 15, 16 to 32, and 33 to 47, respectively.

(b) Diagnostic alphanumeric display of TDS data in the analog loop-around test.

Figure 14.- Diagnostic displays of TDS data.

TDS/ANALOG SYSTEM
LOOP ACCURACY TEST

DAC CHS OUTPUT		MUX GRP #1 IN		MUX GRP #2 IN		MUX GRP #3 IN	
TEST VOLTAGE		ERROR, % OF F.S.					
DAC 0=	6.00	ERR16=	0.05	ERR32=	0.24	ERR48=	0.14
DAC 1=	6.00	ERR17=	-0.04	ERR33=	-0.24	ERR49=	0.24
DAC 2=	6.00	ERR18=	0.14	ERR34=	-0.24	ERR50=	0.04
DAC 3=	6.00	ERR19=	-0.05	ERR35=	-0.05	ERR51=	-0.10
DAC 4=	6.00	ERR20=	-0.10	ERR36=	0.24	ERR52=	-0.16
DAC 5=	6.00	ERR21=	-0.54	ERR37=	-0.54	ERR53=	-0.54
DAC 6=	6.00	ERR22=	0.14	ERR38=	-0.04	ERR54=	0.09
DAC 7=	6.00	ERR23=	0.04	ERR39=	-0.54	ERR55=	0.24
DAC16=	-6.00	ERR24=	-0.40	ERR40=	-0.09	ERR56=	-0.63
DAC17=	-6.00	ERR25=	-0.03	ERR41=	-0.42	ERR57=	-0.63
DAC18=	-6.00	ERR26=	-0.42	ERR42=	-0.41	ERR58=	-0.52
DAC19=	-6.00	ERR27=	-0.47	ERR43=	-0.42	ERR59=	-0.63
DAC20=	-6.00	ERR28=	0.00	ERR44=	-0.37	ERR60=	0.07
DAC21=	-6.00	ERR29=	-0.40	ERR45=	-0.42	ERR61=	-0.40
DAC22=	-6.00	ERR30=	-0.00	ERR46=	-0.33	ERR62=	-0.52
DAC23=	-6.00	ERR31=	-0.03	ERR47=	-0.43	ERR63=	-0.03

Note: (1) Each uplink channel is looped around into three downlink channels.
(2) Left column shows values of uplink channels 0 to 15.
(3) Right three columns show values of downlink channels 0 to 15, 16 to 32, 33 to 47, repectively.

(c) Diagnostic alphanumeric display of TDS data showing loop-error display mode.

Figure 14.- Concluded.