IOS DESIGN TRENDS FOR A FULL MISSION TRAINING DEVICE

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ABSTRACT

Link has recently applied state-of-the-art instructor operator station (IOS) technology to an existing full mission training device. An intelligent workstation, designed to focus on the instructor's specific needs for each training task, has been added to an F-16 Full Mission Simulator, replacing an IOS representing an earlier technology. This system was conceived with the participation of the user, taking advantage of past experience with F-16 training requirements and methodologies. The new IOS technology addresses the needs of the instructor to accomplish specific training tasks by providing displays and controls optimized for specific tasks. Windows, color, icons, and merged text and graphics contribute significantly to the system's ability to support the instructor. Maintainability has been enhanced by decentralizing the IOS software in commercial off-the-shelf workstations. Instructors using the system indicate that it is meeting its training design goals, and that it is significantly more effective than the earlier design.

INTRODUCTION

A typical full mission training device consists of one or more student stations, one or more instructor operator stations (IOS), a computational system, and auxiliary equipment. The auxiliary equipment includes power distribution equipment and safety equipment such as fire detection and suppression devices. The computational system provides the environment for the simulation exercise, a replication of the performance characteristics of the simulated system, and instructional features to promote effective and efficient training. The IOS provides the instructor with controls and displays designed for monitoring the student's performance and for controlling the simulation exercise.

BACKGROUND

The training device instructor station is the instructor's interface with the student, the simulator, and the simulator's instructional system. It supports the instructor's unique capabilities in facilitating the learning process. Historically, instructor stations have been less than efficient in providing essential information and in permitting the control needed by the instructor in facilitating training. Steady advances in information processing and display technologies, and in the development of equipment for supporting instructor inputs, have made possible significant advances in the quality and the utility of the instructor station. In 1969, CRTs were first employed by Link in the UH-1 instrument trainer, Device 2B24 [1]. They permitted increased flexibility in the display of information to the instructor as well as more direct control over the training environment.

The use of CRTs, keyboards, and matrices of special function switches greatly increased the capabilities available at the instructor station at the expense of significant increases in instructor workload. Gamache addressed this problem in a 1982 paper [2] and recommended ways of simplifying the instructor station without compromising its flexibility. These recommendations were summarized in a series of design objectives, all focused on the functions required of the instructor in exercising his unique capabilities in facilitating learning. Later, Setty, Epps, and Meara [3] described an implementation of these guidelines in a paper on the development of user-friendly instructional systems. Detailed analyses were made of both the crew training mission scenarios and of the instructor's responsibilities and capabilities in supporting training in those scenarios. The insights gained here subsequently influenced the design of instructor stations in a number of simulators.

In 1986, the display equipment in the Link F-16 Operational Flight Trainer (OFT) became obsolete and the vendor notified the Air Force that key components could no longer be supported. The system was oriented toward the simulator's systems rather than its instructional functions, requiring the instructor to access numerous display pages in accomplishing any specific training task. The obsolescence of the existing instructor station equipment provided an opportunity to replace the 1970s technology it represented with modern equipment based on further analyses of the instructor's requirements.

A study was conducted in order to determine the additional features and capabilities that would be useful to instructors if an opportunity arose to change the F-16 IOS basic design. A tradeoff study was conducted to evaluate the cost savings in adapting the existing software to the vendor's new hardware versus the advantages of redesigning the display software to incorporate additional features to enhance training effectively. Based on the results of this analysis, the customer elected to invest in a "new generation" IOS capable of providing an improved user format and additional features.

After it was determined that a new design would be beneficial, a system engineering approach was used to analyze requirements and define the new system. The process began by developing a clear understanding of the user's requirements. White [4] in 1987 had emphasized the importance of user insights in instructor station development to avoid reliance on technology developed in isolation from the user's requirements and to ensure that the requirement, rather than the technology, drives the design process. User participation in this process was considered essential.

UNDERSTANDING THE USER AND THE TRAINING REQUIREMENT

The F-16 simulator is procured by the Aeronautical Systems Division (ASD) of the United States Air Force. It is delivered to the end user, who may be the Tactical Air Command, the Air National Guard, or an approved foreign government. Requirements are developed jointly by the user and ASD, who formalizes them. The simulator must pass both the contractual requirements of the procurement agency and the functional requirements of the user in the field. The ultimate quality of the device is established by the user, and thus the user is the focus of the system engineering analysis.

DEFINING THE CAPABILITIES REQUIRED OF THE NEW IOS

Pilot and Instructor Task Analysis

A pilot task analysis was performed to identify and analyze the pilot's tasks in the F-16 aircraft, and in the F-16 training device. Instructor tasks related to the pilot tasks were identified and analyzed to develop a clear understanding of requirements needing to be incorporated in the IOS design. The instructor task analysis focused on the information and control requirements.

In general, the instructor needs to organize and set up the training problem, brief the student, monitor and evaluate his performance, and coach, guide, and critique him in facilitating the training process. The purpose of the instructor task analysis was to identify the information display and control capabilities needed at the instructor station to provide the best possible support to the instructor in performing these functions.

Training missions are organized around specific pilot procedures, tasks, and maneuvers. In the F-16 simulator syllabus, training activities are organized into the following groups:

OFT Training

- Ground Operations
- Departures
- Approach and Landing
- Navigation
- Air-to-Air Combat
- Air-to-Ground Weapon Delivery

WST Training

- WST Task Training
- WST Mission Training

Each of these groups involves specific information needed by the instructor in controlling and supporting the training process.

A set of display pages was specifically designed for each of the listed groups. User inputs were crucial to the design process, providing data about training and instructor requirements. Each set of pages provides information and control necessary to set up, monitor, and manipulate its scenario. These task-oriented pages are supplemented with auxiliary pages, permitting control of functions indirectly related to each group.

Auxiliary pages are provided for displays which are not required during training support and simulation control tasks. These include:

Mission Setup

Weapon Scoring

Emergency Activation and Cockpit Monitoring

Cockpit Status Display

WST Device Control and Status

Facilities Index

Malfunction Selection and Removal

Target Characteristics

User-friendly Controls and Displays

All control and display pages were designed to the standard format depicted in Figure 1. The bottom and right edges of the screen are used for user selection and control. The right side of the display is divided into three parts that provide: 1) a system message area with messages such as "please stand by" or "DRLMS integrated", 2) a list of the five most recently activated malfunctions, and 3) a window area used for additional controls for the selected page. The remainder of the screen is dedicated to providing the user with the specific information most often needed for the selected training task in an uncluttered format. Information that is infrequently used or used for short periods of time is selectable via a control "button" in the window area and causes one or more pop-out windows to be displayed, generally in the upper right corner of the main display area.

For ease of operation, user controls are provided almost exclusively as touch-sensitive icons on the CRT displays. These icons may represent single activate/deactivate buttons, a pop-out calculator with display and keyboard, a group of related items, such as symbols where

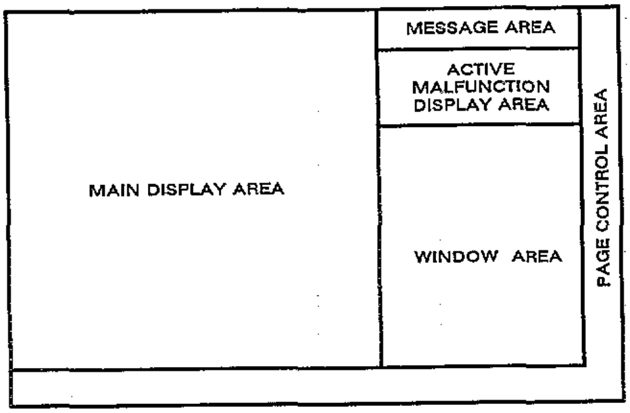

Figure 1 INSTRUCTOR'S PAGE LAYOUT

one is selected when the stylus (finger) is removed, or a movable control called the "dragger" which moves a pointer along a scale or repositions things in the simulated gaming area. Icons in the form of symbols representing functions to be activated are selected by the touch of a pointer — a finger or a stylus. The pointer is placed on a symbol and its function is activated when the pointer is withdrawn from the screen. This avoids making inputs before the pointer is placed precisely on the symbol, and it assures the instructor that the function will be initiated at exactly the instant it is required.

Instructor Display Pages

Instructor display pages are designed to provide information and controls needed to perform specific training tasks. Because circumstances and needs vary within a task as training progresses, pages are designed to be reconfigurable. A page is reconfigured by using windows — display and control areas that can be looked at, used, and removed.

Instructional data is displayed in the main display area, which is also known as the high interaction area and is always visible. The associated controls are provided in either the page control area or the window area, depending on their commonality among that set of display pages. Touching one of the buttons will cause a window to appear. Windows that contain high-interaction data appear in the main display area. These windows provide additional details about some aspects of the exercise, such as flight data, target data, and bogey information. Multiple windows may be activated and are coordinated to provide minimum interference with each other and the underlying display. Most windows contain data requiring little instructor interaction, however, and appear in the window area which is away from the main display area. Again, multiple windows are used to provide the instructor with exactly what is needed at any point in the training exercise without superfluous information camouflaging pertinent information.

Map Pages

"Map" pages provide information and information formats designed to help the instructor to visualize various kinds of training situations. They permit the instructor to select the point of view and the scale required at any given time, providing a "God's eye view" of all of the pertinent relationships and dynamics in readily interpretable form. The ownship pilot's eye view is a pseudo-three-dimensional view of the exercise looking out the front of the ownship cockpit. The view pitches and rolls with the ownship. Ground objects, air targets, and the refueling tanker are shown. A chase position view provides the same presentation but with the reference point slightly above and 1000 feet behind the ownship. A target eye view places the reference point looking out the front of the selected target aircraft and provides the same presentation as the ownship pilot's eye view.

Symbols patterned after those on the F-16's HUD represent targets and ground objects. Air target symbols are more elaborate. They are shown as "paper airplanes" and give a true indication as to their proximity, relative location, and relative heading to the selected eye point. When air targets exceed visual range, they are replaced with a new symbol that indicates its position and relative heading. This "too far away" symbol resembles the F-16 radar "aircraft in track" symbol. Shadows under the aircraft symbol are used to help the instructor judge the relative position of each aircraft. The "paper airplanes" appear in different colors to represent who they are and what they are doing. Blue is used to distinguish the ownship, tanker, and friendly air targets. Yellow denotes unfriendly air targets. Red identifies air targets that are locked on to the ownship. Flashing red means that the air target has a weapon in flight against the ownship.

Additional controls are provided at one of the IOS control panels to allow the instructor to select a target and fly it. These controls are the target selector, a throttle, and a joystick. When a target has been selected for "flying", the target's pitch and roll positions will be displayed to assist the instructor in "flying" it.

An example of a page with many of the features discussed above is shown in Figure 2. This is a MAP page showing a chase position. The target shown above the horizon is out of visual range. A bridge, a target-of-interest symbol (ring of towers) superimposed with an adjacent bridge, and a surface-to-air missile site are displayed. A group of selectable ground target symbols is displayed along the lower part of the display.

Putting It All Together

The IOS is designed to accommodate two instructors: one for OFT training and a second for WST training. The IOS consists of four IOS consoles or positions as illustrated in Figure 3. Position 1 is to the left of the OFT instructor's normal position. It contains those cockpit repeater instruments that are not well suited for graphic displays, such as the multifunction displays, and/or those that are used frequently during a training exercise. Position 2 is designed for OFT task training monitoring and control. The applicable training task page is usually displayed here, supplemented by the repeater instruments on the left and auxiliary pages on the right. Position 3 is the center console and is intended to support both the OFT and WST instructors with the auxiliary pages. Position 4 is designed for the WST instructor to monitor and control the WST devices.

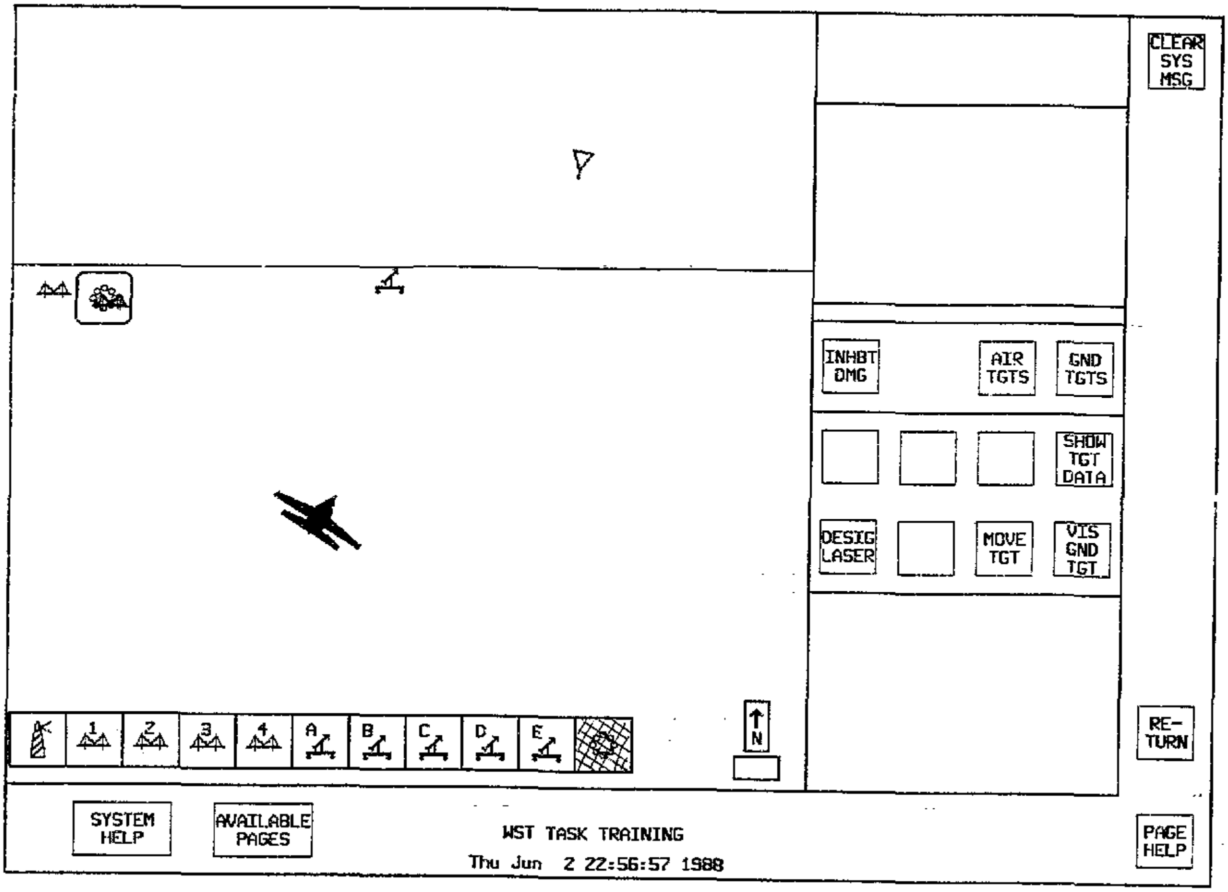

Figure 2 INSTRUCTOR'S MAP PAGE

IOS positions 2 through 4 consist of identical autonomous workstations and small dedicated control panels. These control panels provide additional controls for the instructors that are better implemented via hardware switches. Examples are a joystick for instructor control of the selected target, simulator control buttons (e.g., freeze/run), and emergency power off.

IOS DESIGN

Predecessor System Summary

The original F-16 IOS system utilized alphanumeric-graphic CRT displays with down-loadable memory for the executable display commands. All of the real-time data collection and insertion, data calculation, and most of the display management functions were performed in the host computational system. The user interacted with the IOS via the keyboard (and optionally a light pen) where specific field numbers were used to identify and select input fields. Error feedback was given to the user when invalid data entry was attempted — e.g., too large a number for a field expecting degrees between −180 and +180, or alphabetic data in a numeric field.

New System Architecture – Hardware

The architecture of the new IOS system capitalizes on current technology. The IOS workstations are commercial off-the-shelf units and are connected to the host via Ethernet in round-robin fashion. Each workstation consists of a Silicon Graphics 3020 processor configured with a 70-MB hard disk, 19-inch-diagonal color screen, and infrared-beam touch panel. The Silicon Graphics 3020 system features Motorola's 68020 microprocessor system and a Geometry Engine* which manipulates objects in three dimensions, providing clipping, transformation, and rotation functions. A tape backup system is configured on one of the three workstations for fast and convenient disk backup. Only one is required since the three workstations are identical, including software. Also, an attachable keyboard and mouse are configured for communicating with a workstation's operating system.

New System Architecture – Software

The IOS software has been offloaded from the host and placed in the lower-cost microprocessor-based workstations where possible. However, the host still has the tasks of data collection and data insertion, real-time snapcopy output to the printer/plotter, and some data preprocessing that is more efficiently done in the host.

The IOS workstation software operates under the standard UNIX operating system supplied by Silicon Graphics. To avoid the high processing overhead of UNIX, which is typical of current operating system technology, an IOS page executive has been developed. It takes control from UNIX and only relinquishes control when the workstation is

* Trademark of Silicon Graphics, Inc.

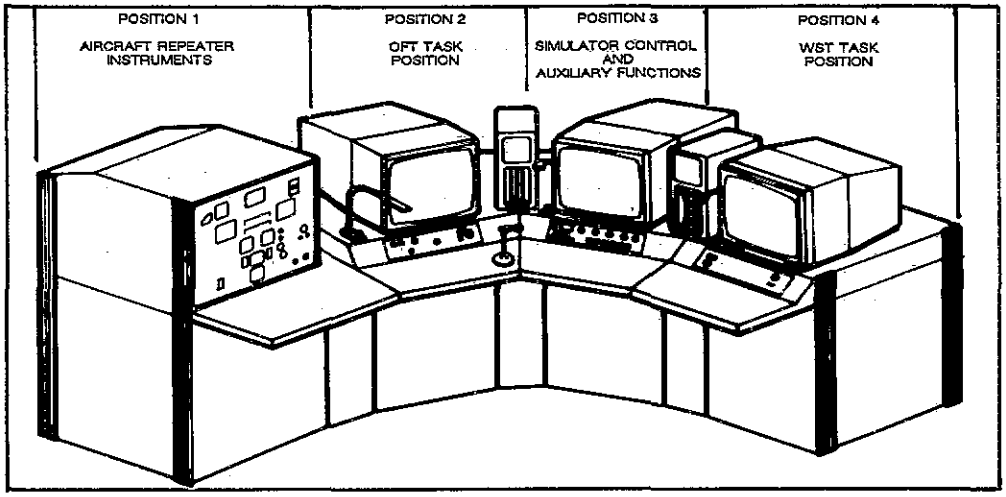

Figure 3 IOS LAYOUT

taken off line. The IOS page executive consists of the following subsystems and support systems: Page Process, Transport Process, Data Manager, Data Converter, Page Loader, and Snapcopy Processor (Figure 4).

Page Process performs the following functions:

1. Controls all the real-time functions of the active page.

2. Generates the graphic images on the CRT.

3. Requests all the necessary variables from the host to process the active page.

4. Processes all operator inputs from the touch panel, including new page requests, page forward, page back, menu selections, and data insertions.

5. *Builds the ground map for the map pages from the* points contained in the target data file, navigation facility file, flight profiles file, waypoints file, terrain data file, and trail data file.

Transport Process is a system level routine that controls the bus traffic over Ethernet.

Data Manager coordinates the transfer of data to/from the host. It includes the data transfer list that correlates page variable names to host variable names. This feature uncouples the IOS workstation software from the host application software, thereby enhancing its portability to other simulators. For example, ownship altitude might be called FOSALT in one OFT and ALT in another. Without the data manager, a potentially large renaming task would exist whenever the IOS was applied to a new device.

Data Converter converts nondisplayable integer and boolean input data formats into ASCII character strings for display on the CRT.

Page Loader loads specified page modules from hard disk and displays them. It also interprets page forward and page back requests as well as initialization and halt messages from the host.

Snapcopy retrieves the raster image of the selected display page to be snapcopied and sends the pixel buffer to the host.

New System Architecture - Support Software

The insertion of another computer system into the OFT computational system complex introduced another operating system (UNIX), a new programming language (C), and thus new support software requirements. UNIX and C are the commercial off-the-shelf operating system and language for the selected workstation. The workstation software is coded in C and therefore must be compiled where the C compiler for the Silicon Graphics system resides — on the Silicon Graphics workstation. However, a rather comprehensive configuration management (CM) system resides on the host. To take advantage of mature CM software, software and procedures were generated to maintain CM-controlled module sources and objects on the host system and to support the workstation compilation and linking processes as required. Similarly, page code is developed and compiled on the workstation, but the CM version of the source and object are maintained on the host. UNIX software is unmodified and is maintained at the workstation.

In addition to previously existing IOS support software, a local area tailoring tool has been added to assist users at each training device site in customizing their training initialization data. This system interactively communicates with the user and allows modification of initial conditions sets and the building of customized malfunction pages.

LESSONS LEARNED

The original design goals of software maintainability and transportability have not been accomplished to the degree that we had hoped. When viewed as an entity, the new IOS possesses excellent software maintainability. However, when viewed as part of an existing device, the new IOS has increased the overall complexity of the software maintainability task. The significant maintainability driver has been the increase in programming disciplines

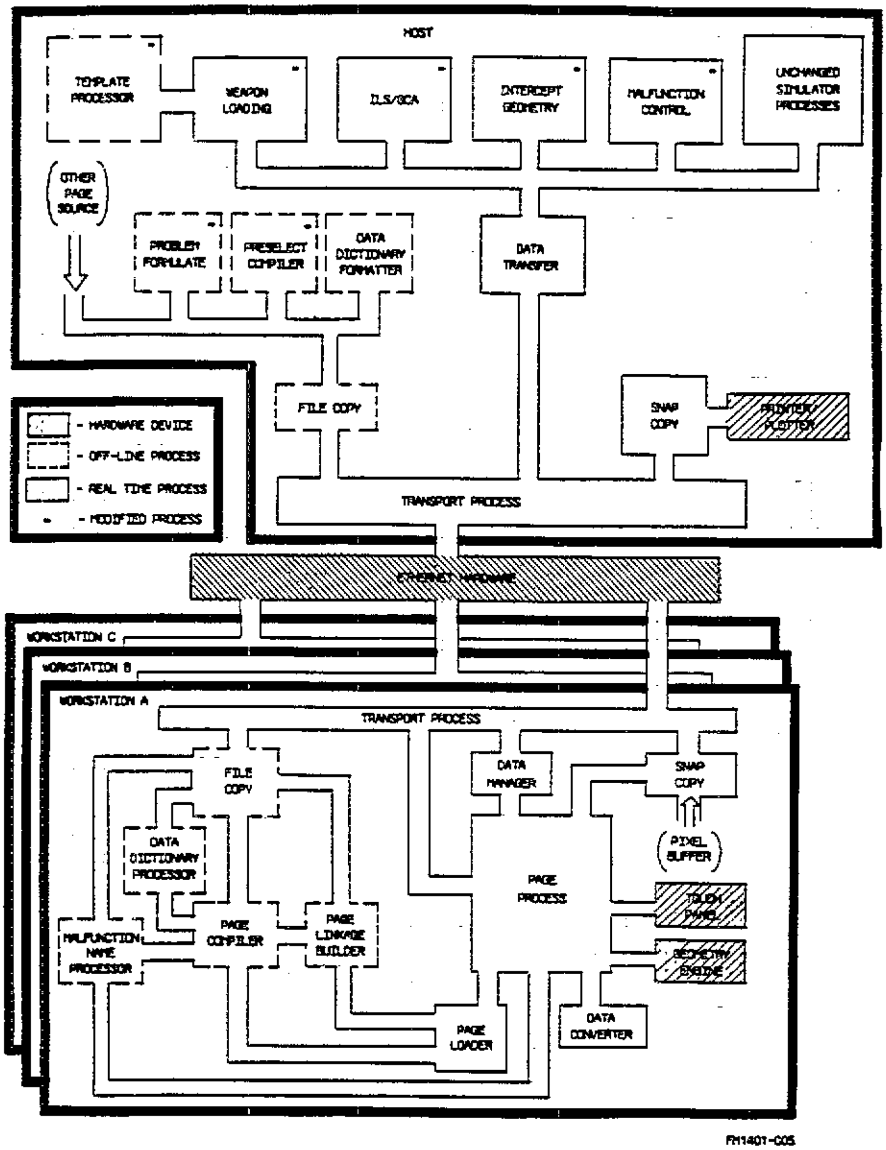

Figure 4 IOS REAL-TIME SOFTWARE ARCHITECTURE

required over the old system. In addition to mastering the host operating system, FORTRAN, and a dedicated page language, one must now adapt to UNIX and C. Also, the addition of another target environment has complicated the CM task.

The transportability design goal has been nearly achieved. The new IOS can be easily attached to almost any existing training device which can accommodate an Ethernet interface. The primary problem, however, is the complexity of a full mission simulator. Data will frequently not be readily accessible to an added interface, such as Ethernet, and may not be in the format required by the IOS. In addition, many display pages have been specifically designed to F-16 configuration and missions. However, except for user-specific pages, the workstation software is directly reusable and portions of the host software could be rehosted for a new application. All aspects of the original host hardware and software environment must be carefully analyzed when adding a newer-generation capability. The final system cannot be ideal, but must combine the features of old and new in a reasonable compromise.

SUMMARY

Obsolescence of the existing IOS alphanumeric/graphic system provided the opportunity to evaluate alternative IOS architectures with the goal of increasing instructor effectiveness. Tradeoff analysis confirmed many of the trends occurring in industry today. The most exciting and germane trend is the incorporation of intelligent hardware and software to make a system "user friendly". Intelligent hardware provides three-dimensional text/graphics representations that can be rotated, translated, and clipped with a few simple software commands. Intelligent software is commercially available to provide multiple windows, user-created icons, and a rainbow of colors.

Another major trend incorporated in this program is that of modularization, or decentralization. The IOS hardware is a set of intelligent workstations connected to each other and to the host via a popular medium-speed local area network (LAN). The IOS real-time software is still partially centralized, but the support software is essentially all decentralized. Taking the host out of real time does not affect the IOS workstations other than loss of simulation data. When the host is returned to real time, the host-IOS communication is automatically re-established. Likewise, one or more IOS workstations may be taken off line or disabled with no detrimental effects on the remaining equipment. Disregarding limitations imposed by the host-resident CM system, a workstation could be taken out of real time, one or more pages edited, compiled, built into its library, then brought back on line without ever affecting a training exercise.

In conclusion, a modular IOS incorporating the latest available graphic technology in independent workstations, organized to support specific, well-defined instructor functions, has significantly enhanced the effectiveness of the F-16 instructor. The new IOS provides the instructor with information and controls in clear, concise, unambiguous, and uncluttered formats by employing a standardized color scheme, liberal use of icons, multiple windows, touch control, and validation of commands.

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