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ESSEX

ANALYSIS AND SELECTION OF A REMOTE DOCKING SIMULATION VISUAL DISPLAY SYSTEM

CONTRACT FINAL REPORT NAS8-35473

PREPARED FOR:
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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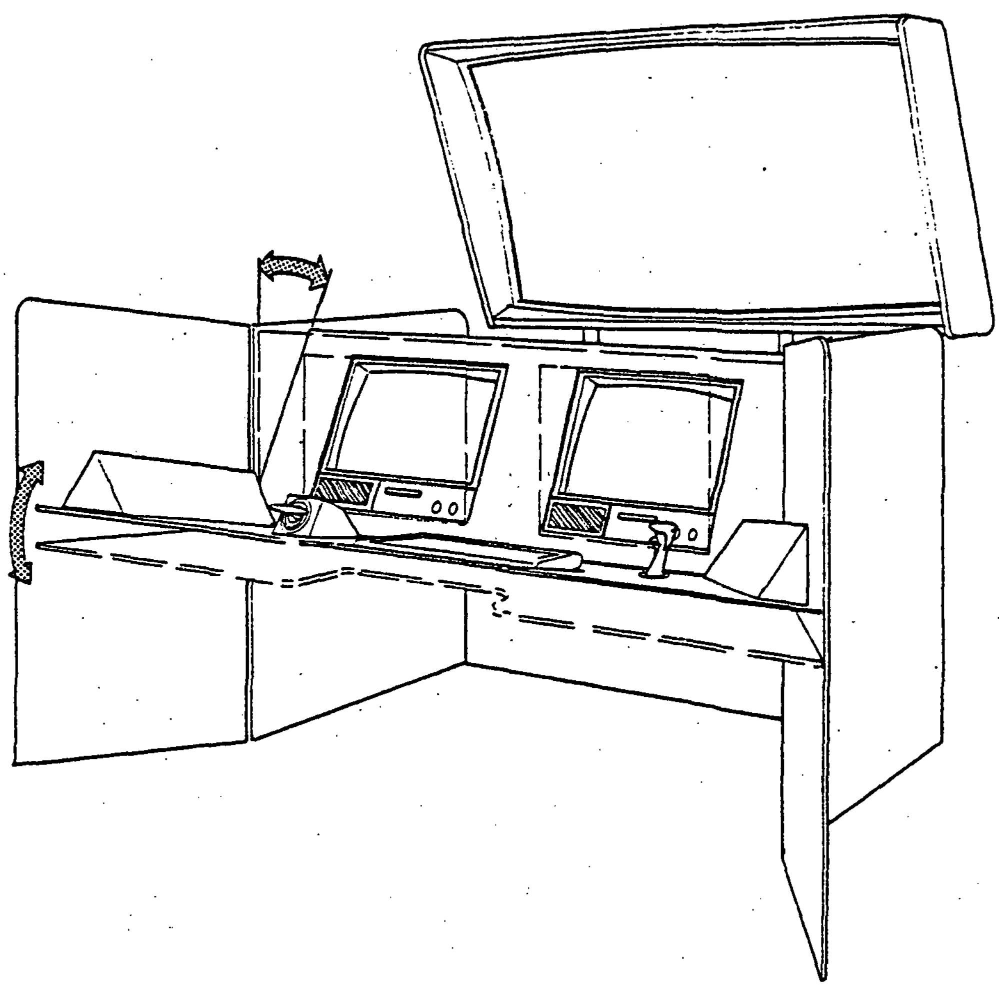

FOREWORD

This report is submitted as the final contract report in partial fulfillment of the contractual requirements of contract NAS8-35473.

The contract was accomplished by the Essex Space Systems Group from May 1983 to August 1984 under the technical direction of Mr. Fred Roe. His technical guidance, comments and constructive participation contributed to the overall success of the program and his efforts are gratefully acknowledged by the technical staff.

Questions and comments concerning this report should be addressed to Fred Roe, EB24, NASA/MSFC at (205) 453-3369 or to Nicholas Shields, Jr., Essex Corporation, at (205) 883-7470.

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ABBREVIATIONS AND ACRONYMS

CTU - Command Telemetry Unit
DOF - Degrees of Freedom
MMS - Multi-Mission Modular Spacecraft
RWS - Reconfigurable Workstation
ST - Hubble Space Telescope
TMS - Target Motion System
TOM-B - Teleoperator Motion Base
TOREF - Teleoperator and Robotics Evaluation Facility

1.0 INTRODUCTION

The program described in this technical report was undertaken to design and provide the Marshall Space Flight Center's Teleoperator and Robotics Evaluation Facility (TOREF) with a control and display workstation which incorporated the wide range of requirements inherent in a remote control workstation and still satisfied the human/machine interaction requirements.

1.1 BACKGROUND AND PROBLEM STATEMENT

Since 1971, Marshall Space Flight Center has conducted extensive research into the human factors requirements for remotely managed systems. The Teleoperator Technology Development Program, as the effort is called, has evolved from studying specific issues such as human visual responses utilizing televised feedback, or operator performance on manipulative tasks using joystick controllers, to a fully integrated research program dealing with issues at the systems level such as rendezvous and docking, closed-loop computer controlled applications, and satellite capture and servicing.

The initial workstations for the control of uncomplicated tasks such as manipulator positioning were relatively straightforward control stations with only that equipment which was necessary for that specific task. Also, there are sufficient engineering design criteria on which to base simple workstations which involve only one or two control or display systems such as keyboards or video display units. The technical problems involved in designing more complex workstations with many interactive controls and displays cannot be as readily solved by using the usual human factors guidelines and standards. For those situations where the task and operator requirements exceed the normal standards, it is necessary to develop new approaches to workstation design. Considerations of task requirements, anthropometry, operator training, visual perception, body support, communication, auditory signals and human/machine roles must be taken into account, and design simulations must be conducted to assure that all of the component considerations can be optimally integrated into a workstation.

For control of remotely managed tasks, the assumption has always been made that visual displays will represent the principal feedback mechanism for the operator. This assumption has been based on the human visual capabilities, perceptual experience and on sensor and display technology. The reliance on visual feedback as a primary display mode does not come without costs in terms of data transmission, bandwidth, power requirements, lighting support, signal-to-noise degradation and other aspects of trying to present the operator with a well-defined visual representation of a remote scene. In addition to these issues, most visual displays are adequate for use only by a single operator and when secondary controls and displays are required they tend to either interfere with the primary visual display or be located at inconvenient positions due to the primary display. These conditions are not acceptable for the multi-channel human/machine requirements of remote systems management and this technical effort was undertaken to compensate for those design problems.

2.0 VIDEO SYSTEM CHARACTERISTICS AND HUMAN OPERATOR PERFORMANCE

The first task undertaken by Essex in the selection of a visual display system for the Teleoperator and Robotics Evaluation Facility was an extensive review of the human factors research on visual displays and human operator capabilities. The results of this research were incorporated into an annotated bibliography and a summary of desirable video system parameters which are included in the Reference Section of this report. During this investigation, several video system characteristics which have a particularly strong impact on human performance emerged. These characteristics and their effects on the selection of two 33 cm Mitsubishi color monitors and a 91x123 cm Mitsubishi large screen display for installation in the TOREF are reported in the following sections.

2.1 MONITOR SIZE

Previous research conducted by Essex Corporation has shown that the optimal monitor size for a particular situation is dependent upon the type of information displayed, the type of visual task to be performed, operator viewing distance, and resolution characteristics of the CRT (Kirkpatrick, Shields, & Malone, 1975; Kirkpatrick, Shields, Malone, & Guerrin, 1976). This research was originally conducted to determine the optimal size of multifunction displays to be employed in the Payload Specialist Station of the Space Shuttle. Although size constraints are not as critical in the Teleoperator and Robotics Evaluation Laboratory as they are at the Payload Specialist Station, the variables investigated in these studies are applicable to any teleoperation activity.

The monitors in the TOREF will be used to display both imaged scenes to provide visual feedback to the operator and alphanumeric characters such as numerical data and printed instructions. In responding to imaged scenes, the operator is required to perform two basic visual tasks -- detection and recognition. Detection is defined as the instant at which an operator can distinguish a figure from its background and recognition is the point at which the figure can be correctly named or identified by the operator. Teleoperation tasks such as docking and retrieval may be considered to be specialized cases of detection and recognition. Kirkpatrick, Shields, and Malone (1975) concluded from their studies and from previous research that the successful accomplishment of detection and recognition tasks is dependent upon several variables and is related to monitor size. These authors derived formulae for determining the optimal monitor size for a particular task from previously collected empirical data.

The following equation--

$$\frac{M}{L} = .00175 \cdot \frac{R}{T} \cdot \frac{Wr}{R}$$

where M = monitor width, L = viewing distance, R = range from camera to target, T = displayed target dimension, and Wr = field of view width at R--expresses the relationship between viewing parameters necessary for the image of the target dimension (T) to be detectable on the display with a probability of .99. Similarly,

$$\frac{M}{L} = .01163 \cdot \frac{R}{T} \cdot \frac{Wr}{R}$$

expresses the relationship between viewing parameters necessary for the image to be recognized on the display. The numerical constants in these equations were derived from previous data and these equations assume that the monitor has a signal-to-noise ratio of at least 32 db, a band width of 4.5 MHz, and contrast ratios of at least .33. These two equations were employed to determine optimal monitor sizes for typical teleoperation tasks in the laboratory by plotting the full range of possible values for each variable in the equation and solving for M in all possible combinations. The optimal monitor sizes for detection ranged from 10 to 35 cm with the 35 cm dimension resulting from the worst case condition of a long range from camera to target (R), a small target size (T), and the maximum viewing distance (L). The resulting monitor dimensions for recognition tasks ranged from 15 to 226 cm with a concentration of values between 33 and 127 cm.

Although the display of alphanumeric characters is not as critical in determining monitor size in the TOREF, it was necessary to determine that the monitors chosen could display an adequate number of characters for all proposed tasks. Based on their research, Kirkpatrick, Shields, and Malone (1975) determined that a 20x20 cm monitor would permit a maximum of 930 characters to be recognized. A monitor of this size or larger would adequately serve the character generation requirements of the laboratory.

Based on this research, two 33 cm monitors and a 91x123 cm large screen display were incorporated into the RWS. This combination of monitors will allow for the successful accomplishment of the full spectrum of visual tasks required in the TOREF.

2.2 RESOLUTION

Video resolution data show that for targets which subtend fewer than 5 raster lines, the probability that an operator will correctly recognize a target is low, something on the order of 70% for 5 lines down to 20% for fewer than 5 lines. Performance in resolving images increases to 90% with 10 raster lines of information.

For geometric shapes, the average displayed visual angle required for correct recognition is twice that for direct viewing. Under adequate visual system conditions--contrast, signal-to-noise ratios, etc.--25 to 40 arc minutes will be needed for television systems.

For detection/resolution of high contrast gaps or lines being searched on CRT's, the visual angle required will vary from 5 to 20 arc minutes depending on the signal transmission characteristics. As characteristics are degraded due to bandwidth compression, digital transmission and signal-to-noise ratios, the resolving power will be reduced and the amount of information to be correctly recognized will have to be reduced.

2.3 CHROMATICITY

In a review of 42 studies concerning color coding conducted between 1952 and 1973, Christ (1975) concluded that color coding may improve performance in some cases and may be detrimental in others. It has been clearly established that color coding graphic displays aids in both search and identification of targets if the code is known in advance by the operator and if the color is unique to the target.

There has been some debate over the number of color codes that an operator can successfully perceive and process. Although humans are able to perceive many variable shades and color combinations, there is a point in the performance of a task using a coded graphic display at which perceptual or memory overload occurs. Cahill and Carter (1976), in a study in which subjects searched for three digit numbers in displays coded in one to ten colors, found that adding colors to the display decreased search times until approximately seven colors were used, after which, search times increased. Other researchers (Carter, 1979; Kopala, 1979) have obtained similar results.

From this review of the literature on color displays, it was clear that color graphics capability was desirable for the TOREF. The Mitsubishi 33 cm monitors chosen for the workstation provide a color graphics capability of eight colors - red, green, blue, cyan, yellow, magenta, black, and white. This set of colors will be completely adeaquate for the range of graphic displays anticipated for teleoperation activities and will accommodate the range of human operator capabilities.

2.4 STEREOPSIS

The clear requirement for stereoscopic vision in televised tasks has not been demonstrated. This is not to say that its usefulness has not been shown, but that other visual system configurations such as orthogonal arrangements can achieve better results.

Stereoscopic systems have been evaluated in the teleoperator visual laboratory, and the range of systems evaluated has been from split-field lenses which reduce contrast and field-of-view to two-channel mixed stereoscopic systems which limit eye movement to sequential field systems and can produce perceptible flicker at the display.

The ultimate advantage of stereoscopic systems may be in the engineering arrangements of the two sensors which can provide inter-lens distances both larger and smaller than those of the human interpupillary distances, thus enlarging the range over which stereopsis can be achieved. There are also system engineering advantages to two-channel stereoscopic systems in that the failure of any part of one channel is backed up by the other channel in a monoscopic condition.

3.0 OPERATOR COMMAND AND CONTROL REQUIREMENTS

During remote operations, the human operator will be required to make manual, and in some cases pedal, responses to changing visual and auditory information. Limited visual fields-of-view, transmission time delays, tactile inhibition and absence of acoustic and secondary sensory feedback will have a profound effect on operator performance as compared to real-time, non-remote operations. For OMV operations, some of the operator requirements for command and control are outlined below.

3.1 PRIMARY CONTROL CHARACTERISTICS

The visual displays used by the operator should be operator selectable; that is, among the CRT displays the operator should have control over graphics, visual scenes and alphanumeric data and be able to select where those data are displayed. The contrast, brightness, focus and stability of the display should also be controlled by the operator. The operator should control individual adjustments and viewing angles of the primary displays and, as an integral part of the workstation, have control over the ambient illumination in the surrounding area.

The hand control systems will generally be derived from the mission functions. For mobility control the usual approach has been to provide a rotational and a translational hand controller. This has, also, generally been true for controllers for single manipulators, but multiple manipulator arms will necessitate individual six degree-of-freedom controllers. The extent to which auxilliary feedback is required--force feedback, tactile sensing, etc.--for manipulator control will be a function of the delicacy of the manipulative tasks. The general rules for hand control operation of manipulators suggest that forearm and wrist support be provided and that displacement of the hand controller be accomplished with minimal operator force. The positioning and orientation of hand controllers at the workstation will be dependent on the hand controller design and other primary control activities such as the use of keyboards as primary control devices.

Keyboards used to call up functional routines, request or manipulate data, display graphics and similar functions will generally have to be located in the center of the workstation due to the fact that they require simultaneous two-handed operations. Keyboard positioning is one of the significant design drivers for integrated remote systems workstations in that they force the positioning and placement of visual displays and hand controllers.

3.2 SECONDARY CONTROL REQUIREMENTS

The operator functions with less frequent use rates are normally placed outside the primary operating envelope of 30°. The control requirements still dictate that visual and manual access be maintained to any space used for secondary controls. For remote systems operations it is important to remember that the operator's attention will be focused into the primary work envelope; consequently secondary control devices might require unusual placement or unique coding.

3.3 INTERACTIVE KEYBOARDS

The specific requirements for keyboard layout and function will be defined by the mission objectives. The general requirements for central location, bilateral access and positive inclination toward the operator should be maintained regardless.

The standard "QWERTY" keyboard is most often employed, with program function keys or calculator keys arranged to the right of, and isolated from, the alphanumeric keyboard. The form of keyboards is more often dictated by supplier availability than by appropriate human engineering design; however, most often the costs and retraining associated with unconventional keyboards outweighs any immediate increase in performance.

The requirements for keyboard entries which communicate with active computer software should follow such general rules as:

- Commands to be sent via a keyboard should require that the full command be displayed for operator review, prior to execution, and
- That commands be initiated through a special entry key
- Keyboard modification to software programs should require both an initiation key stroke and a verification key stroke prior to a transmit command
- The response of the display to key stroke entries should be immediate. Input and feedback delays have been shown to have a negative effect on operator performance
- Command usage and display design guidelines are detailed in MSFC-PROC-711A.

4.0 DESIGN CRITERIA FOR A RECONFIGURABLE WORKSTATION INCORPORATING VIDEO SYSTEMS AND COMMAND AND CONTROL SYSTEMS

Research concerning VDT workstation parameters and their effect on human operator performance has been conducted since the early 1970s. Optimal workstation characteristics which have emerged from this research are summarized in Table 1. The preferred display and transmission characteristics listed have become relatively standardized. The workstation dimensions listed have been shown to accommodate the 5th to the 95th percentile of the operator population and to enhance operator performance. More recent research has shown that workstations which are adjustable to the operator's preference lead to improved performance and reduced complaints of musculoskeletal and visual fatigue (Grandjean, Hunting & Piderman, 1983; Miller & Suther, 1983; Shute & Starr, 1984).

Although many adjustable workstation components are now available on the market, these separate component systems did not meet the requirements of the TOREF for a workstation which included multiple monitors, a keyboard, hand controllers, and secondary displays. Based on the review of the VDT human factors research and a review of currently available workstations, Essex determined that a new design for a Reconfigurable Workstation (RWS) was required to meet the TOREF requirements. The criteria which were established for this design were that the workstation should:

- accommodate the 5th to the 95th percentile of the anthropomorphic range of the user population
- optimize both hand controller and keyboard operations
- provide the optimal viewing angles for monitors and visual systems
- reduce operator fatigue by supporting the forearms and wrists during keyboard and hand controller operation and by reducing excessive requirements for head/eye and hand/forearm movement
- be easily reconfigurable to include mission specific equipment
- be easily adjustable to settings most comfortable to the individual operator
- focus the operator's attention on the primary task.

4.1 OPERATOR WORK SPACE

The RWS operator work space is composed of a primary work panel, a primary visual panel, secondary control and display panels, and a large screen display. These components, separately and in conjunction with one another, meet the design criteria previously listed.

TABLE 1

A SUMMARY OF VDT AND WORKSTATION CHARACTERISTICS RECOMMENDED BY HUMAN FACTORS RESEARCH

Workstation Dimensions:	
Floor to table top	63.5 - 76.2 cm (25 - 30 in.)
Floor to top of screen	106.7 - 129.5 cm (42 - 51 in.)
Keyboard height - floor to home keys	75.0 - 76.5 cm (29.5 - 30.1 in.)
Top of screen to seat	68.5 - 83.8 cm (27 - 33 in.)
Keyboard angle	10 - 18° above horizontal
Screen angle	10 - 20° below perpendicular
Viewing distance	40 - 50 cm (15.8 - 17.9 in.)
Eye level	Even with top of screen
Display Characteristics:	
Display density	Not greater than 60%
Video luminance	Approximately 65 cd/m^2
Ambient illumination	Minimum - 540 lx (50 ft/c) Recommended - 755 lx (70 ft/c)
Contrast	At least 10 gray levels target/background ratio of .25
Glare	A filter on the CRT face is recommended
Character design	Font - futura demibold character height 30 arc min. character width 23 arc min. stroke width 5.5 arc min.
Transmission Characteristics (preferable):	
Signal-to-noise ratio	$\geq$ 21 dB
Signal format	Analog
Band width	4.5 MH_z
Frame rate	30 frames per sec.

The primary work panel is much like a desk top with an alcove in front of the keyboard. The alcove permits the operator to correctly position him/herself for both keyboard and hand controller manipulation. This aspect of the work space also serves to support the operator's forearms and wrists during both keyboard and hand controller operation.

As seen in Figure 1, the operator may elect to position the primary work panel at an angle declining away from him/herself. This unique aspect of the RWS should serve to increase forearm and wrist support, thus reducing fatigue and focus the operator's attention to the primary work areas of the panels. This research issue will be investigated in the near future.

The primary work panel incorporates a keyboard panel which will accommodate a wide range of keyboard sizes and is adjustable in inclination from +15° to -3°. Human Factors research clearly demonstrates that, in standard workstations, a positive keyboard slope of 10°-18° serves to improve performance and is preferred by subjects to a flat keyboard. It is believed that this will hold true for the RWS even when the primary work panel is in a negative inclination; this is another issue for further research. It is possible that a flat or less positively inclined keyboard may be preferable for simultaneous keyboard/hand controller operations.

The RWS primary visual panel contains two 33 cm monitors and will accommodate two monitors of up to 50 cm in the diagonal. This panel is adjustable to -20° from perpendicular to accommodate height variability in the population and to allow for individual viewing preference. The angle adjustment of this panel will also be advantageous in reducing ambient glare.

The secondary control and display panels are located to the right and left of the operator. The secondary control panels are within the reach envelope of male and female operators for the 5th to 95th percentile range. As shown in Figure 2, these panels are easily removed or rearranged to accommodate mission specific equipment such as the sequential stereo controls shown in this configuration. The secondary display panels are located on two vertical "wings" at the sides of the workstation. These panels provide space for infrequently used displays and they also provide an environmental enclosure which focuses the operator's attention to the primary task. These panels may also be removed, if necessary, for certain types of equipment or operations.

The final component of the RWS is a large screen display. This display is positioned in front of the workstation and can be easily seen by the operator because of the position of the primary visual panel. The advantages or disadvantages of this type of display and what type of information is appropriate for display on a large screen are future research issues.

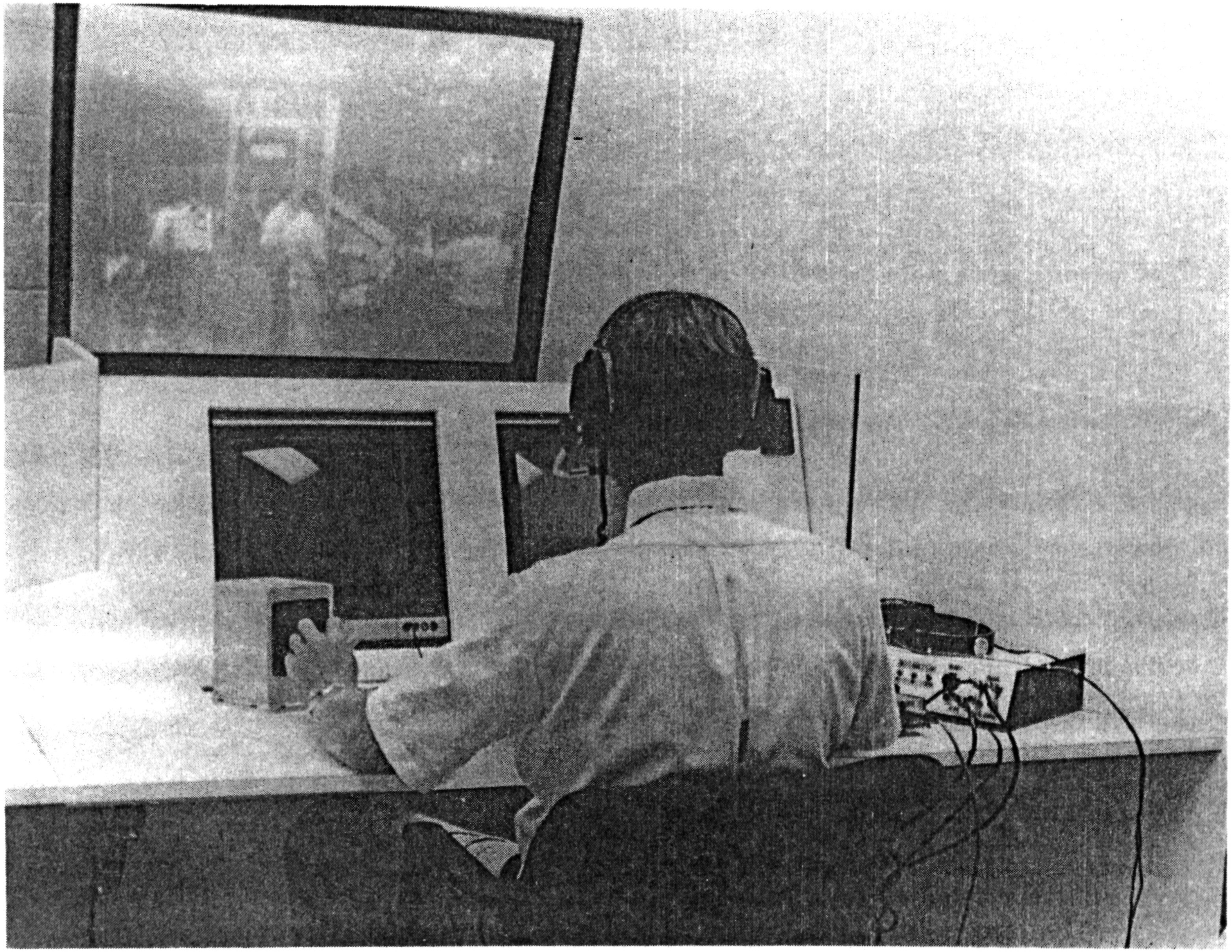

Figure 1: RWS - Primary Work Surface Declined Away From the Operator

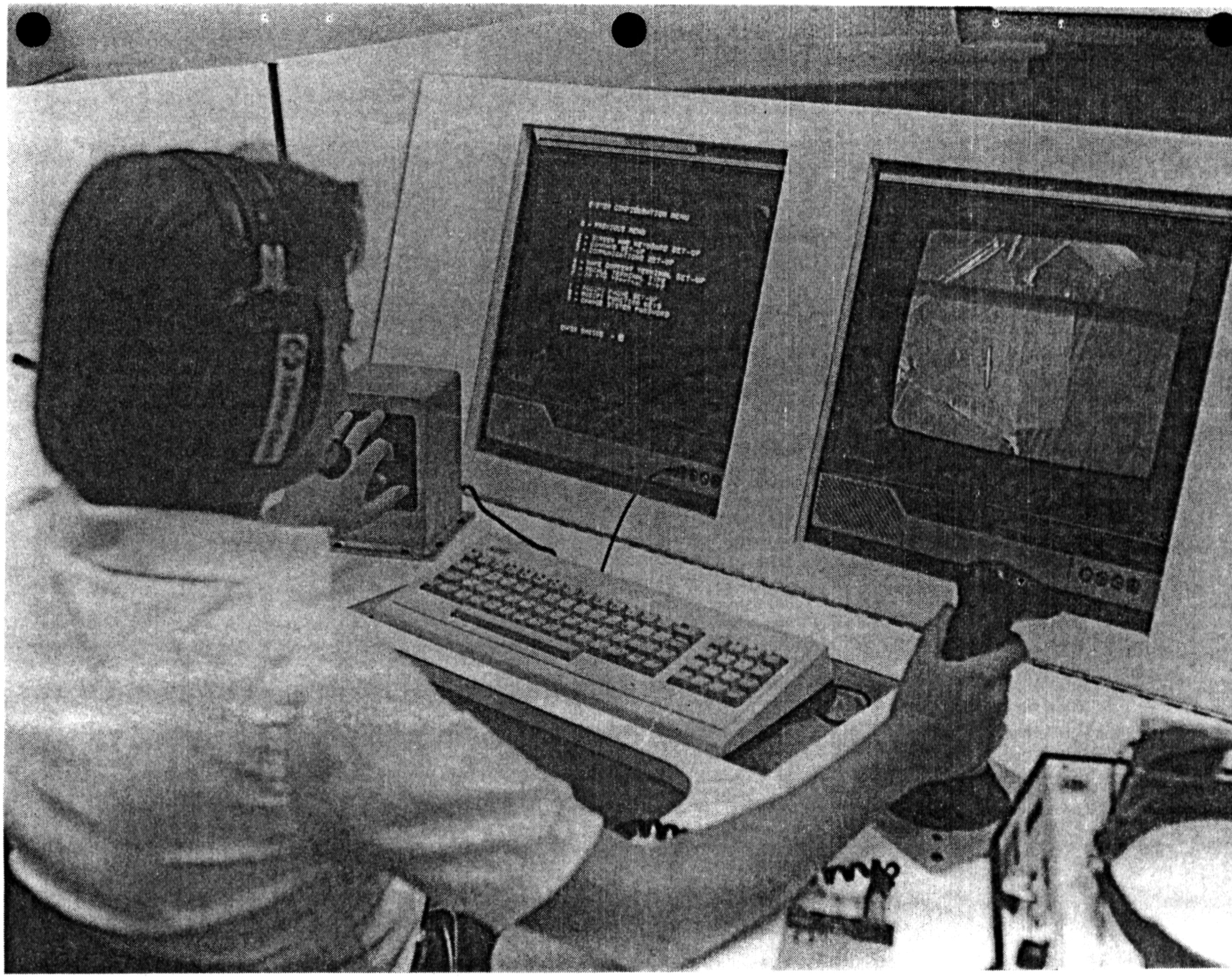

Figure 2: RWS - Secondary Control Panel Removed to Accommodate Mission Specific Equipment

4.2 SYSTEM INTEGRATION

Although the separate components of the RWS embody human factors design standards which will improve operator comfort and performance, it is the integration of these components into a complete system for teleoperation tasks which makes the RWS a unique design. The integration of the RWS components was accomplished through the use of design standards and experimentation.

The location of the hand controllers with respect to the keyboard is of primary importance in reducing hand/forearm movements in tasks which combine keyboard and hand controller functions. The hand controllers were positioned so that the operator's hands could be moved from keyboard to hand controllers with a minimum of effort and attention to this movement. Simultaneously, the hand controllers were positioned so that the forearms of all operators in the 5th to 95th percentile of the population would be supported.

The combination of the RWS primary work surfaces serves to reduce unnecessary movement and to focus the operator's attention to the task at hand. When the visual panel is properly adjusted, the operator may easily view both monitors and the large screen display with a minimum of head and eye movement.

4.3 SYSTEM RECONFIGURATION

The RWS is reconfigurable in two respects--it is adjustable to operator size and preference and it provides for additions and deletions of equipment in response to mission requirements.

One unique aspect of the RWS is that, by removing the secondary display panels, two workstations may be combined for missions requiring cooperative control by two operators. The secondary control panels are modular in design and may be quickly changed or removed for particular task requirements. The RWS has been equipped with two 6 DOF hand controllers. These hand controllers may be exchanged or reconfigured by removing a few screws and disconnecting a standard D-type electrical connector.

The RWS is also reconfigurable to operator preference so that as shifts change, for example, the workstation may be adjusted to the new operator's preference in a matter of minutes. The primary work panel is adjustable from +8° to -6° by means of a hand crank located under the panel. This crank is easily adjusted by the operator in the seated position. The keyboard panel is adjusted from +15° to -3° by tightening two thumb screws located under this panel. The monitor panel is adjusted from perpendicular to -20° by use of a shock absorber system. Based on the human factors research previously cited and an analysis of the TOREF requirements, the degree of flexibility inherent in the RWS should enhance operator performance and comfort and should fulfill the laboratory requirements for rapid equipment exchange.

5.0 PATENT DISCLOSURE AND NEW TECHNOLOGY REPORT FOR THE ESSEX RECONFIGURABLE WORKSTATION

NASA Case No.____________

NASA
National Aeronautics and Space Administration

Disclosure of Invention

This is an important legal document. It should be carefully completed by the inventor(s) and forwarded to the Patent Representative. Two copies of each document are desired.

1. Descriptive Title of Invention

Reconfigurable workstation for video display units and keyboards

2. Name(s), Title(s), and Home Address(es) of Inventor(s)

1. Nicholas Shields, Jr., Senior Staff Scientist, 2704 Churchill Drive, Huntsville, AL
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4. David Henderson, Research Associate, Ardmore Highway, Harvest, AL

3. Name and Address of Employer

1, 3, 4 Essex Corporation 3322 S. Memorial Parkway 2. NASA-MSFC/Huntsville, AL

4. Stage of Development	Date Month/Yr.	Location	Identify persons or records supporting facts stated in 4a-4e
a. First disclosure to others	Oct 83	NASA/Essex	Walt Frost - NASA Edwin Pruett - Essex
b. First sketch or drawing	Sep 83	Essex	John Haslam - Essex
c. First written description	Jan 84	Essex/NASA	
d. Completion of first model or full size device	Oct 83	Essex	Edwin Pruett - Essex Valerie Neal - Essex
e. First successful operational test			

5. List other pertinent notebook entries, photographs, reports, drawings.

Developmental photographs - Oct/Nov 83

6. If the invention was disclosed outside of NASA, identify the individuals, the companies or activities they represent, and the date of disclosure.

Facility tours by Martin Marietta, USAF, Vought, General Dynamics, European Space Agency (Oct - Dec 83) permitted views of the full-scale mockup

7. List any known or contemplated public use, publication, or oral presentation of the invention.

Use in the MSFC Integrated Robotics Laboratory Control Room (Feb 84)

8. Indicate any past, present, or contemplated Government use of the invention.

Used for keyboard and hand controller control of, and visual feedback for, remotely operated systems, particularly the orbital maneuvering vehicle.

h. If a joint invention, the contribution of each inventor.

The completed description should be signed by the inventor(s), and then read and signed by a technically competent witness, using the statement, "Disclosed to and understood by me this _____ day of ____________________ 19 _________."

Drawings, sketches, photographs, reports, if available, may form a part of the disclosure, and reference thereto can be made to complete this description.

10. Recommended Security Classification of Invention.

[X] Unclassified [ ] Confidential [ ] Secret [ ] Other (Specify)____________

11. Signature of Inventor(s) and Date

[signature] 25 January 1984 Mary Frances Fagg 1/25/84

Fred D Roe, Jr. 1/25/84 David E Henderson 1/25/84

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RECONFIGURABLE WORKSTATION FOR
VIDEO DISPLAY UNITS AND KEYBOARDS

1. General Purpose of Workstation

The purpose of the invention is to provide a workstation which incorporates the operational and anthropometric requirements of the human operators while they are performing viewing and keying activities. The workstation is designed to accommodate visual display and feedback, hand controller operations and keyboard tasks as an integrated set of operations for the 5th to the 95th percentile of the operator population.

2. Previous Approach and Technology

Design standards exist for keyboards, for hand controllers and for visual display units. These standards treat each component's operation as separate from any of the others and result in design incompatibilities when the overall system operations are evaluated. Typing keyboards are to be sloped approximately 15° toward the operator and provide palm support; hand controllers are to provide full arm support; video display units (VDU) should be tilted 15-25° up toward the operator.

The conventional workstation configurations result in a VDU which is located too high with respect to the operator's keyboard and a comfortable viewing angle, a keyboard which is too radically tilted toward the operator with regard to hand controller or joystick operations, and a support surface for joystick operations which does not adequately support the operator's arms.

3. Disadvantages of Prior Art and Methods

The primary disadvantages of simply stacking VDU's, keyboards or hand controllers on a conventional work place are: human operator fatigue, incompatible eye/hand feedback and excessive head and hand movements which result in decreased productivity by increasing operations time and error rates.

4. Reconfigurable Workstation Components and Operations

The Reconfigurable Workstation has three primary and three secondary work surfaces.

A. The primary visual panel provides for two VDU's of up to 19 inches diagonal and their associated controls for brightness contrast and focus. The VDU panel is adjustable in pitch angle to accommodate variability in the operator population as well as individual operator viewing preference for viewing angle. Within the primary visual panel, each VDU can be tilted in toward the operator's focal cone, thereby reducing eye scanning requirements.

B. The primary keyboard panel is designed to accommodate a wide range of keyboard configurations. Keyboards equipped with standard alphanumeric keys, as well as special function key pads, have been provided for at the primary keyboard panel. The panel itself is movable through an arc of 30° allowing the operator to adjust the keyboard position to his or her own comfort, and the system task requirements.

C. The primary work panel is a desk top with an alcove in front of the keyboard. The alcove permits the operator to be correctly positioned for keyboard and visual display functions, but was designed principally to support the operator's forearms and wrists during joystick or hand controller operations. The primary work panel can be outfitted with one or two hand controllers on either side of the keyboard panel. What is unique about the primary work panel is that it permits the operator to adjust the attitude of the work surface in a negative attitude with respect to the operator. Unlike flat tables or inclined or sloped panels found on conventional desks, the Reconfigurable Workstation is declined away from the operator permitting full support of the operator's arms during hand movements. This has the effect of physically focusing the operator's attention and movements into the primary work area of the three panels.

D. Secondary control panels are located to the left and right side of the operator alcove within the reach envelope of male and female operators for the 5th to 95th percentile range. The secondary control panels are independent slanted wings attached to the primary work table. They are designed to be removable to permit reconfiguration of the workstation as a function of the mission requirements. The secondary control panel design continues to emphasize the focusing of the operator's attention to the primary work envelope.

E. Secondary display panels are located on two vertical side wings of the workstation and provide an environmental enclosure as well as providing for mounting of infrequently used displays. While controls can also be mounted on these panels, they will be outside of the nominal reach envelope for some operators. For this reason, only appropriately formatted displays should be considered for the secondary display panel.

F. A large screen display is the third of the secondary components. The three-by-four foot television projection display is mounted in front of the workstation itself and provides a view of either of the two primary visual monitors or a third independent display. The workstation operator can easily see over the primary display panel because of its design, and other mission personnel can view the large screen display from a distance and not interfere with the activities and responsibilities of the system operator.

Summary of Reconfigurable Workstation Elements

A. Primary visual panel
B. Primary keyboard panel
C. Primary work panel
D. Secondary control panels
E. Secondary display panels
F. Large screen display

5. Alternate Embodiments

The reconfigurable workstation provides room to mount two visual display units, side-by-side, on the primary visual display panel. When only one VDU is required, the monitor can be mounted in the center of the panel and peripheral displays and controls mounted on the sides of the display. This alternative would be most effective for use as a graphics workstation or a word processing station where an operator would need only one monitor and would be using a disc or tape drive for programming. The physical size of the Reconfigurable Workstation would not change, only the functional arrangements of it would.

6. Advantages of the Reconfigurable Workstation Over Conventional Designs

The advantages of the design are embodied in the fact that it considers the workstation requirements in a systematic framework. The visual, manipulative and spatial requirements are taken as an interactive proposition rather than one at a time. Arm support, for instance, is crucial to the correct sustained performance of tasks involving hand controllers. The most comfortable support position for the forearms is slightly declined from the elbow. Keyboard operations, on the other hand, are most effectively accomplished with the successive rows of keys inclined slightly toward the operator. The Reconfigurable Workstation achieves both of these operational advantages by positively inclining the keyboard with respect to the negative decline of the work panel.

Another advantage of the Reconfigurable Workstation regards the position and orientation of the visual display with respect to the keyboard. Conventional systems place the display behind and up from the keyboard such that the operator must nod his or her head up and down while going from the keyboard to the visual display. The Reconfigurable Workstation places the visual displays beyond the keyboard and in line with the inclination of the keyboard which minimizes the requirement for operator head movement.

Further, the overall workstation physically and perceptually focuses the operator's attention, eyes and hands, into the three primary control and display areas. This will have the effect of reducing operating response times, and decreasing the probability of error since the input devices and operator feedback are collocated. Operator fatigue will be reduced as a function of the arm, wrist and hand support offered and the functional grouping of the primary work areas.

The other significant advantage offered by the Reconfigurable Workstation is that the relative attitudes of the manual and visual work panels are adjustable to accommodate a very wide range of the potential user population.

7. Features Of The Reconfigurable Workstation Which Are Believed To Be New

The unique characteristic of the workstation is that it has a work surface which slopes away from the operator and this slope is adjustable to suit the individual requirements of the operator and the task. This is a radical departure from conventional designs of operator panels which usually slope toward the operator forcing the operator to bend his or her wrists up and constraining the position of the VDU to be above a convenient and comfortable line of sight.

The individual component adjustments available with the Reconfigurable Workstation for the three primary work spaces are also unique features. Like the recently patented tilt head toothbrush and the bent handle hand tools, the Reconfigurable Workstation incorporates the human factors requirements into the engineering design rather than ignoring them or imposing them after the fact. The human factors design was accomplished using system criteria which permitted a design solution to the operator's task problems which is completely different than those specified in conventional design handbooks and guidelines.

8. Contributions Made By Members Of The Design Team

Nicholas Shields, Jr., developed the system requirements for the visual displays, the keyboard and hand controller interactions. He supplied the human factors criteria for the Reconfigurable Workstation and proposed the development of the negatively inclined work surface.

Fred Roe, Jr., developed the operational criteria for the Reconfigurable Workstation including the primary and secondary operations and contributed the large screen display as a means of making the operations data available to a technical group without disturbing the operator.

Mary Frances Fagg contributed to the development of the Reconfigurable Workstation by conducting human engineering analyses to determine hand placement, field-of-view and keyboard placement. Modifications in the overall system were based on the analyses.

David Henderson provided design and development of the secondary control and display panels based on user requirements, operations maintenance and repair requirements, and human factors design criteria.

All members of the development team participated in the mockup design, engineering design, subject testing and evaluation. All members are participating in the development of the operational model.

ESSEX

SIGNATURE PAGE

27 Jan 84

Nicholas Shields, Jr. Date

1-30-84

Fred Roe, Jr. Date

1/30/84

Mary Frances Fagg Date

1-30-84

David Henderson Date

Disclosed to and understood by me this 26th day of January, 1984.

Edwin C. Pruett

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

NEW TECHNOLOGY REPORT

NT CONTROL NO. *(Official use only)*

INSTRUCTIONS

This report form may be used when reporting inventions, discoveries, improvements or innovations to NASA. Use of this report form is optional; provided, however, that whatever report format is used contain the essential information requested herein.

Please provide information requested in each section as follows:

Section I - A description of the problem that motivated the technology development.

Section II - A technically complete and easily understandable description of the new technology that was developed to solve the problem or meet the objective.

Section III - The unique or novel features of the technology and the results (or benefits) of its application.

Section IV - The inclusion or listing of any pertinent additional documentation or references which aid in the understanding or application of the new technology.

In completing each section, use whatever detail deemed appropriate for a "full and complete disclosure," as required by the New Technology or Property Rights in Inventions Clause. For further guidance as to what constitutes a satisfactory report, please refer to NHB 2170.3, Documentation Guidelines for New Technology Reporting.

Available additional documentation which provides a full, detailed description should be attached, as well as any additional explanatory sheets where necessary.

1. TITLE

Reconfigurable workstation for video display units on keyboards

2. INNOVATOR (S) *(Name and Social Security No.)*

1. Nicholas Shields, Jr. [redacted]
2. Fred Roe
3. Mary Frances Fagg [redacted]
4. David Henderson

3. EMPLOYER *(Organization and division)*

Innovators 1, 3, 4 Essex Corporation
Huntsville, AL
Innovator 2 MSFC, Huntsville, AL

4. ADDRESS *(Place of performance)*

3322 S. Memorial Parkway
Huntsville, AL

5. NASA PRIME CONTRACT NO. NAS8-35415

6. CONTRACTOR DISCLOSURE NO. 00461

SECTION I - DESCRIPTION OF THE PROBLEM THAT MOTIVATED THE TECHNOLOGY DEVELOPMENT *(Enter A.-General Description of Problem Objective; B.-Key or Unique Problem Characteristics; C.-Past History/Prior Techniques; D.-Limitations of Prior Techniques)*

Design standards exist for keyboards, for hand controllers and for visual display units. These standards treat each component's operation as separate from any of the others and result in design incompatibilities when the overall system operations are evaluated. Typing keyboards are to be sloped approximately 15^{o} toward the operator and provide palm support; hand controllers are to provide full arm support; video display units (VDU) should be tilted 15-25^{o} up toward the operator.

The conventional workstation configurations result in a VDU which is located too high with respect to the operator's keyboard and a comfortable viewing angle, a keyboard which is too radically tilted toward the operator with regard to hand controller or joystick operations, and a support surface for joystick operations which does not adequately support the operator's arms.

The primary disadvantages of simply stacking VDUs, keyboards or hand controllers on a conventional work place are: human operator fatigue, incompatible eye/hand feedback and excessive head and hand movements which result in decreased productivity by increasing operations time and error rates.

SECTION II - TECHNICALLY CO[illegible] ETE AND EASILY UNDERSTANDABLE DES[illegible] 'TION OF NEW TECHNOLOGY THAT WAS DEVELOPED TO SOLVE THE PROBLEM OR MEET THE OBJECTIVE *(Enter as appropriate A.-Specific description of item; B.-State of development; C.-Operation as a unit; D.-Functional operation; E.-Supportive theory; F.-Engineering specifications; G.-Peripheral equipment; H.-Drawings, graphs, etc.; I.-Parts or ingredients lists; and J.-Maintenance, reliability, safety factors)*

The purpose of the invention is to provide a workstation which incorporates the operational and anthropometric requirements of the human operators while they are performing viewing and keying activities. The workstation is designed to accommodate visual display and feedback, hand controller operations and keyboard tasks as an integrated set of operations for the 5th to the 95th percentile of the operator population.

The Reconfiguration Workstation has three primary and three secondary work surfaces.

A. The primary visual panel provides for two VDUs of up to 19 inches diagonal and their associated controls for brightness contrast and focus. The VDU panel is adjustable in pitch angle to accommodate variability in the operator population as well as individual operator viewing preference for viewing angle. Within the primary visual panel, each VDU can be tilted in toward the operator's focal cone, thereby reducing eye scanning requirements.

B. The primary keyboard panel is designed to accommodate a wide range of keyboard configurations. Keyboards equipped with standard alphanumeric keys, as well as special function key pads, have been provided for at the primary keyboard panel. The panel itself is movable through an arc of 30° allowing the operator to adjust the keyboard position to his or her own comfort, and the system task requirements.

C. The primary work panel is a desk top with an alcove in front of the keyboard. The alcove permits the operator to be correctly positioned for keyboard and visual display functions, but was designed principally to support the operator's forearms and wrists during joystick or hand controller operations. The primary work panel can be outfitted with one or two hand controllers on either side of the keyboard panel. What is unique about the primary work panel is that it permits the operator to adjust the attitude of the work surface in a negative attitude with respect to the operator. Unlike flat tables or inclined or sloped panels found on conventional desks, the Reconfigurable Workstation is declined away from the operator permitting full support of the operator's arms during hand movements. This has the effect of physically focusing the operator's attention and movements into the primary work area of the three panels.

D. Secondary control panels are located to the left and right side of the operator alcove within the reach envelope of male and female operators for the 5th to 95th percentile range. The secondary control panels are independent slanted wings attached to the primary work table. They are designed to be removable to permit reconfiguration of the workstation as a function of the mission requirements. The secondary control panel design continues to emphasize the focusing of the operator's attention to the primary work envelope.

E. Secondary display panels are located on two vertical side wings of the workstation and provide an environmental enclosure as well as providing for mounting of infrequently used displays. While controls can also be mounted on these panels, they will be outside of the nominal reach envelope for some operators. For this reason, only appropriately formatted displays should be considered for the secondary display panel.

F. A large screen display is the third of the secondary components. The three-by-four foot television projection display is mounted in front of the workstation itself and provides a view of either of the two primary visual monitors or a third independent display. The workstation operator can easily see over the primary display panel because of its design, and other mission personnel can view the large screen display from a distance and not interfere with the activities and responsibilities of the system operator.

Summary of Reconfigurable Workstation Elements

A. Primary visual panel
B. Primary keyboard panel
C. Primary work panel
D. Secondary control panels
E. Secondary display panels
F. Large screen display

Alternate Embodiments. The reconfigurable workstation provides room to mount two visual display units, side-by-side, on the primary visual display panel. When only one VDU is required, the monitor can be mounted in the center of the panel and peripheral displays and controls mounted on the sides of the display. This alternative would be most effective for use as a graphics workstation or a word processing station where an operator would need only one monitor and would be using a disc or tape drive for programming. The physical size of the Reconfigurable Workstation would not change, only the functional arrangements of it would.

SECTION III - UNIQUE OR NOVEL FEATURES OF THE TECHNOLOGY AND THE RESULTS (OR BENEFITS) OF ITS APPLICATION *(Enter as appropriate A.-Novel or unique features; B.-Development or conceptual problems; C.-Operating characteristics, test data; D.-Analysis of capabilities; E.-Source of error; and F.-Advantages/shortcomings)*

Further, the overall workstation physically and perceptually focuses the operator's attention, eyes and hands, into the three primary control and display areas. This will have the effect of reducing operating response times, and decreasing the probability of error since the input devices and operator feedback are collocated. Operator fatigue will be reduced as a function of the arm, wrist and hand support offered and the functional grouping of the primary work areas.

The other significant advantage offered by the Reconfigurable Workstation is that the relative attitudes of the manual and visual work panels are adjustable to accommodate a very wide range of the potential user population.

The advantages of the design are embodied in the fact that it would consider the workstation requirements in a systematic framework. The visual, manipulative and spatial requirements are taken as an interactive proposition rather than one at a time. Arm support, for instance, is crucial to the correct sustained performance of tasks involving hand controllers. The most comfortable support position for the forearms is slightly declined from the elbow. Keyboard operations, on the other hand, are most effectively accomplished with the successive rows of keys inclined slightly toward the operator. The Reconfigurable Workstation achieves both of these operational advantages by positively inclining the keyboard with respect to the negative decline of the work panel.

Another advantage of the Reconfigurable Workstation regards the position and orientation of the visual display with respect to the keyboard. Conventional systems place the display behind and up from the keyboard such that the operator must nod his or her head up and down while going from the keyboard to the visual display. The Reconfigurable Workstation places the visual displays beyond the keyboard and in line with the inclination of the keyboard which minimizes the requirement for operator head movement.

The unique characteristic of the workstation is that is has a work surface which slopes away from the operator and this slope is adjustable to suit the individual requirements or the operator and the task. This is a radical departure from conventional designs of operator panels which usually slope toward the operator forcing the operator to bend his or her wrists up and constraining the position of the VDU to be above a convenient and comfortable line of sight.

The individual component adjustments available with the Reconfigurable Workstation for the three primary work spaces are also unique features. Like the recently patented tilt head toothbrush and the bent handle hand tools, the Reconfigurable

SECTION III *(Con.)*

Workstation incorporates the human factors requirements into the engineering design rather than ignoring them or imposing them after the fact. The human factors design was accomplished using system criteria which permitted a design solution to the operator's task problems which is completely different than those specified in conventional design handbooks and guidelines.

SECTION IV - ADDITIONAL DOCUMENTATION *(Include or list below any pertinent documentation which aids in the understanding or application of the new technology. IF NOT TOO BULKY OR DIFFICULT TO REPRODUCE, INCLUDE COPIES WITH THIS REPORT. For those references or additional documentation available but NOT included in this report (due to their being nonessential to a basic understanding of the new technology and which may be costly to reproduce or handle) complete item A. below)*

A. AVAILABLE DOCUMENTS *(Check and complete)*						
	☐	1. PAPERS, ARTICLES	☐	4. ASSEMBLY/MFG. DRAWINGS	☐	7. TEST DATA
	☐	2. CONTRACTOR REPORTS	☐	5. PARTS OR INGRED. LIST	☐	8. ASSEMBLY/MFG. PROCED.
	☐	3. ENGINEERING SPECS.	☐	6. OPERATING MANUALS	☐	9. COMPUTER TAPES/CARDS
	10. OTHER *(Specify)* Developmental photographs - Oct/Nov 83					

B. INDICATE THE DATES OR THE APPROXIMATE TIME PERIOD DURING WHICH THIS TECHNOLOGY WAS DEVELOPED *(i.e., conceived, constructed, tested, etc.)*

a. First disclosure to others 10/83
b. First sketch or drawing 9/83
c. First written description 1/84
d. Completion of first device 10/83

C. LIST THE FIRST PUBLICATION OR PUBLIC DISCLOSURE OF THE NEW TECHNOLOGY, AND DATES

Facility tours by Martin Marietta, USAF, Vought, General Dynamics, European Space Agency (Oct-Dec 83)

D. LIST THE DATES AND ANY PARTICULARLY PERTINENT PAGE NUMBERS OF OTHER PUBLICATIONS WHICH ARE AVAILABLE BUT NOT ATTACHED

E. DEGREE OF TECHNOLOGICAL SIGNIFICANCE *(Check in your best judgment the statement which best expresses the degree of technological significance of this technology)*

☐ 1. MODIFICATION TO EXISTING TECHNOLOGY ☐ 2. SUBSTANTIAL ADVANCE IN THE ART ☐ 3. MAJOR BREAKTHROUGH

COMMENTS

SIGNATURE OF INNOVATOR(S)	DATE

GPO 874-181

6.0 REFERENCES AND ANNOTATED BIBLIOGRAPHY

Beldie, I.P., Pastoor, S. & Schwarz, E. Fixed versus variable letter width for televised text. The Journal of the Human Factors Society, 1983, 25(3), 273-277.

Variable matrix, a character design in which narrow letters (such as "i") occupy less space than wide letters (such as "m"), resulted in improved efficiency on two out of three tasks. This design was recommended for television screens.

Billmayer, H., Rodriguez, R.C., & Wheeler, S.C. Terrain edit system/evaluation matrix processing system (TES/EMPS) human engineering study. Unpublished manuscript, Essex Corporation, 1983.

The authors evaluated two VDT workstations from a human factors engineering standpoint. Their recommended workstation dimensions were: 27 in. to 33 in. (685.8 mm to 838.2 mm) from top of screen to seat; 42 in. to 51 in. (1066.8 mm to 1245.4 mm) from top of screen to floor; 25 in. to 30 in. (635 mm to 762 mm) from floor to table top. The maximum recommended viewing distance was 27.6 in (701 mm) with an optimum distance of 15.8 in. to 19.7 in. (401.32 mm to 500.38 mm). The optimum eye level was found to be even with the top of the screen. The minimum acceptable lighting level at the workstation surface was 540 lx (50 ft/c) and the recommended level was 755 lx (70 ft/c).

Bury, K.F., Boyle, J.M., Evey, R.J., & Neal, A.S. Windowing versus scrolling on a visual display terminal. The Journal of the Human Factors Society, 1982, 24(4), 385,394.

In most cases, subjects in the "window" display groups performed significantly faster and with significantly fewer moves than subjects in the "scroll" display groups.

Cahill, M., & Carter, R.C. Color code size for searching displays of different density. The Journal of the Human Factors Society, 1976, 18(3), 273-280.

Twenty subjects searched for three digit numbers in displays ranging from 10 to 50 items in density and coded in 1 to 10 colors. Search times increased linearly with density and curvilinearly with the number of colors. Adding colors to the display reduced search times until approximately seven colors were used, after which, search times increased.

Carter, R.C. Visual search and color coding. Proceedings of the Human Factors Society - 23rd Annual Meeting, 1979, 369-373.

Search time increased by one order of magnitude when the number of display items in the target's color increased from one to the display density. Items not of target color affected search time only to the extent that their color was similar to target color. Personnel characteristics - ability and experience - were unrelated to search speed.

Chao, B.P., Beaton, R.J., & Snyder, H.L. Evaluation of CRT - displayed digital imagery using subjective scaling. Proceedings of the Human Factors Society - 26th Annual Meeting, 1982, 329-333.

Researchers investigated perceived interpretability of two digital image degradations - blur and noise. Ten scenes, each degraded by five levels of blur (20, 40, 80, 160, and 320 micrometers) and five levels of noise (200, 100, 50, 25 and 12.5 s/n ratio), yielded 250 images displayed on a CRT. As perceived by 15 photointerpreters, the blur, noise, and interaction effects were significant. At the two lowest blur levels and the two highest signal-to-noise ratios there were no differences in interpretability. Otherwise, the reduction in interpretability was more distinct with increased degradation. In non-noise images, the addition of blur decreased interpretability in a linear fashion. With noisy images, the impact of adding blur was lessened.

Christ, R.E. Review and analysis of color coding research for visual displays. The Journal of the Human Factors Society, 1975, 17(6), 542-570.

A review of 42 studies between 1952 and 1973 found that color coding may be a very effective performance factor in some cases and detrimental in others. Color aided both identification and search if the color code was known in advance and unique to the target. A problem occurred when color was used in multidimensional displays; specifically, when colors were added to an achromatic display, the subject's ability to identify achromatic targets decreased.

Crooks, W.H., Freedman, L.A., & Coan, P.P. Television systems for remote manipulation. Proceedings of the Human Factors Society - 19th Annual Meeting, 1975, 428-435.

A two-view monochromatic system was preferred over a black and white monoscopic, a color monoscopic, and a stereoscopic system.

Dainoff, M.J., Happ, A., & Crane, P. Visual fatigue and occupational stress in VDT operators. The Journal of the Human Factors Society, 1981, 23(4), 421-438.

One hundred and twenty-one office workers reported relatively high levels of incidence of eye fatigue symptoms and complaints of glare and lighting. Complaints appeared to be independent of job pressure and hostility to computerization.

Dodson, D.W., & Shields, N.L. Man/terminal interaction evaluation of computer operating system command and control concepts. Proceedings of the Human Factors Society - 22nd Annual Meeting, 1978, 388-392.

No significant differences were found between menu, command key, and multi-display concepts. The authors recommended that some combination of command key and multi-display concepts would provide the best definition for an ECOS command and control service scheme in terms of human-terminal interaction.

Dodson, D.W., & Shields, N.L. Development of display design and command usage guidelines for Spacelab experiment computer applications. Proceedings of the Human Factors Society - 23rd Annual Meeting, 1979, 70-74.

With regard to display density, the researchers found the response times increased rapidly as display density exceeded 60%. No relationship was observed between display density and number of operator errors. Columns that were functionally arranged had lower response times. There was no difference in response times related to the percent of dynamic display parameters.

Emmons, W.H., & Hirsch, R.S. Thirty millimeter keyboards: How good are they? Proceedings of the Human Factors Society - 26th Annual Meeting, 1982, 425-429.

The study compared keyboard heights of 30, 38, and 45 millimeters above a table top 72 centimeters from the floor. Performance on the higher keyboards was significantly superior to the 30 millimeter height. Questionnaire data showed significant operator preference for the higher keyboards.

Grandjean, E., Hunting, W., & Piderman, M. VDT workstation design: Preferred settings and their effects. The Journal of the Human Factors Society, 1983, 25(2), 161-175.

In this field study, 68 subjects employed by four different companies performed their regular jobs using a workstation with an adjustable CRT, keyboard, and chair. Subjects were free to adjust the components at any time during the study. Preferred settings were consistent across the five days of the study. Seat heights ranged from 44 to 54 cm and keyboard heights ranged from 73 to 97 cm. The preferred CRT angles ranged from 88° to 103° with a mean of 94°. Questionnaire data revealed that complaints of tension or impairment of the neck, forearm, shoulders, back, and wrists were much lower in the preferred settings than in a non-adjustable setting.

Habinek, J.K., Jacobson, P.M., Miller, W., & Suther, T.W. A comparison of VDT antireflection treatments. Proceedings of the Human Factors Society - 26th Annual Meeting, 1982, 285-289.

Three antireflection treatments - a micromesh filter, a quarter-wave length thin film, and an etched face plate - did not differ in terms of effectiveness. All were preferred to an untreated screen.

Isensee, S.H., & Bennett, C.A. The perception of flicker and glare on computer CRT displays. The Journal of the Human Factors Society, 1983, 25(2), 177-184.

Results suggested that low to moderate levels of ambient illuminance (approximately 100-260 lx) and moderate levels of video luminance (65 cd/m^2) minimized discomfort due to direct glare, reflected glare, and flicker. Video luminance appeared to be a much greater factor in producing flicker and glare than ambient illuminance. A filter over the face of the CRT was suggested.

Kirkpatrick, M., Shields, N.L., Malone, T.B., & Guerin, E.G. A method and data for video monitor sizing. Proceedings of the 6th Congress of the International Ergonomics Association, 1976, 218-221.

Analytical methods based on operator performance were used to establish monitor size requirements for a particular application. Formulas for determining monitor size as related to viewing distance, target size, distance from target to camera, and field of view width were developed. Authors suggested that because viewing distance is not constant a useful approach is to plot the equations over a range of viewing distances. The researchers stated that larger monitors will not produce improved performance due to resolution limits.

Knowles, W.B., & Wolfeck, J.W. Visual performance with high-contrast Cathod Ray Tubes at high levels of ambient illumination. The Journal of the Human Factors Society, 1972, 14(6), 521-532.

Trace brightness required to perform the visual tasks was primarily a function of the reflectances and resulting background brightness of the CRT faces. Background brightness was determined by the reflectance of the CRT face.

Kolers, P.A., Ducknicky, R.L., & Ferguson, D.C. Eye movement measurement of readability of CRT displays. The Journal of the Human Factors Society, 1981, 23(5), 517-527.

Smaller characters (70 per line as opposed to 35) and static page display were preferred for efficiency of reading.

Kopala, C.J. The use of color-coded symbols in a highly dense situation display. Proceedings of the Human Factors Society - 23rd Annual Meeting, 1979, 397-401.

Redundant color-coding (both color and shape coded) significantly reduced response time and error rate compared to color or shape coding alone.

Miller, W. & Suther, T.W. Display station anthropometrics: Preferred height and angle settings of CRT and keyboard. The Journal of the Human Factors Society, 1983, 25(4), 401-408.

Thirty-seven subjects ranging in anthropometric characteristics from the 5th to the 95th percentiles of the population were placed in a work setting with a CRT, keyboard, and chair. The subjects performed a text input task after adjusting each of the three workstation components to their preferences. A −0.71 correlation between seat height and keyboard angle indicated that the standard fixed keyboard angle of 15° may be inappropriate for operators who prefer low seat heights. Preferred keyboard slopes ranged from 14° to 25° with a mean of 18°. Keyboard heights ranged from 63 to 78 cm and CRT heights ranged from 81 to 104 cm (measured from floor to center of CRT face). The authors suggested that the CRT angle be adjustable from -5° to 20°.

Mourant, R.R., Lakshmanan, R., & Herman, M. Hard copy and cathode ray tube visual performance - Are there differences? Proceedings of the Human Factors Society - 23rd Annual Meeting, 1979, 367-368.

In this study, visual fatigue increased as a function of time as compared to copy. The amount of information processed had an effect on fatigue. The authors found that larger amounts of information processed produced greater visual noise in peripheral vision requiring longer rest periods. Low display contrast was shown to increase fatigue.

Pastoor, S., Schwarz, E., & Beldie, I.P. The relative suitability of four dot-matrix sizes for text presentation on color television screens. The Journal of the Human Factors Society, 1983, 25(3), 265-272.

The authors tested characters with four dot-matrix sizes (5x7, 7x9, 9x13, and 11x15). In all tasks, the smallest size elicited the worst performance. Qualitative performance was equal for all sizes, however, time varied up to 20%. The 9x13 size (9 horizontal rows of 13 dots each), which subtended an angle of 17 minutes of arc, was rated significantly better than the smaller sizes.

Shields, N.L., Kirkpatrick, M., Malone, T.B., & Huggins, C.T. Design parameters for a stereoptic television system based on direct vision depth perception cues. Proceedings of the Human Factors Society - 19th Annual Meeting, 1975, 423-427.

The authors determined parameter requirements for provision of natural and exaggerated stereoptic cues. Parameters were related to the depth cues of convergence and retinal disparity. Range resolution limits based on retinal disparity threshold were specified.

Shields, N., Kirkpatrick, M., & Malone, T.B. Assessment of three CRT stereoptic display concepts. Proceedings of the Human Factors Society - 22nd Annual Meeting, 1978, 87, (Abstract).

A single camera split field system, a dual camera full field system, and a dual sensor full field display projected onto a Fresnel lens were compared. Performance on lab tasks and potential applications were discussed.

Shields, N., Piccione, F., Kirkpatrick, M. & Malone, T.B. Human Operator Performance of Remotely Controlled Tasks: A Summary of Teleoperator Research Conducted at NASA's George C. Marshall Space Flight Center Between 1971 and 1981. Unpublished manuscript, Essex Corporation, 1982.

The authors reported that high contrast, analog signals and adequate signal-to-noise (S/N) separation yield the best recognition of shapes and patterns. Target to background contrast was determined by the following formula: % contrast = $100 \times \frac{(R \text{ of } B) - (R \text{ of } T)}{R \text{ of } B}$; where R = reflectance, B = background, and T = target. Brightness discrimination between two targets was enhanced by contrast values $\geq .25$. For size discrimination between two targets, contrast ratios of .6 should be used. Analog signals were found to enhance visual acuity, brightness discrimination, and character recognition. Character recognition was also improved by high contrast and a 32 dB S/N. The character font recommended was futura demibold with a character height of 30 arc min., character width of 23 arc min., and stroke width of 5.5 arc min. S/N below 15 dB significantly degraded performance while a S/N above 21 dB did not exert a negative influence. Orthogonal monoptic camera pairs yielded good results in judgment of separation of targets. Split field stereoscopic systems yielded less accurate results.

Shute, S.J. & Starr, S.J. Effects of adjustable furniture on VDT users. The Journal of the Human Factors Society, 1984, 26(2), 157-170.

Fifty-seven telephone operators served as subjects in this eight week field study of advanced furniture design for VDT workstations. The advanced work table and chair were characterized by dimensions that were easily adjustable by users in comparison to a conventional table and chair which provided no means of adjustment or inconvenient adjustments that could only be made with difficulty. Four combinations of advanced and traditional components were compared. Although on-the-job discomfort was reduced when either of the traditional components was replaced by an advanced component, the effect was far greater when the advanced chair and table were used in combination. Each adjustment on the advanced workstation was used by at least 70% of the subjects every day. Subjects reported statistically significant reductions in discomfort and intensity of discomfort in 8 out of 15 areas of the body. The authors concluded that because working posture is heavily dependent on the task performed, the ease of adjusting the advanced station was the most influential factor in the obtained results.

Sidorsky, R.C. & Parrish, R.N. Guidelines and criteria for human-computer interface: Design of battlefield automated systems. Proceedings of the Human Factors Society - 24th Annual Meeting, 1980, 98-102.

The authors devised a format for recasting human factors data into a form that makes it more digestible for other members of the design team.

Stammerjohn, L.W., Smith, M.J., & Cohen, B.G.F Evaluation of work station design factors in VDT operations. The Journal of the Human Factors Society, 1981, 23(4), 401-412.

An onsite evaluation at five establishments examined VDT workstation designs and compared them to recommendations in the literature. Design factors evaluated were keyboard height, screen position, illumination, and glare. Ambient illumination of 500-700 lx was found to be acceptable. Problems encountered were excessive keyboard height (75 cm from floor to home keys), screen angle (a 10-20 degree angle was recommended), and reflected glare. The authors recommend that the keyboard be placed at or below elbow height to reduce forearm fatigue. Elbow height varies between the 5th and 95th percentiles from 60.5 cm to 82.0 cm, therefore, the authors recommend a wide range of adjustability in workstation designs.

Suther, T.W., & McTyre, J.H. Effect on operator performance of thin profile keyboard slopes of 5°, 10°, 15°, and 25°. Proceedings of the Human Factors Society - 26th Annual Meeting, 1982, 430-434.

An IBM Datamaster (System 123) keyboard was set at a 5°, 10°, 15°, and 25° angle on a table top 685.8 mm from the floor. Sixteen experienced subjects typed in each of the four conditions. No significant differences were found in performance. Subjects reported that the keyboard was uncomfortable at 5° and 25° and that they noticed no difference between 10° and 15°. The authors recommended a setting of 10°-18°.

Tullis, T.S. Human performance evaluation of graphic and textual CRT displays of diagnostic data. Proceedings of the Human Factors Society - 24th Annual Meeting, 1980, 310-316.

Four CRT display formats - narrative text, structured text, black and white graphics, and color graphics - were evaluated with respect to speed and accuracy of response. Accuracy did not vary with display. Initially, response to graphic formats was faster. With additional practice, response to textual formats was just as fast as response to graphics.

Tullis, T.S. An evaluation of alphanumeric, graphic, and color information displays. The Journal of the Human Factors Society, 1981, 23(5), 541-550.

Speed and accuracy of subjects interpreting alphanumeric, graphic, and color coded displays were measured. Accuracy did not vary with format. Response time for graphic formats was consistently shorter than for the narrative format. No significant difference was found in response times for black and white versus color graphics.