

## General Disclaimer

### One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.
- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.
- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.
- This document is paginated as submitted by the original source.
- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

(NASA-TM-84943) HUMAN FACTORS ANALYSIS OF  
WORKSTATION DESIGN: EARTH RADIATION BUDGET  
SATELLITE MISSION OPERATIONS ROOM (NASA)  
85 p HC A05/MF A01

N83-19478

CSCL 05H

G3/54

Unclas  
08904



## Technical Memorandum 84943

# HUMAN FACTORS ANALYSIS OF WORKSTATION DESIGN: EARTH RADIATION BUDGET SATELLITE MISSION OPERATIONS ROOM

Lisa J. Stewart, Elizabeth D. Murphy,  
Christine M. Mitchell

DECEMBER 1982

National Aeronautics and  
Space Administration

Goddard Space Flight Center  
Greenbelt, Maryland 20771



TM 84943

HUMAN FACTORS ANALYSIS OF WORKSTATION DESIGN

EARTH RADIATION  
BUDGET SATELLITE  
MISSION OPERATIONS ROOM

Lisa J. Stewart  
Elizabeth D. Murphy  
Christine M. Mitchell

Decision Sciences Faculty  
George Mason University  
Fairfax, Virginia

December 1982

GODDARD SPACE FLIGHT CENTER  
Greenbelt, Maryland

# CONTENTS

	<u>Page</u>
INTRODUCTION . . . . .	1
WORKSTATION DESIGN PRINCIPLES . . . . .	5
Physical Layout . . . . .	6
Environmental Issues . . . . .	7
Component Arrangement . . . . .	13
Framework for ERBS MOR Analysis . . . . .	13
GENERAL METHOD: A PROPOSAL FOR HUMAN FACTORS ANALYSIS OF MOR DESIGN . . . . .	15
Initial Phase . . . . .	15
Goals and Criteria . . . . .	15
Research Questions . . . . .	16
Applied Analysis . . . . .	16
Design Development and Review . . . . .	18
CASE STUDY . . . . .	19
Design Review . . . . .	19
Human Factors Rationale . . . . .	19
Statement of Working Assumptions . . . . .	21
Goals and Criteria . . . . .	22
Horseshoe Design . . . . .	24

PRECEDING PAGE BLANK NOT FILMED

	<u>Page</u>
Benefits/Limitations Analysis . . . . .	25
Design Evolution . . . . .	31
Ideal Design . . . . .	37
Environmental Issues . . . . .	37
Component Arrangement . . . . .	39
DISCUSSION . . . . .	49
Timing . . . . .	49
Areas of Ambiguity . . . . .	50
Analytical Process . . . . .	52
Climate of Co-operation . . . . .	53
Systems Approach . . . . .	54
Reflections on Success . . . . .	55
SUMMARY AND FUTURE APPLICATIONS . . . . .	59
ERBS MOR Workstation Design . . . . .	59
Integration of Human Factors Analysis . . . . .	59
On-going Attention to Human Factors . . . . .	60
REFERENCES . . . . .	63
APPENDICES . . . . .	65

## LIST OF FIGURES

<u>Figure</u>		<u>Page</u>
1	Original proposed MOR layout and component arrangement . . . . .	20
2	MOR layout: Design II . . . . .	26
3	MOR layout: Design IIA . . . . .	27
4	MOR layout: Design IIB . . . . .	28
5	MOR layout: Design III . . . . .	33
6	MOR layout: Design IV . . . . .	35
7	MOR layout: Ideal design . . . . .	36
8	Component arrangement: Original spacecraft support cluster, units 6-13. . . . .	41
9	Component arrangement: Recommended changes, units 6-13. . . . .	41
10	Component arrangement: Original shift analyst cluster, units 14-19. . . . .	42
11	Component arrangement: Recommended changes, units 14-19. . . . .	43
12	Component arrangement: Recommended changes for Design IV, units 6-9. . . . .	44
13	Component arrangement: Recommended changes for Design IV, units 10-12. . . . .	45
14	Component arrangement: Recommended changes for Design IV, units 20-22. . . . .	46

LIST OF TABLES

<u>Table</u>		<u>Page</u>
1	Recommended illumination levels in footcandles . . . . .	11
2	Evolving designs ranked on human factors and other criteria . . . . .	56

PRECEDING PAGE BLANK NOT FILMED

LIST OF APPENDICES

<u>Appendix</u>	<u>Page</u>
A Status Report on ERBS Human Factors Analysis . . . . .	67
B ERBS MOR Workstation Design, Presented on September 24, 1982 . . . . .	69
C Benefits/Limitations Analysis, Design III . . . . .	73
D Benefits/Limitations Analysis, Design IV . . . . .	75
E Benefits/Limitations Analysis, Ideal Design . . . . .	77
F Environmental Issues, Benefits Analysis . . . . .	79
G Chronology of Command-Control Observations and Analysis of ERBS MOR Workstation Design . . . . .	83

PRECEDING PAGE BLANK NOT FILMED



## ACKNOWLEDGEMENTS

We would like to express our appreciation to three groups of operations personnel at Goddard whose time, patience and assistance was invaluable in conducting this analysis: the Data Operations Control (DOC) shift-team supervised by Jim Clark; the DE-A Mission Operations Room (MOR) shift-team supervised by Ray Boyle; and Gary Vincent (Code 565) and J. D. Rhodes (RCA Corporation). Their knowledge and helpful suggestions greatly contributed to our understanding of operations at Goddard.

We would also like to thank Karen Moe (Code 502), Bill Worrall (Code 406), Mike Fatig (Code 406/Bendix), and Paula Van Balen (George Mason University) for their helpful suggestions, sharing of knowledge, and encouragement.

Last, but not least, we thank Teresa Duron for typing the final report.

Lisa J. Stewart  
Elizabeth D. Murphy  
Christine M. Mitchell

PRECEDING PAGE BLANK NOT FILMED

## INTRODUCTION

This document is the final report on the human factors analysis of workstation design for the Earth Radiation Budget Satellite Mission Operation Room (ERBS MOR). It summarizes the background, process, and results of the analysis conducted by George Mason University (GMU).

The human factors analysis addressed three related yet distinct issues within the area of workstation design. The first issue, physical layout of the MOR, received the most intensive effort because it was a Goddard priority. It involved the positioning of clusters of equipment within the physical dimensions of the ERBS MOR. The second issue for analysis was comprised of several environmental concerns, e.g., lighting, furniture, and heating and ventilation systems. The third issue was component arrangement, involving the physical arrangement of individual components within clusters of consoles, e.g., a communications panel adjacent to a KCRT. Thus, when used in this report, the phrase workstation design refers to these three issues.

What follows in this document is more than a series of recommendations pertaining to these three issues. The rigorous application of human factors to a project had never before been attempted at Goddard. Human factors analysis of the ERBS MOR workstation design was the initial attempt to conduct a demonstration scenario of the benefits gained by incorporating human factors into Goddard systems and projects. Accordingly, the going was rough because resistance to change and the unknown is characteristic of both humans and organizations. However, the very nature of Goddard's mission, that of space-age exploration and experimentation, requires forward-looking approaches and philosophies. Goddard has demonstrated its willingness to maintain a future-oriented organization by making a major commitment to the implementation of

human factors recommendations. Therefore, this first step in a year long demonstration involved several procedural as well as applications-related considerations. This report details all of these considerations as a means of developing and setting precedents for future human factors work at Goddard. A strong human factors perspective is utilized throughout this report to increase recognition that the human component of a system is as important as the hardware and software components. An integrated approach to workstation design balances the varied perspectives of systems engineering, human factors, and management.

The section immediately following this introduction contains a summary of human factors workstation design principles. These guidelines, culled from an extensive literature survey conducted by GMU, represent the findings of the most recent available research on workstation design. Several of the sources are guideline documents used by agencies such as the United States Nuclear Regulatory Commission and the Department of Defense. Guidelines specifically pertaining to command and control room environments are also included (Mitchell, Stewart, Bocast, & Murphy, 1982). The human factors analysts used these guidelines as a framework throughout the ERBS MOR design analysis. The summary of these principles also provides a useful context for the reader unfamiliar with human factors as a discipline.

A general method or procedure for workstation design analysis is proposed within the next section of this document. It outlines a generic human factors approach that can and should be applied to future planning and evaluation of designs for command and control environments. This approach could not always be taken by the ERBS MOR human factors analysts due to several constraints, the most severe being time. However, it was followed as closely as possible in an attempt to make the analysis a rigorous one.

Procedures actually followed in the ERBS MOR workstation design analysis are

described in the case study section of the document. All meetings, materials, and actions taken are covered in this section, along with the actual method or approach devised in response to the constraints. Several iterations of the physical layout, depicted in drawings, are included as Figures 1 through 7.

Following the case study is a discussion section that elaborates on the actual-versus-proposed process for conducting an MOR workstation design analysis. It identifies the problems faced by the human factors analysts in their attempts to provide a balanced assessment and to work within the given constraints on the ERBS project. The success of the analysis is also reflected upon.

The remainder of the report summarizes the human factors approach to ERBS MOR workstation design and makes suggestions for future applied human factors analysis at Goddard. A series of appendices provides supplementary documentation of the process described in the text.

## WORKSTATION DESIGN PRINCIPLES

A significant amount of experimental research has been conducted on workstation design, resulting in extensive guidelines that are utilized by human factors analysts to evaluate proposed designs and to suggest new ones. For purposes of this report, only a summary of these guidelines will be presented, specifically those pertaining to the three areas addressed by the GMU human factors analysis: physical layout, environmental issues, and component arrangement. An expanded version of these guidelines can be found in Mitchell et al. (1982), the base from which the ERBS MOR workstation design analysis was conducted.

Before starting any design effort, workstation planners must have a good grasp of three areas: existing documentation, hardware, and the user population. All existing, pertinent documentation should be reviewed. A complete understanding of the task at hand will necessarily make the resulting workstation more effective. Documentation reviews help provide that complete understanding. The capabilities and limitations of the proposed hardware should be examined. Many pieces of equipment are task-required (e.g., VDTs for monitoring tasks), and the designer must complement these pieces with a choice of other equipment that provides an integrated workstation. Workstation designers must also consider the user. Workstations must be designed so that humans can use them and use them effectively. Anthropometric data should be acquired and later used for the physical design. The designer should also have a knowledge of human visual and auditory capabilities and incorporate these considerations into the workstation. From a human factors perspective, understanding the user population, and its ramifications for workstation design, is a priority (Bailey, 1982; LeCocq, 1982).

PRECEDING PAGE BLANK NOT FILMED

Physical layout. The emphasis of the ERBS MOR workstation design analysis was on physical layout. The human factors analysis adhered to several general principles in assessing tradeoffs:

- o **Accessibility**—All equipment, displays, and controls should be easily accessible. Maintenance access should also be provided.
- o **Coverage**—Layout of equipment should facilitate and be consistent with staffing levels.
- o **Furniture and equipment**—Ease and efficiency of use should be facilitated by the furniture and equipment layout.

Specific guidelines pertaining to furniture and equipment layout include:

- o **Visual access**—Workers should have an unimpeded view of all critical task components and not have to strain physically to see them. Size and distance considerations of displays are thus implied.
- o **Communication access**—Workers should be able to communicate easily with others in the workstation. Physical barriers to communication, as well as excess noise, should be avoided.
- o **Circulation**—Traffic and communication flow should be facilitated. Both physical and verbal interference between users should be avoided.
- o **Maneuvering space**—Users should have adequate space for moving in and out of their workstation. It is recommended that there be a 36-inch minimum between the back of the workstation and any opposing surface; a lateral space of at least 30 inches; a minimum of 50 inches separating the front edge of the equipment and any opposing surface when one person attends the equipment; and a minimum of 8 feet between two opposing rows of equipment when two or more individuals are present.

The physical layout includes peripheral concerns such as documentation storage and access. Necessary documents should be stored where they are easily reached by personnel, clearly labeled, movable, and easy to use. Documents should be of a standard

size, bound so as to lie flat when opened, and in good condition. Another important peripheral issue is provision of access for supervisory and other personnel. It is necessary for the supervisor to have direct access to the workstation. Access for non-task related personnel should be provided but only to the extent necessary. Potentially bothersome noise and activity should be discouraged by limiting unnecessary access to the workstation.

Environmental issues. Several workstation components can be considered within the realm of environmental issues, e.g., seating, lighting, and acoustics. The human factors analysis identified these components together with associated flexibilities and limitations, and recommendations were made based upon the following guidelines. A consideration of the environmental issues ensures optimal working conditions and achieves several goals as suggested by Bailey (1982). Performance and organizational images can be enhanced by creating optimal workstation environments. Comfortable environments can be maintained, and user task learning can be facilitated. All these benefits result from a thorough consideration of the workstation environment during the design phase.

The ERBS MOR requires seated operations. This position is best suited for the requisite task because research shows that the seated position is superior to a standing one in terms of fatigue. It appears that the arms can perform light work much longer when the worker is seated than when he/she is standing. Console dimensions for the seated operator are based on several considerations:

- o If the operator needs to see over the workstation console, the maximum height to accommodate the shortest user is 45 inches.
- o Control height should be within the functional reach of the fifth and ninety-fifth percentile user; a range of 8-34 inches above the sitting surface is suggested.

- o Controls should be set back from the console edge a minimum of 3 inches, to prevent accidental activation and not further than 25 inches, ensuring reach by the 5th percentile user.
- o Acceptable display height is between 6 and 46 inches above the sitting surface.
- o The optimal distance for viewing displays, especially VDT displays, is 13-20 inches.
- o The console controls should be laterally spread within the functional reach of the operator, between 25 and 35 inches.
- o When writing surfaces are required for the console, it is recommended that they be a minimum of 16 inches deep, 24 inches wide, and 29-31 inches above the floor.

The seated operator needs sufficient leg and foot space and comfortable seating. The chair should be designed to complement the task and the user's needs. If the operator is comfortably seated, chance for fatigue and stress is reduced. The likelihood of error due to awkward, uncomfortable positioning is also reduced. Seating guidelines include these recommendations:

- o The space needed for knee room should be a minimum of 18 inches deep.
- o The distance for knee clearance between the seat and table should be a minimum of 8 inches.
- o Footrests for short users should be provided, and if a console that extends to the floor is being used, a kickspace 4 inches high and 4 inches deep should be provided.
- o The chair should provide mobility for the operator; it should swivel and have casters.
- o Because the optimum angle between chair seat and back for seated tasks is 100 degrees, chairs should have adjustable backrests. It is further recommended that the seat bottom be adjustable to heights between 15 and 18 inches from the floor.



- o The seat and backrest should have at least 1 inch of cushioning.
- o When the operator's task is data entry, arm rests should not be used; when the task such as monitoring does not require constant arm movements, arm rests should be provided.
- o Operators should be made aware of the adjustable features of their equipment and how to use them.

Comfortable temperature levels can be and should be maintained within the ERBS MOR. Important recommendations regarding work-environment temperatures include the following:

- o The heating levels should not fall below 65 degrees F.
- o The air conditioning levels should not exceed 85 degrees F.
- o Cold or hot air should not discharge directly onto personnel.
- o Temperatures at floor level and at head level should not differ by more than 10 degrees F.

The air quality within the workstation must also be maintained. Health and safety needs must be met under all circumstances. Provision should be made for worker comfort, reducing the chance for fatigue and stress, and ensuring benefits to performance. Regarding humidity levels it is recommended that:

- o Relative humidity levels should range from 45% to 50% when the temperature is 70 degrees F.
- o As temperatures rise, humidity levels should decrease relatively. However, to ensure physical comfort, they should not fall below 15%.
- o Humidity levels should not vary greatly over shifts.

The ventilation system maintains the air quality and several minimum guidelines are suggested:

- o A minimum of 30 cubic feet of air per minute, per person, should be introduced to the work area.
- o The intakes for ventilation systems should not be located near contaminated air sources (e.g., exhaust pipes).
- o Air velocities should not exceed 45 feet per minute measured from head level.
- o Noticeable drafts should not be present.

A major workstation component affecting the environment is the illumination system. Workers must have adequate lighting to best perform their tasks. It appears that illumination levels are task dependent, as illustrated by Table 1, implying the need for availability of adjustable overall illumination levels. However, the level of illumination at individual stations in the work area should not vary greatly, in order to reduce worker eyestrain, fatigue and reading errors. Easily available supplemental lighting can help provide the level of illumination necessary for the task and consistent illumination at the work area. An illumination-related problem especially evident in work areas using video display terminal (VDTs) is glare. Glare increases the possibility for reading errors and encourages eyestrain. Therefore, designers should seek to eliminate both direct glare, i.e., glare due to actual light sources, and reflected glare, i.e., glare from illuminated surfaces. This can be achieved through the use of indirect or diffuse lighting, the elimination of distracting contrasts in the work area, adjustment of the angle of the VDT screen, and covering the VDT screen with a glare reducing filter.

The acoustical environment of a workstation also deserves attention during the design phase. Noise can be detrimental to the worker's performance, irritating, fatiguing, and unsafe if loud enough. Some reports, however, indicate that a complete

ORIGINAL PAGE IS  
OF POOR QUALITY

RECOMMENDED ILLUMINATION LEVELS IN FOOT CANDLES

Work Area or Type of Task	Task Illuminance, footcandles		
	Mini- mum	Recom- mended	Maxi- mum
Panels, primary operating area	20	30	50
Auxiliary panels	20	30	50
Scale indicator reading	20	30	50
Control operator stations	50	75	100
Reading:			
• Handwritten (pencil)	50	75	100
• Printed or typed	20	30	50
Writing and data recording	50	75	100
Maintenance and wiring areas	20	30	50
Emergency operating lighting	10	As above for area/task	

(Source: Illuminating Engineering Society of North America,  
*IES Lighting Handbook*, 1981 Application Volumes.)

Illumination levels.

Table 1: NUREG-0700, p. 6.1-46, 1981.

absence of noise can be detrimental to worker performance (Bailey, 1982). Acceptable levels of background noise for effective communication are dependent upon the speaking voice being used and the distance between speaker and listener. It is recommended that:

- o Background noise levels should not exceed 65 decibels.
- o Noise distractions should be minimized.
- o Acoustical materials should be used to limit reverberation time to one second or less.

Related to the acoustical environment is the need for adequate communication systems. The system most necessary in the ERBS MOR is a telephone system, providing both internal and external lines. The lines should have a standard frequency bandpass of 200-3300 Hz to ensure intelligibility. The system should be easily accessible to all positions within the workstation and provide adequate coverage. Handset telephones should be easy to use, have cords of sufficient length that do not tangle, and have clearly labeled switching mechanisms. The distinction between internal and external lines should be clear; labeling, color coding, and spatial grouping help achieve this. Headset telephones should be lightweight and comfortable. Adequate storage space should be provided for headsets.

An often neglected environmental issue is workstation ambience. The ambience of a work area affects the psychological state of the worker and, in turn, influences his/her performance (Seminara, Gonzalez, & Parsons, 1977). Other indirect determinants of job performance, such as job satisfaction, morale, and motivation, are affected by the environmental ambience. Thus, the following recommendations are made:

- o The surrounding atmosphere should be visually pleasing; colors should be coordinated and cheerful, and visual relief from banks of instrumentation should be provided.
- o The environment should look and smell clean.

- o The user's needs and comfort should be provided for, e.g., restroom and eating facilities are necessary.

Component arrangement. The third area addressed in the GMU human factors analysis was arrangement of individual components within console clusters. Several human factors principles for arrangement exist and those pertinent to the ERBS MOR include arrangement by function and by importance. (NUREG-0700, 1981).

The most common arrangement found in practice is a functional one. All elements that are used to perform a function are grouped together. It is the preferred arrangement when there are no consistent sequences of operations, because it allows for quick and accurate location of the components needed for any function. An order of importance arrangement places the components that are most important to operations within the operator's optimal visual and reach distance.

Framework for ERBS MOR Analysis. Workstation design principles do not offer answers for every situation. Many areas have yet to be researched and many workstation-specific considerations necessitate tradeoffs when applying the existing guidelines. However, the principles do provide a framework within which human factors criteria can be developed. These principles were invaluable in providing a basis for conducting the ERBS MOR workstation design analysis. For example, human factors criteria for component arrangement, discussed on page 45, were defined with reference to guidelines in the literature. Inclusion of these principles in this report is intended to provide a conceptual context for the reader.

## GENERAL METHOD: A PROPOSAL FOR HUMAN FACTORS ANALYSIS OF MOR DESIGN

Initial Phase. Human factors analysts need to attain a reasonable level of familiarity with a particular project before beginning an analysis of its workstation design. Although it is not necessary to learn operators' jobs in detail, it is necessary to reach a conceptual understanding of what the system is designed to do and why each operator performs various tasks before, during, and after a pass. Accordingly, available documentation should be reviewed carefully. On-site observation in the command and control rooms is essential, giving analysts an opportunity to observe operations, ask questions, and discuss any relevant issues with operational and supervisory personnel. A minimum of four sessions lasting four to five hours each should be spent in control environments at Goddard. It is a good idea to observe the same shift on two consecutive days to gain a sense of continuity and a basic understanding of the group dynamics which must be considered in designing multiperson MORS.

Goals and Criteria. Given a conceptual grasp of the system, a discussion of goals and criteria for achieving those goals is required. All decision-makers who will have an impact on the final design should be included in this discussion to provide each other and the human factors analysts with an understanding of the various, often conflicting, criteria which explicitly or implicitly guide design choices. Discussion should address the following questions:

- o What are the purposes or goals of the system as a whole?
- o What functions must be performed within the room under consideration?
- o How can workstation design contribute to the achievement of system goals?

PRECEDING PAGE BLANK NOT FILMED

PAGE 14 INTENTIONALLY LEFT BLANK

Following such a discussion and, ideally, a ranking of human factors and other criteria, various questions about operator performance need to be addressed.

Research Questions. Before any effort is made to position the physical components of a control room, arrange units within console clusters, or make recommendations on other environmental variables, research questions requiring investigation are as follows:

- o How is performance affected by the number of operators on duty and by their location in relation to the equipment?
- o What tasks and sequences of tasks are required of each operator; and how, if at all, do these sequences depend on each other?
- o How much person-to-person communication, both formal and informal, is required under routine and anomalous conditions?
- o To what extent is it necessary and/or desirable for all operators to have visual and physical access to all display screens?
- o How much movement within and through the MOR is necessary for efficient and effective job performance?
- o What is the frequency of use of the various types of documentation stored in the MOR?
- o How is performance affected by different levels of the various environmental variables, e.g., glare, noise, and temperature?
- o How do different component arrangements affect operator fatigue, job satisfaction, and job performance?

The caveat to researchers is, of course, that any experimentation based on these or other research questions must be preceded by operational or measurable definitions of such terms as "effective and efficient" and by appropriate choice of criterion measures.

Applied Analysis. Particular research questions can be investigated by means of such human factors tools as task analysis, link analysis, and simulation. Task analysis and

link analysis are essentially techniques designed to quantify behavioral actions and to describe the temporal sequencing and interrelationships of job-related activities. Details of methodology for task and link analysis can be found in Mitchell, et al. (1982) and in McCormick and Sanders (1982). Task analysis is recommended as the first step in any analysis of overall workstation design (Williams, 1982). The estimated time-to-completion for task and link analysis is three months of full-time effort by one human factors analyst, as suggested by Moe and Weger (1982).

A particularly useful technique involves the evaluation of different workstations using empirically tested mockups to determine which design best contributes to the achievement of the ranked criteria. In a typical empirical test, for example, several groups of operators control a simulated system using simulated and/or recorded data in several mocked-up environments, under both normal and emergency conditions. Measures such as time-to-completion, error rates, levels of human stress, and operator job satisfaction are used to determine the significance of workstation design parameters (Caldir, Hart, & Stewart, 1980; MIL-STD-1472C, 1981; Mitchell, et al., 1982; NUREG-0700, 1981). Computer simulation techniques, as described by Jones, Jonsen, and Van (1982), allow the comparison of "many alternative designs across a variety of operating conditions at minimal expense" (p. 40). Performance of such analyses can be envisioned as an appropriate function for the Goddard Human Engineering Laboratory.

Another potentially beneficial technique is the use of a survey of current operations room personnel to identify any patterns of preference among operators in such areas as physical layout, arrangement of components within consoles, lighting, acoustics, and temperature. Operators might also be asked to comment on the various proposed designs. Results from such surveys would provide a valuable perspective on day-to-day spacecraft operations, one that is not always apparent in technical documents or in



administrative materials and briefings.

Design Development and Review. Results from the task analysis, link analysis, simulation experiments, and operator surveys, as well as existing recommendations and guidelines in the literature, contribute to the development of a design that fulfills human factors criteria to the extent possible within the constraints. Before agreeing on a final design, however, decision-makers are likely to suggest and consider several possible alternative designs. During this process of design evolution, the human factors analysis should include an assessment of the benefits and limitations of each design in relation to human factors criteria. The final design should not satisfy one set of criteria, e.g., standards for hardware, to the serious detriment of another set, e.g., requirements for optimal human performance. Of necessity, the final design will be a compromise for each perspective represented among decision-makers, but it can and should be a balanced compromise which makes the hardware, software, and human components as compatible as possible.

## CASE STUDY

Design Review. GMU's participation in workstation design for ERBS began with attendance at an informal working review meeting which included the presentation of a proposed physical layout for the ERBS MOR and arrangement of components within the console clusters (e.g., Figures 8 and 10). After the presentation, the group inspected the rooms where the MOR will be located, and the GMU team was asked for a human factors evaluation. During the discussion which followed, some areas of flexibility and constraint became apparent.

As documented in the Status Report on ERBS Human Factors Analysis (Appendix A), it was assumed that the physical layout could be rearranged within the limits of existing cabling. Other areas open to enhancement included lighting, acoustics, temperature and ventilation, furnishings and equipment, communications, and keyboards. It was suggested, for example that the addition of plexiglass covers would prevent accidental activation of existing keyboards. Design constraints identified at this meeting included the fact that KCRTs and monitors will be rack-mounted, a severe limitation violating the conventional guidelines which recommend that VDT screens should be horizontally and vertically adjustable or have a vertical angle of 90 degrees if fixed (Mitchell, et al., 1982). Due to available cable length and requirements for maintenance, the color printer must be kept within 25 feet of the IDT graphics terminal (Figure 1, unit 16), and a minimum of three feet must be allocated for access behind console racks.

Human Factors Rationale. In discussions of the status report with the ERBS Mission Operations Manager, GMU analysts provided an underlying rationale and specific justifications for considering modifications in each of the areas where some flexibility

ERBS MOR

ORIGINAL PAGE IS  
OF POOR QUALITY

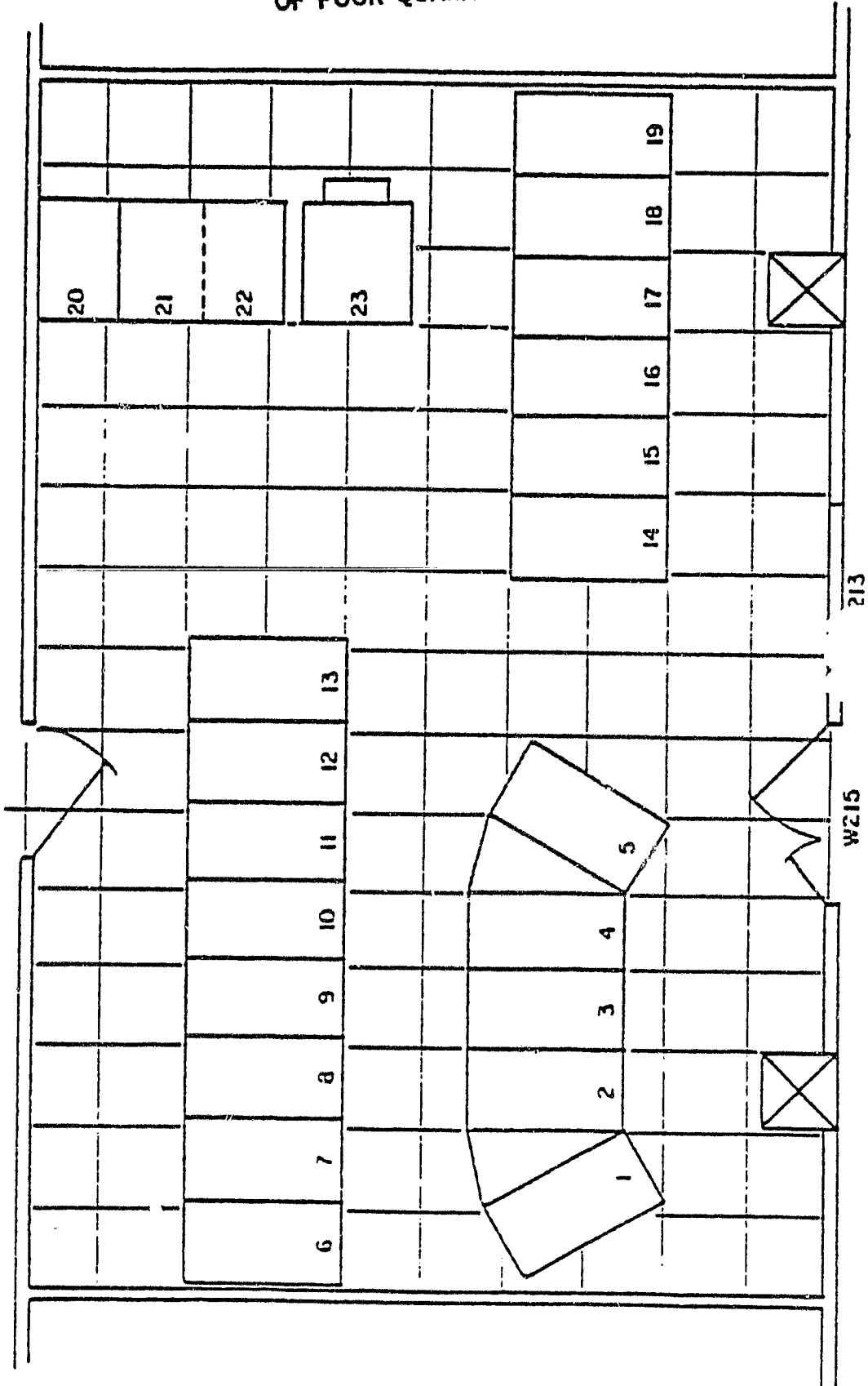


Figure 1. Original proposed MOR layout and component arrangement

seemed possible. The rationale stated that the essential purpose of a human factors effort on any project is to contribute to the achievement of system goals by doing whatever is possible to minimize error. Where large amounts of time and money are being spent on the development and testing of hardware and software, it seems sensible and prudent to consider the human component, to humanize the environment in order to enhance performance. For example, if person-to-person interaction is required for effective and efficient performance, then the workstation design should facilitate, rather than hinder, human communication. If control over lighting and temperature levels contributes to better morale and greater job satisfaction, thereby enhancing job performance, then some provision should be made to allow operators to control these variables.

Statement of Working Assumptions. Ideally, demonstration of requirements for person-to-person interaction and environmental control is made by task and link analysis and by simulation under varying levels of operator-controlled variables. However, due to time constraints and technical considerations, it was not possible to conduct a task analysis or link analysis of ERBS MOR operations. For the same reasons, experiments using mockups of different physical layouts, arrangements of components, and controllable vs. non-controllable environments could not be performed. In the absence of any formal discussion of criteria and lacking results from such analyses, an explicit statement of system goals and human factors criteria for workstation design was developed on the basis of the literature on control room design, observations in current command and control rooms, and conversations with personnel involved in spacecraft operations and ERBS development (Appendix B). Review of existing technical documents on ERBS was helpful in providing a conceptual overview of the project, but it did not contribute significantly to workstation design because available documents do not include

behavioral descriptions of operations requiring human interaction.

Goals and Criteria. As documented in Appendix B, the working assumptions of this analysis included two interrelated concepts about system goals: Any satellite support system exists to maintain the health and safety of the spacecraft; a second goal is optimization of the data-collecting process. The design of the workstation will best contribute to achievement of these goals if it fulfills basic human factors criteria such as ease of human interaction, ease of human-machine interaction, ease of traffic flow within and through the MOR, and ease of maintenance. Each of these human factors criteria is directly related to reduction of error, the key to successful spacecraft operations.

The need for person-to-person communication or human interaction was apparent in the control rooms where operations were observed and human factors issues were discussed with MOR staff.<sup>1</sup> Even under normal or routine conditions, voice communication and visual contact between operators are essential for task performance. Under anomalous or emergency conditions, the need for such interaction becomes even more intense. For example, during one observation of spacecraft contact, data was not being received from a ground station. To communicate visually and verbally, the command operator had to twist in his chair and raise his voice, while the support operator had to stand and lean forward over his console rack. Discussion and planning for various contingencies took place, and the anomaly was dealt with satisfactorily; but it appeared that the job got done in spite of the physical layout of the

---

<sup>1</sup>These observations occurred during 17 total site visits in the Data Operations Control (DOC) at Goddard, the Solar Mesosphere Explorer (SME) facility at the University of Colorado, Boulder, and the Dynamics Explorer Mission Operations Rooms (DE MORs) at Goddard. Two analysts devoted approximately 56 hours to these sessions.

room, that workstation design did nothing to facilitate the required interactions. Rather, the layout worked against efficient performance. This observation, then, supports the rationale for ease of human interaction as a criterion of workstation design: Relative ease of voice and sight communication, especially in the case of an anomaly or emergency, will facilitate performance. Additional support for this position can be found in Bailey (1982) and in Mitchell et al. (1982).

Similarly, the three remaining human factors criteria and their underlying rationales are recommended and supported in the literature on control room design. Performance will benefit, for example, if the design provides for ease of human-machine interaction, if operators can view all displays with relative ease and have rapid access to all units (Bailey, 1982; Mitchell et al., 1982; NUREG-0700, 1981). Timely performance and safety will be enhanced if the design provides for ease of traffic flow within and through the MOR; direct and short routes will decrease the likelihood of fatigue, frustration, and lengthy human response times (NUREG-0700, 1981). To provide for the system's maintainability and to minimize potential interruptions of regular operations, ease of maintenance must be provided by the design (MIL-STD-1472C, 1981).

An additional human factors criterion, ease of access to documentation, was considered in assessing the benefits and limitations of each of the alternative ERBS MOR designs. Clearly, operators need quick, unhampered access to documentation if they must consult a manual or computer print-out during a spacecraft contact; however, this criterion should not constrain the design to the extent that access to documentation dictates the placement of physical components. Alternative approaches to documentation storage include use of console-top space in cases where visibility over racks is not required.

Other criteria included ease of working within the limited range of existing cabling,

provision of an unobstructed view into the MOR from the hall windows, and retention of a standard MOR layout in which physical components are arranged in parallel rows with operators separated from each other by equipment racks. Although these are not human factors criteria per se, they were included in the benefits/limitations analyses in order to provide as complete an evaluation as possible of the original design and the alternatives. The intention was to include as many criteria as could be identified in the absence of any explicit discussion of criteria or standards for MOR workstation design. The non-human factors criteria were implied by the proposed design (Figure 1) and by discussions with ERBS-development personnel.

Horseshoe Design. In addition to outlining system goals and human factors criteria for workstation design, the statement of working assumptions (Appendix B) recommended a U-shaped or horseshoe design as a standard against which to evaluate proposed designs. This design is suggested for command and control rooms, particularly those located in nuclear power plants, by McCormick and Sanders (1982), NUREG-0700 (1981), and Seminara and Parsons (1979). The validity of generalizing the suitability of this design to satellite command and control rooms remains to be demonstrated by further research; however, it appears that this design would allow for more than satisfactory achievement of the four basic human factors criteria: ease of human interaction, ease of human-machine interaction, ease of traffic flow, and ease of maintenance. An additional benefit of this design is that it would promote cross-training of MOR personnel to a greater degree than would the standard layout. Operations personnel at Goddard who have worked in horseshoe-shaped environments spoke very favorably about their experiences; and the positive reactions of SME control room operators to their L-shaped or half-horseshoe layout further support the recommendation that the final design should approximate a U-shape as closely as possible, within the existing constraints.

Benefits/Limitations Analysis. At a second informal review meeting attended by ERBS-project and Code 500 personnel, the conceptual framework of system goals and human factors criteria for workstation design were presented along with the recommendation that a horseshoe design would best contribute to achievement of system goals. This presentation (Appendix B) included a benefits/limitations analysis of the proposed design (Figure 1) and three alternate layouts (Figures 2, 3, and 4). The benefits/limitations of the proposed design were described as follows:

- o Benefits:
  - allows for side-to-side communication between command operator and shift analyst.
  - provides for ease of maintenance, although there appears to be less than three feet of clearance behind unit 1.
  - provides ease of access to documentation for command operator and shift analyst.
  - provides a clear view of units 1-5 and 14-19 from the hall windows.
  - makes use of existing cabling, lighting, doors and physical dimensions of the combined rooms.
  - is consistent with traditional MOR layout.
- o Limitations:
  - raises barriers to communication between operators in front half of room and those in back half.
  - results in segmented human-machine interaction, especially access to strip charts and visual access to other displays.
  - requires relatively angular, long pathways for traffic patterns within the MOR; addition of a work table adjacent to unit 13, as suggested, will lengthen the path between front and rear doors.

Thus, analyzed in relation to the explicit human factors criteria, the proposed



ORIGINAL PAGE IS  
OF POOR QUALITY

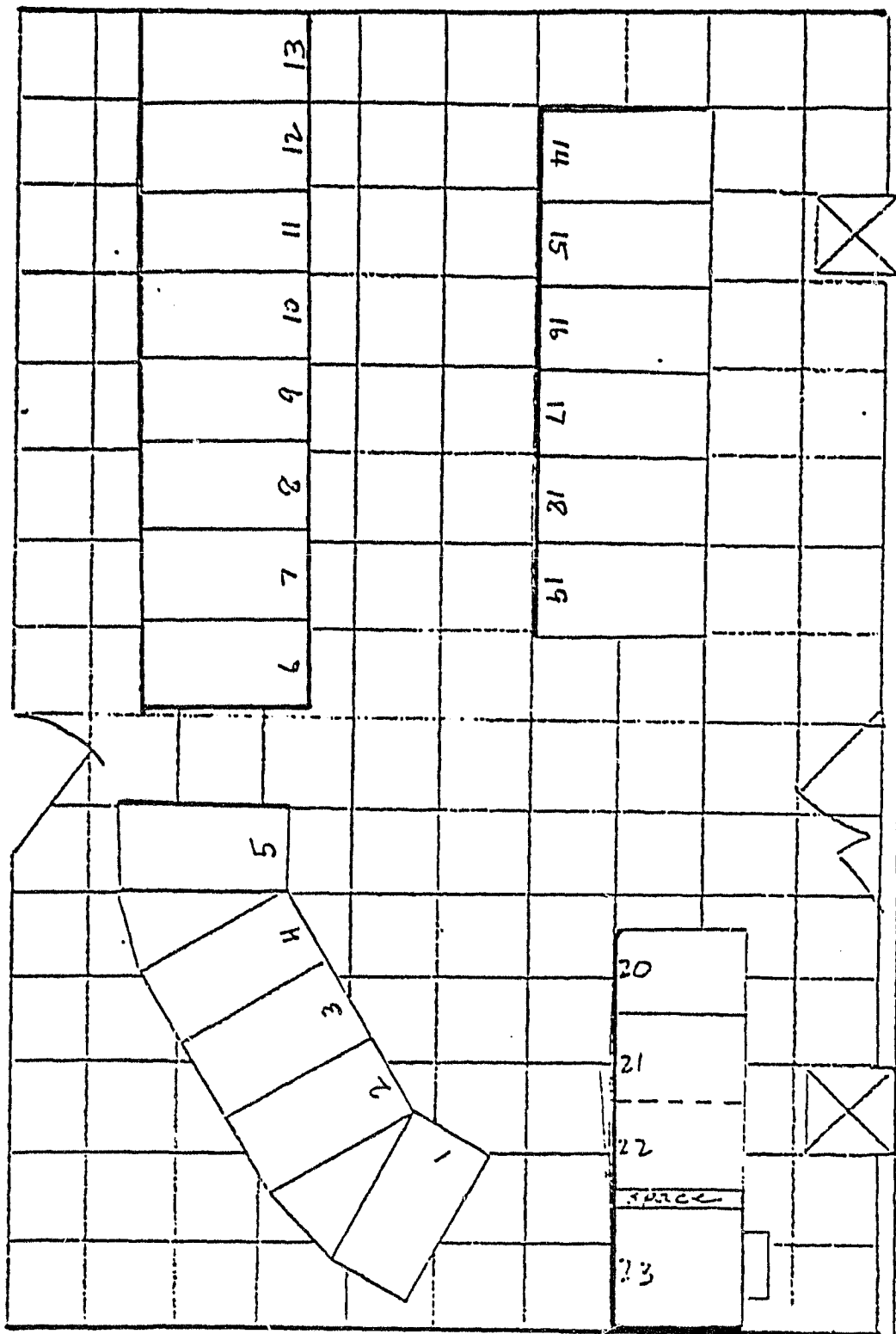


Figure 2. MOR layout.: Design II

ORIGINAL PAGE IS  
OF POOR QUALITY

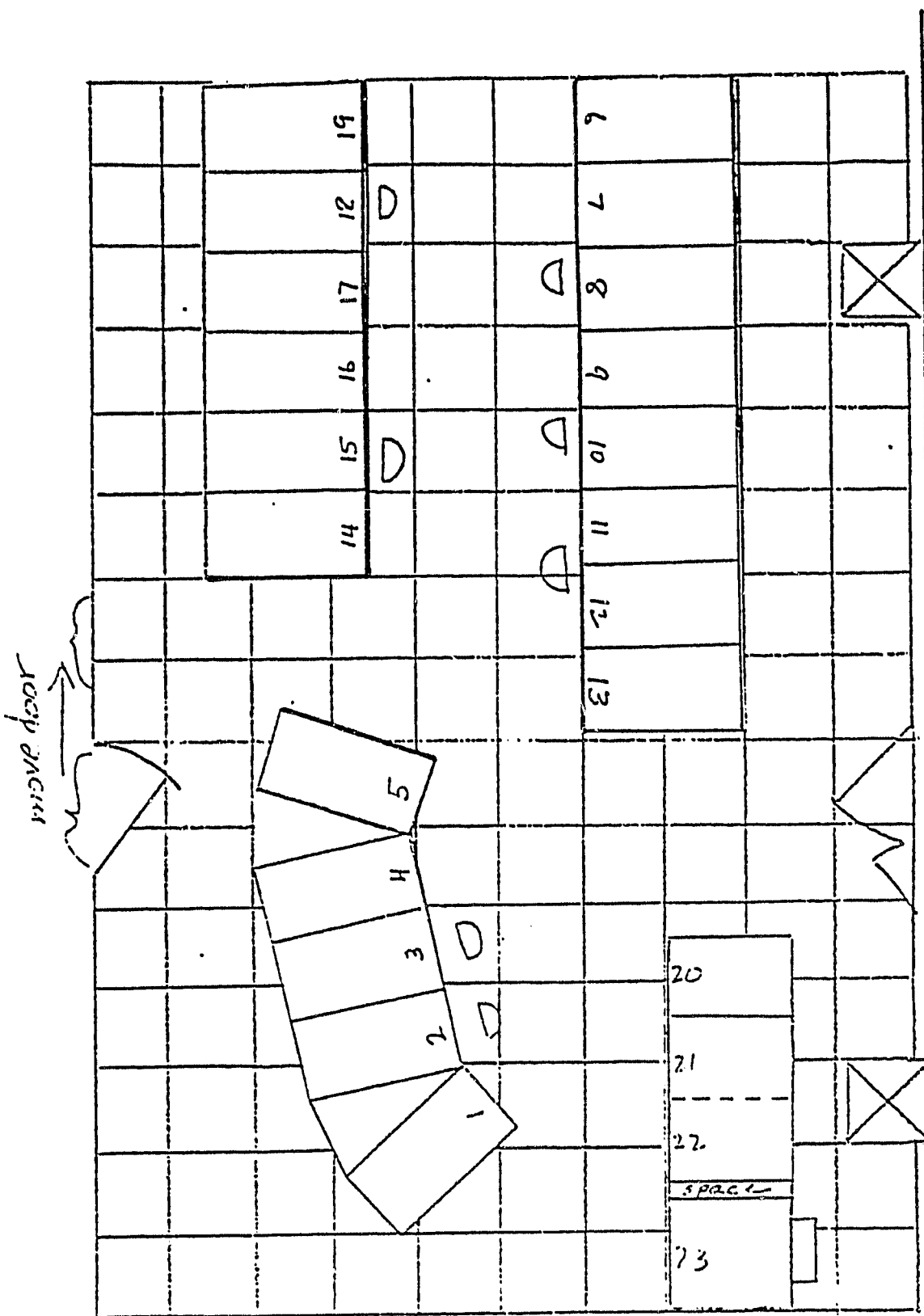


Figure 3. MOR layout: Design IIA

ORIGINAL PAGE IS  
OF POOR QUALITY

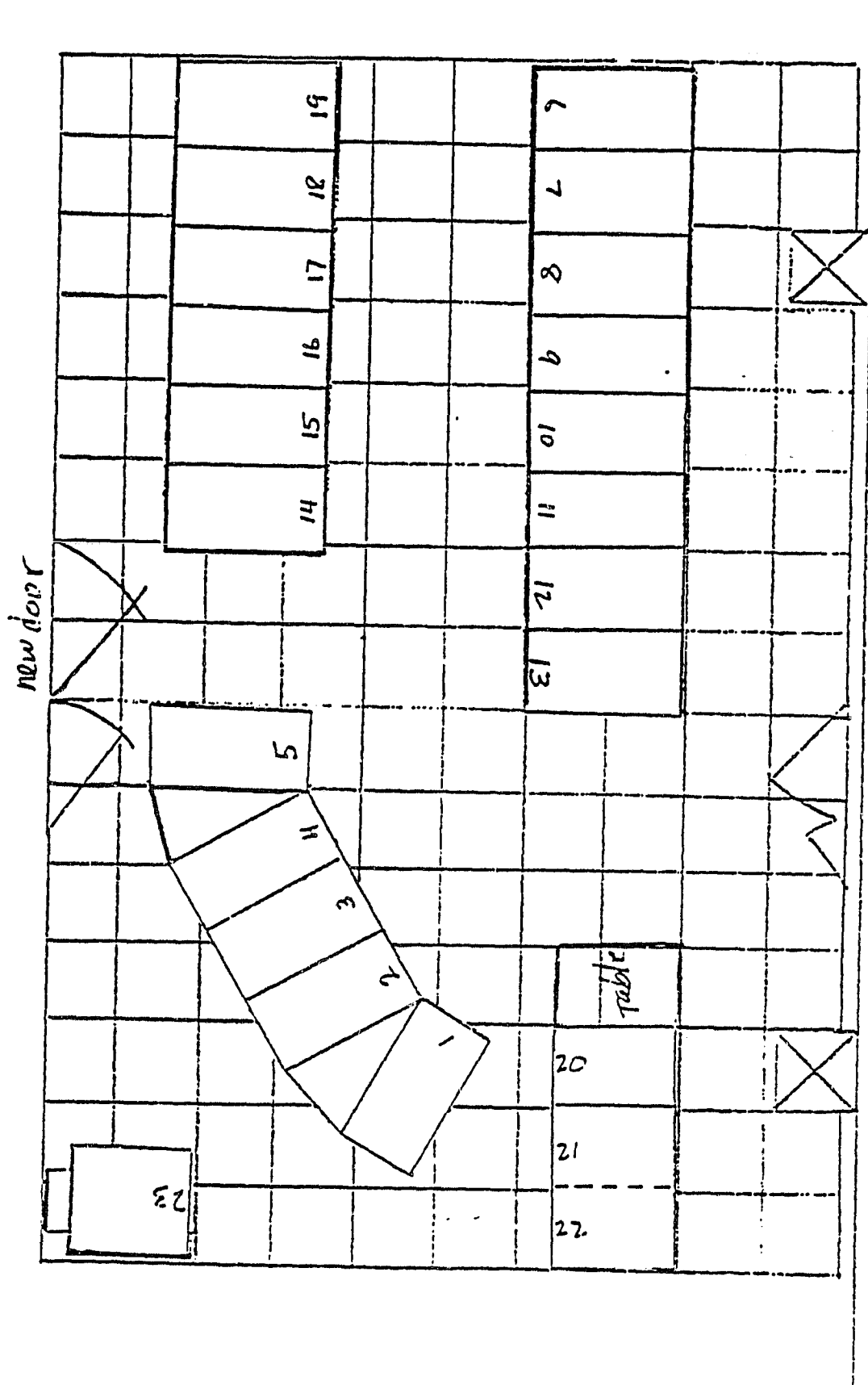


Figure 4. MOR layout: Design IIB

design (Figure 1) provides ease of person-to-person communication between the command operator and the shift analyst but raises barriers to communication between operators in the front half of the room and those in back. If this design were implemented, operators would have visual access only to the displays directly in front of them, resulting in segmentation of overall human-machine interaction. Further, this design would require relatively long, angular routes of access to other workstations and equipment located within the MOR. Addition of a work table, although desirable, would lengthen the path between front and rear doors, if it were placed in the only available space adjacent to unit 13.

The proposed design does, however, provide for ease of maintenance behind all racks except for unit 1; it provides ease of access to documentation for the command operator and shift analyst as well as a clear view of units 1-5 and 14-19 from the hall windows. Existing cabling, lighting, and doors are utilized by the proposed design, which is consistent with standard MOR layout.

Alternative approaches to physical layout are depicted in designs II, IIA, and IIB (Figures 2, 3, and 4). Because of the limits of the room's dimensions (20' x 30') and requirements for maintenance, it is not possible to configure the required equipment into a horseshoe shape. However, it is possible to arrange the equipment so that operators are not separated from each other by console racks. The basic modification to the proposed design, represented by Design II (Figure 2), positions the workstations within the MOR so that operators can see and talk to each other without hindrance due to intervening equipment. The benefits and limitations of Design II can be summarized as follows, with reference to the underlined criteria:

- o Benefits, Design II:
  - human interaction: increases opportunities for human interaction, in comparison to the proposed design.

- human-machine interaction: increases possibilities for human-machine interaction, including access to strip charts from command cluster and visual access to other displays
- traffic flow: eases traffic flow within and through the MOR; a work table could be added at either end of units 14-19 without disrupting the flow of traffic.
- maintenance: generally retains ease of maintenance.
- view from hall windows: provides for viewing units 1-5 and 6-13 from the hall windows.

o Limitations, Design II:

- traffic flow: may result in some congestion in the space between units 6-13 and 14-19 because it is possible to provide only five feet rather than the eight feet recommended in guidelines (Mitchell, et al., 1982).
- maintenance: results in lack of clearance behind units 1, 21, and 22.
- view from hall windows: has backs of units of 14-19 and 20-23 facing hall windows, but a standing observer can see over most of these units.
- access to documentation: reduces access to documentation from operator's position unless documents are stored on console tops.
- use of existing cabling: may require different cabling paths.

In designs IIA and IIB, modifications are suggested to overcome some of the more serious limitations of Design II. The positions of units 6-13 and 14-19 are switched, for example, allowing space to move units 1-5 further toward the right for maintenance purposes. In Design IIB, the color printer (unit 23) has been moved into the far left corner to allow space for the addition of a work table adjacent to unit 20.

Questions about the need to have the color printer in the MOR were raised by the human factors analysts throughout the process of considering alternative designs. Any

positioning of the printer near the command units runs the risk of causing detrimental effects on performance due to noise. However, project planners emphasize that the printer will not be used in real-time situations, but only during intervals between passes.

Additionally, designs IIA and IIB suggest moving the rear door to provide a direct path through the MOR. Comprehensive summaries of the benefits/limitations analyses for designs IIA and IIB can be found in Appendix B. Design IIB was recommended for implementation because it best fulfilled the human factors criteria given the requirements and constraints as understood up to that point. It may be worth noting that this second meeting took place only three weeks after initiation of the human factors analysis of the ERBS MOR workstation design.

Design Evolution. During the presentation of alternate layouts, additional areas of flexibility became apparent. Issues previously identified as non-negotiable became open to discussion. The limited range of existing cabling, for example, no longer seemed to present a problem; it became possible to consider different approaches to maintenance and documentation storage; choice of compact, non-bulky chairs was suggested, to lessen the potential for congestion between facing rows of equipment. Design IIB thus, became a point of departure for further examination of possible alternatives to the originally proposed design.

As this meeting continued, many attempts were made to arrive at a design that would be acceptable to all participants and the points of view they represented. Numerous possible re-configurations were tried, using MOR floor diagrams and paper mockups of physical components. The severe constraint imposed by maintenance requirements soon became evident to those participants who had not previously been involved in rearranging the clusters of equipment.

Emerging from these attempts at re-configuration were two new approaches to design of this MOR:

- o Groups of consoles shown as separate clusters on the originally proposed design can be positioned next to each other, e.g., the gap can be closed between the command cluster (units 1-5) and the shift cluster (units 14-19).
- o The longest row of units (6-13) can be divided, with units 6-9 forming one cluster and units 10-12 another.

This report cannot capture or convey the entire range of dynamic interactions that produced the compromise design pictured in Figure 5. However, the role of the GMU analysis team throughout this lengthy review meeting was to assess suggested designs in relation to the established human factors criteria and to propose alternatives that would best accommodate somewhat shifting project criteria.

During the discussion of ERBS MOR operations, the suggestion was made that support personnel, who operate units 6-13, might need ready access to the hallway for purposes of conferring on ways to deal with particular situations. Therefore, units 6-13 were turned around so that these operators would be separated from the center of the MOR, located near the hall door, and less likely to distract the commander. Since these operators will be on duty only 10 per cent of total mission time, for purposes of special maneuvers, and, since they will be interacting primarily with each other, this positioning of the support cluster is somewhat defensible from a human factors perspective. The newly articulated criterion of minimal distraction to the commander, an absolute necessity for error-free operations, had to take precedence over maximal ease of person-to-person interaction.

The outcome of this second meeting, then, was a consensus on Design III (Figure 5). A full benefits/limitations analysis of this design is included here as Appendix C. In summary, this compromise design provides ease of human interaction and human-machine

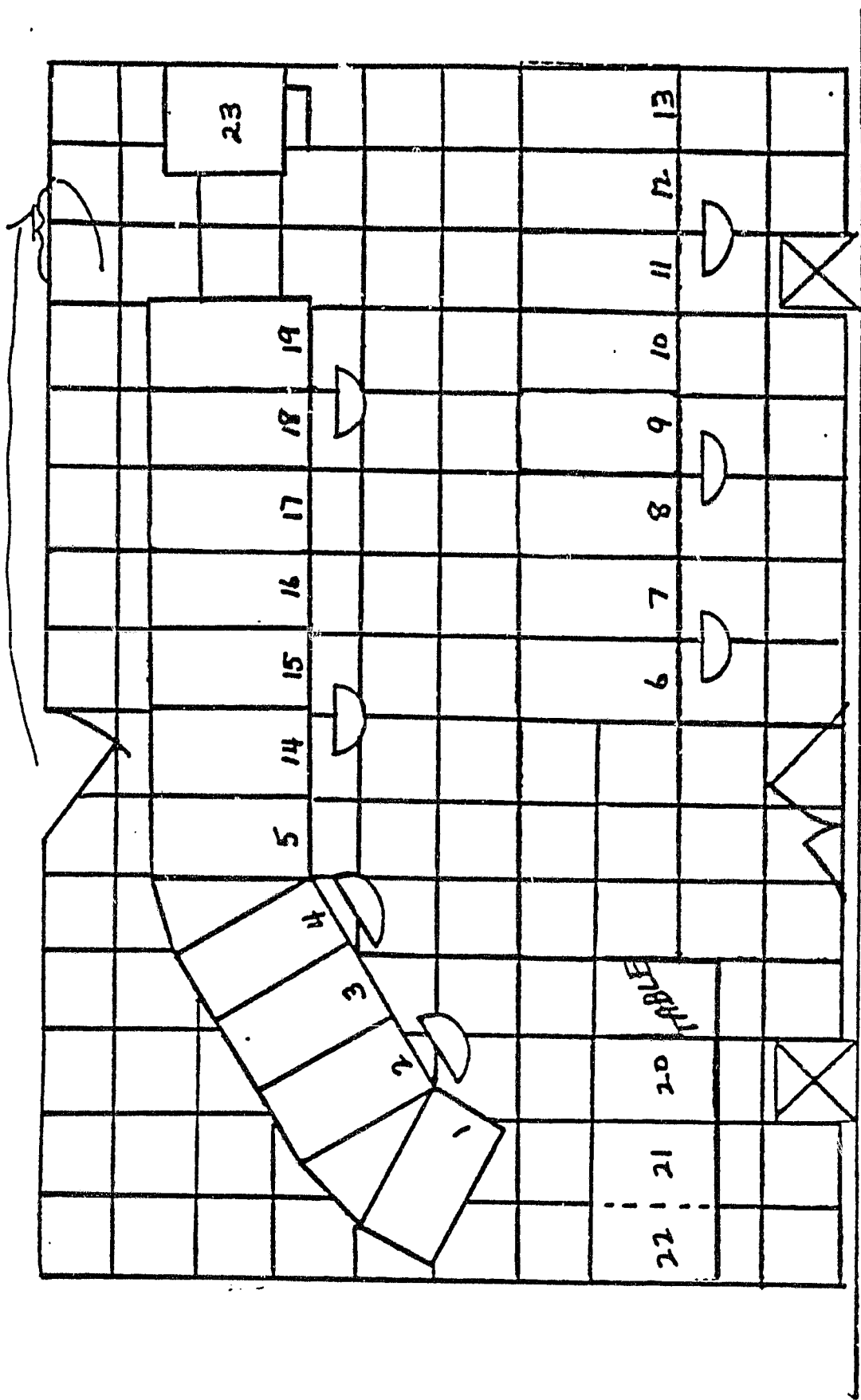


Figure 5. MOR layout: Design III



interaction for positions 1-5 and 14-23; it isolates the support operators, in an effort to minimize distraction of the commander.

Over the next several days, the compromise design was criticized for allowing traffic in the MOR to pass directly behind the commander. Although the original design had the hall door opening right on the command cluster, suggesting that traffic flow past the commander would not be a problem, Design III was rejected on the basis of the strong objections raised by a decision-maker who had not been present at the previous meeting. As a result, the process of design-evolution continued in an attempt to satisfy the need to protect the command operator from distraction. This requirement is essentially a human factors criterion: The design should provide for ease of human interaction while assuring that the commander will not be distracted from his tasks by extraneous verbal communication or physical movement in the MOR.

During the final phase of design development, human factors analysts were not directly consulted, but human factors considerations were incorporated into the final design. The layout which finally emerged as Design IV (Figure 6) locates both the hall and rear doors near the far south wall and divides the cluster of units 6-12 as shown. If it is possible to so locate the doors and to implement Design IV, it will be an improvement on Design III from the standpoint of human factors criteria because the isolation of support operators will be lessened. Appendix D provides a full benefits/limitations analysis of the final design. In summary, of all the workable layouts considered, Design IV does the best job of achieving human factors criteria, including minimal distraction to the commander, while accommodating itself to the less-than-ideal physical dimensions of the room, retaining all equipment required by the project, and meeting maintenance requirements. The various cycles of review and revision produced a balanced compromise which tends to humanize the environment.

REVISION DATE: 10/21/82

ERBS MOR

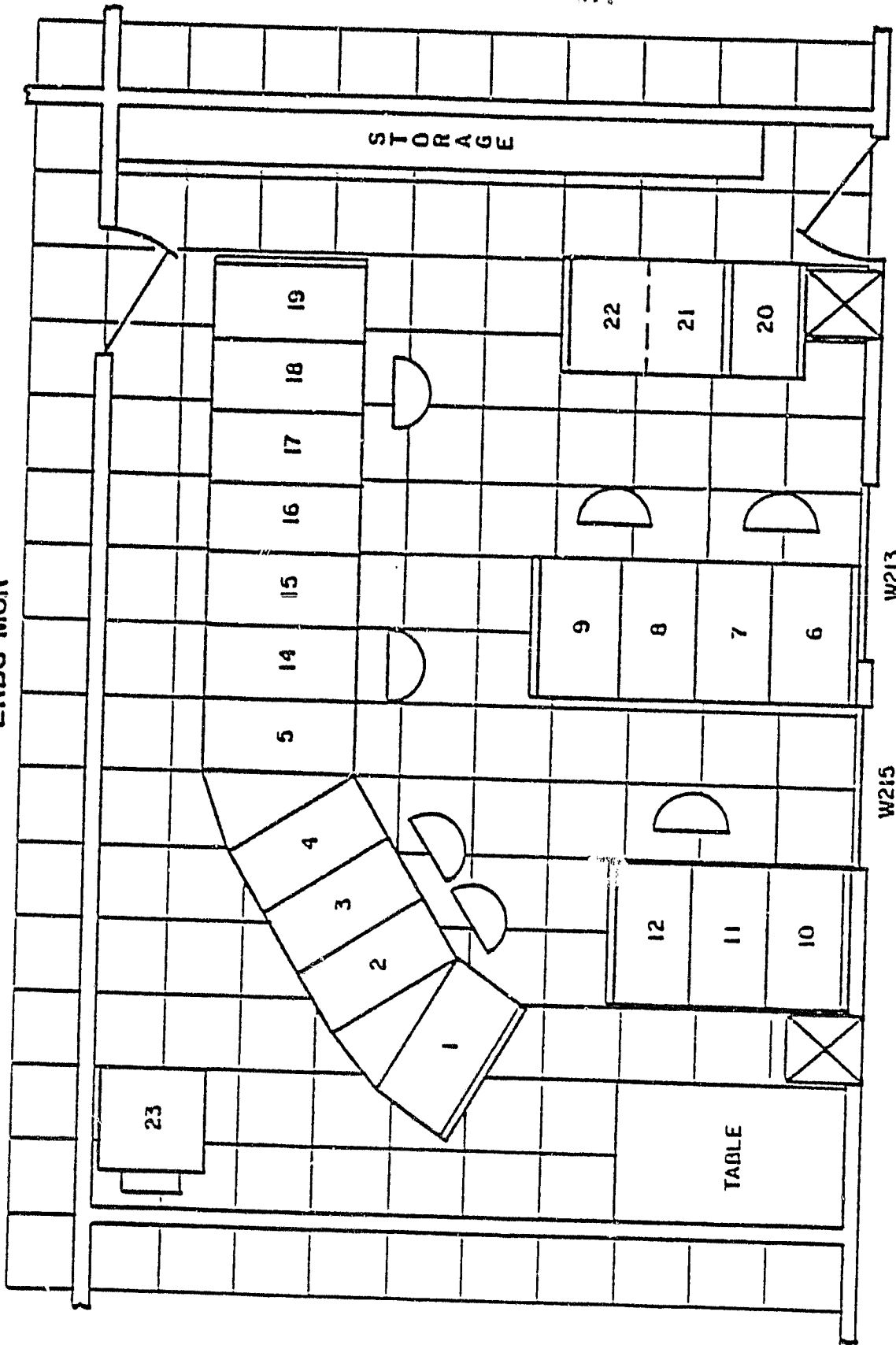
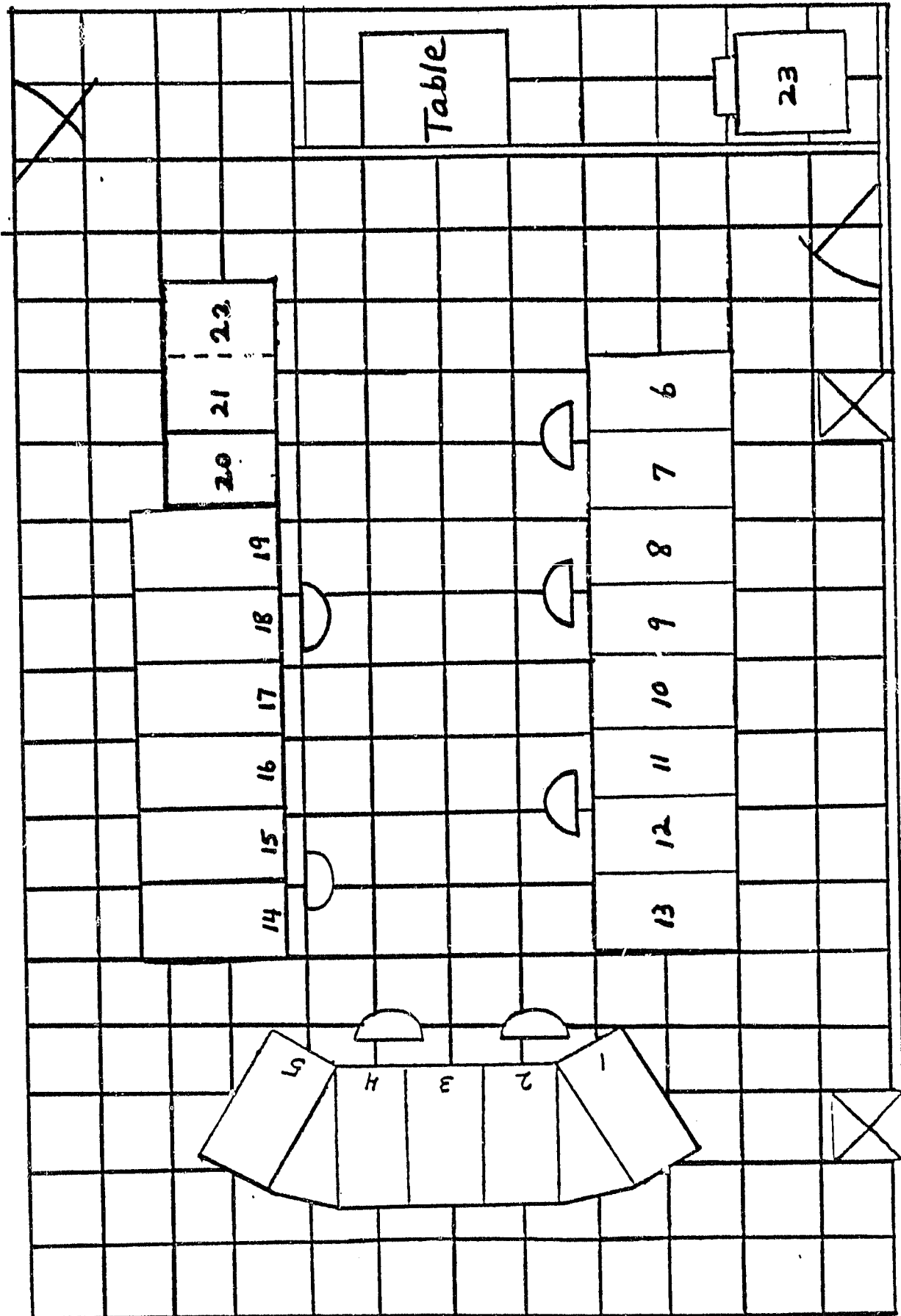


Figure 6. MOR layout: Design IV

ORIGINAL PAGE IS  
OF POOR QUALITY



Viewing ramp

Figure 7. MOR layout: Ideal Design

Ideal Design. Figure 7 presents a design considered ideal from the human factors perspective. It shows the recommended horseshoe design in an MOR enlarged to accommodate all the required equipment. As shown, the room's dimensions are 24 feet by 36 feet, an expansion of only four feet and six feet, respectively. In this environment, distraction to the commander is reduced even below the level of Design IV, which requires persons using the work table to walk behind the commander. The ideal design isolates other potential sources of distraction, the color printer and the work table, in a glassed-in booth at the south end of the MOR. While allowing for ease of interaction among operators, the design provides more than adequate space between units 6-13 and 14-22. The addition of a viewing ramp is suggested to compensate for the partial blocking of the view from the hall windows. Appendix E provides a complete benefits/limitations analysis of this design, which is offered as an illustration of the potential impact of full attention to human factors in workstation design.

Environmental issues. Several areas of flexibility in the ERBS MOR workstation design were identified at the first informal review meeting attended by GMU. These areas were described and discussed at a Human Factors Group (HFG) meeting on September 16, 1982. The supporting documentation can be found in Appendix A, the Status Report on ERBS Human Factors Analysis. An informal separation of areas for concern seemed to emerge from the HFG discussion and was confirmed in the ensuing conversations and meetings with project-related Goddard personnel. The human factors analysis would cover physical layout, environmental issues, and component arrangement. As stated earlier, the immediate priority for human factors analysis was the physical layout of the MOR. Highly related, yet relegated to a secondary priority were several issues grouped under the rubric of work environment. Those issues identified as allowing some flexibility, were: lighting, acoustics, temperature and ventilation,

furniture and equipment, communications, and keyboards.

As reported earlier, in the subsection entitled "human factors rationale," the human factors analysis focused on humanizing the MOR environment in an effort to enhance performance. Although given a secondary priority, the range of environmental issues was investigated in parallel with the physical layout issues. Initially the current conditions and projected operational situations were assessed. For example, it was determined that the existing lighting, temperature, and ventilation systems would continue to be used. While each of these systems was not necessarily optimal from a human factors perspective, enhancing modifications were possible: Sound-absorbant acoustical tiles could be installed on the ceiling and partially down the wall to eliminate a potential noise problem. A shade or blind could be installed on the hall window to help eliminate glare on the CRT screens from the hallway lights. Ergonomically designed chairs could provide comfortable adjustable seating and reduce clutter caused by bulky, heavy arm chairs.

In preparation for the second informal review meeting, recommended human factors enhancements were listed for each environmental issue. Also included on the list were the corresponding benefits of each enhancement, providing justification and a rationale for making the changes or additions. The complete list of situational assessments, recommended enhancements, and beneficial rationales can be found in Appendix F. Unfortunately, due to the necessity for action concerning the physical layout, the environmental issues unintentionally did not receive "air time" at this second meeting. Time and patience simply ran out for that day. The handout was distributed, however, and a quick examination by the group members produced no objections. Most of the enhancements had been informally discussed previously, but without the organization and rationales provided by the handout. The human factors analysts were reassured that these issues and recommendations would not fall by the wayside. Commitment to this

area of concern is illustrated by its inclusion in management status presentations (Moe, 1982; Worrall, 1982).

In some smaller, informal follow-up meetings, the environmental issues were addressed and some of the human factors recommendations accepted. Carpet tiles are being installed on the MOR floor to help insulate against cold and sound. A table is being added to the room to provide extra workspace. It became apparent that sufficient and accessible documentation storage was a major necessity. Console-top documentation storage was recommended to meet this need.

Several of the recommendations the GMU human factors analysts considered crucial to improving the ERBS MOR environment have yet to receive action. Acoustical tiling for the ceiling was recommended to reduce noise levels and to prevent interference due to excess noise. The feasibility of procuring ergonomically designed chairs was also discussed. At the writing of this report responses to these and other concerns were not available, but assurances have been given that these issues will not be dropped; they will comprise a continuation of ERBS MOR workstation design and will be acted upon.

Component arrangement. At the first informal review meeting, the arrangement of components within console clusters was identified as having limited flexibility. The GMU human factors analysts were invited to explore the issue and to present any recommendations. Three types of console components make up the majority of the MOR: KCRTs, monitors, and communications panels. Each KCRT and monitor is mounted in a dedicated console. Three strip chart recorder consoles are also present in the MOR. Each individual position consists of one KCRT, one monitor, and one communications panel. It was considered undesirable to have KCRTs adjacent in any arrangement because the keyboards occupy most available workspace. It was not clear initially if all seven positions were necessary as presented in Figure 1. Additionally, it

was not known whether the existing clusters of consoles need to be preserved intact or could be divided into smaller groupings.

Component arrangement received the least emphasis as a priority in the analysis. GMU reviewed the initially presented arrangement but was not asked to prepare a formal document on this topic. As a result the suggestions made here are based on the analysts' human factors expertise, without the benefit of the working group's feedback. Thus the criteria for evaluation reflect a human factors perspective.

It was assumed that the operator would be seated between the KCRT and monitor racks, providing excellent visual access to both displays and rapid access to the keyboard or the workspace. A left-to-right movement sequence towards the communications panel was assumed from population stereotypes of the right handed person. It was also assumed that the operator should not reach across a keyboard for access to the communications panel because accidental key activation might occur. Thus, placement of monitors adjacent to communications panels is the preferred strategy. While accidental activations of this nature are rare, the possibility must be considered in planning for reduction of possible human error. Placing monitors adjacent to communications panels also provides four to six feet of uninterrupted workspace, rather than occupying every other two feet of workspace with a keyboard.

The original arrangement of the 1-5 component cluster appeared satisfactory with the addition of another communications panel in unit 5 and remote jacks installed for units 1 and 2. The 1-5 cluster will infrequently be required to support two command-controller positions, necessitating the extra communications panel. The location of these panels, to the far right, is a problem when two persons are present and can be remedied by installing remote jacks.

The 6 - 13 component cluster serves three spacecraft support positions and contains one single communications panel and one double communications panel. (Figure 8).

ORIGINAL PAGE IS  
OF POOR QUALITY

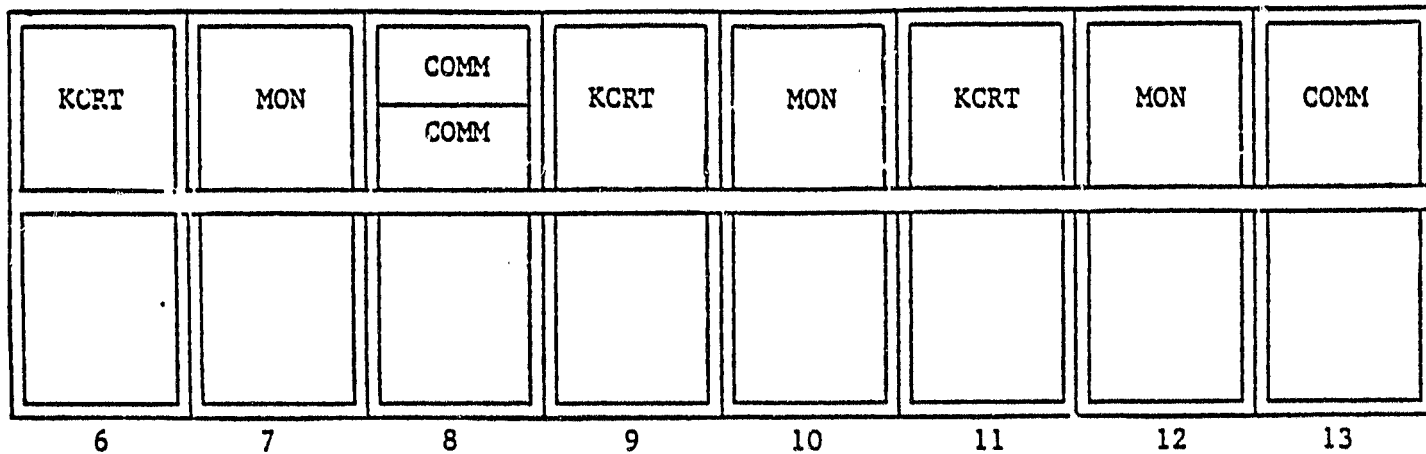


Figure 8. Component arrangement: Original spacecraft support cluster, units 6-13.

The left-to-right sequence for access to the panels was thus not preserved for one person. This may not necessarily be a disadvantage because a left-handed person would prefer to use the opposite sequence. To avoid mirror imaging around the double communications panel and to avoid extensive rearrangement, it was suggested that unit 8 be switched with unit 13. It was then necessary to change unit 8 again with 11 to be consistent in keeping the monitor adjacent to the communications panel. While it appears that a KCRT (9) is adjacent to a communications panel (13), functionally that is not the case. KCRT (9) belongs to the position using the double communications panel (8) and not the single (13). Figure 9 illustrates the component cluster after the recommended changes.

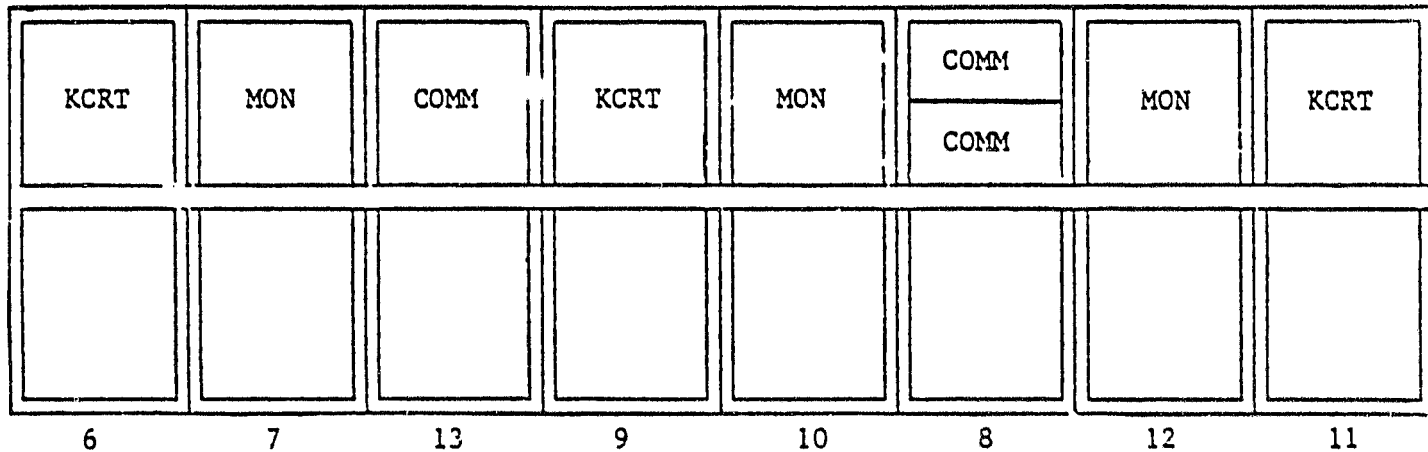


Figure 9. Component arrangement: Recommended changes, units 6-13.



ORIGINAL PAGE IS  
OF POOR QUALITY

The 14-19 cluster serves two spacecraft analyst positions and contains a double communications panel and an IDT graphics terminal identical to that used by the command controller (Figure 10).

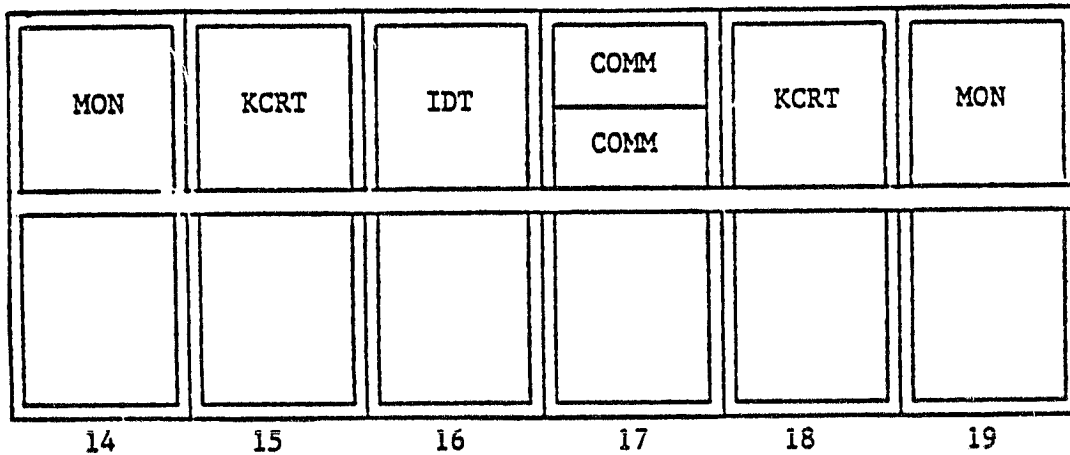


Figure 10. Component arrangement: Original shift analyst cluster, units 14-19

Again, due to the double communications panel, one position violates the left-to-right movement sequence. A left-handed operator would not find this particularly bothersome. Since the IDT graphics terminal (unit 16) includes a keyboard, units 14 and 15 should switch positions. This places the monitor (14) as close to the communications panel (17) as possible and ensures that the KCRT (15) and IDT keyboard (16) are non-adjacent. Units 18 and 19 must also switch positions so the operator does not have to reach over a keyboard to access the communications panel and to be consistent in placing monitors adjacent to communications panels. Figure 11 shows the recommended changes for this component cluster.

ORIGINAL PAGE IS  
OF POOR QUALITY

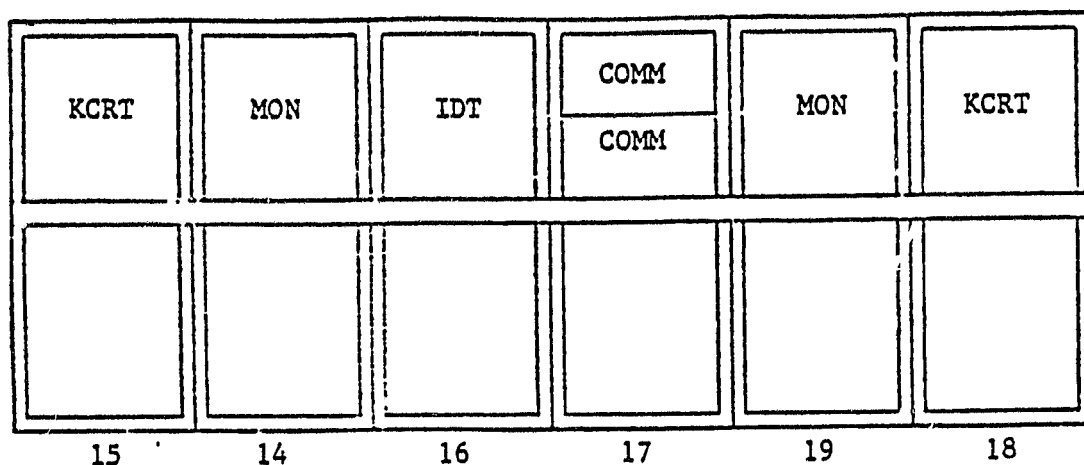


Figure 11. Component arrangement: Recommended changes, units 14-19

The 20-22 component cluster consists of two small strip chart recorder consoles and one short rack. The two tall consoles serve as one unit and, within the original arrangement, are situated to the right of the short console. The operator can sit at the short console and, in accordance with the original arrangement, this provides the recommended left-to-right movement sequence towards the tall strip chart recorders. Thus, from a human factors perspective no changes to this cluster are necessary.

The final MOR workstation design, Design IV, Figure 6, changed two of the original assumptions concerning layout. Specifically, two clusters were joined and one was split up. This necessitates changing some of the recommendations made above for component arrangement in order to remain consistent with the original human factors criteria. The numbering scheme used in the following changes reflects that of Design IV (Figure 6) which differs slightly from the numbering of the original design (Figure 1).

Units 1 through 5 have been joined with units 14 through 19, forming one long bank of consoles. Two command control positions and two shift analyst positions are provided for. The arrangement of components 1-5 remains as originally suggested and appears optimal. Units 14-19 contain a double communications panel requiring the violation of

ORIGINAL PAGE IS  
OF POOR QUALITY

the left-to-right movement sequence. Within that particular position, unit 18 must switch with 19 to be consistent in keeping monitors adjacent to communications panels. Units 14 and 15 in Figure 6 have been interchanged from the original Figure 1 and are in agreement with what GMU recommends.

Design IV shows a major change in units 6-13, the three spacecraft support positions. Essentially, one position has been separated from the other two, forming two component clusters, 6-9 and 10-12; one KCRT has been eliminated. Some component rearrangement is necessary in order to do this and adhere to the human factors criteria.

Regarding the 6-9 cluster which supports two operators with a double communications panel, unit 7 should switch positions with unit 8. Then, unit 8 should switch positions with unit 6, resulting in the arrangement shown in Figure 12.

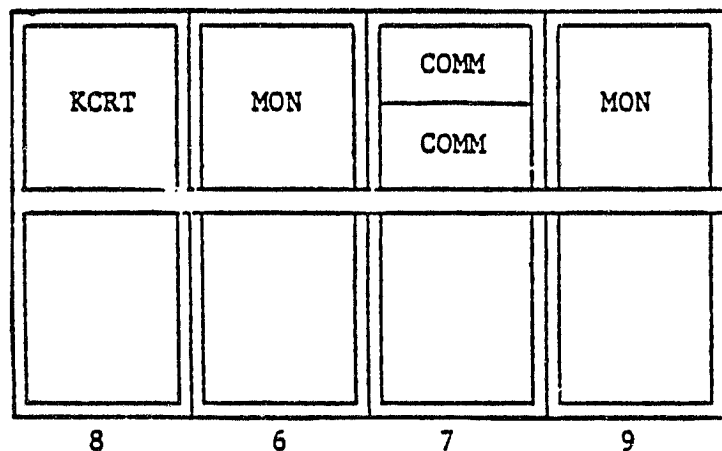


Figure 12. Component arrangement:  
Recommended changes for  
Design IV, units 6-9.

Here monitors are adjacent to the communications panel on both sides, uninterrupted workspace of 6 feet has been provided, and one left-to-right movement sequence has been maintained. The double communications panel again calls for one violation of that movement sequence. This component cluster absorbs the loss of one KCRT leaving one

ORIGINAL PAGE IS  
OF POOR QUALITY

operator position consisting of a monitor and communications panel only. It is this position that violates the left-to-right movement sequence.

Within cluster 10-12, one spacecraft support position, unit 10 should switch positions with unit 11. Then unit 10 should switch positions with unit 12. Figure 13 illustrates this new component arrangement.

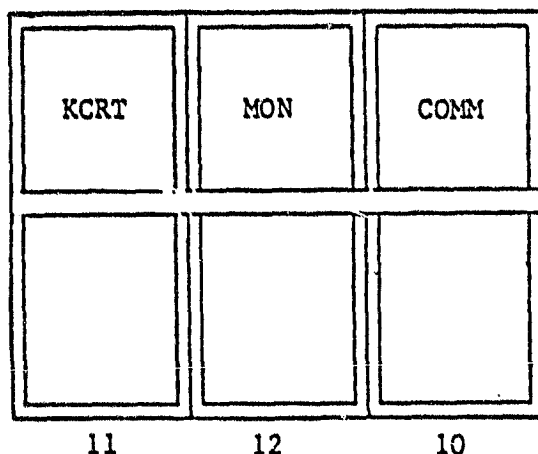


Figure 13. Component arrangement: Recommended changes, units 10-12

Using the human factors criteria this cluster represents the ideal: a left-to-right movement sequence from KCRT and monitor to communications panel, a monitor adjacent to a communications panel, and four feet of uninterrupted workspace.

The strip chart recorder cluster (units 20-22) should be slightly rearranged. Unit 20 should switch positions with unit 21, and then again with unit 22. This places the tall racks flush against the ventilation duct and the short console closer to the area of operations, improving the work environment for an operator sitting at this console. When this occurs, a left-to-right movement sequence towards the tall strip charts has been maintained. Figure 14 shows the new arrangement.

ORIGINAL PAGE IS  
OF POOR QUALITY

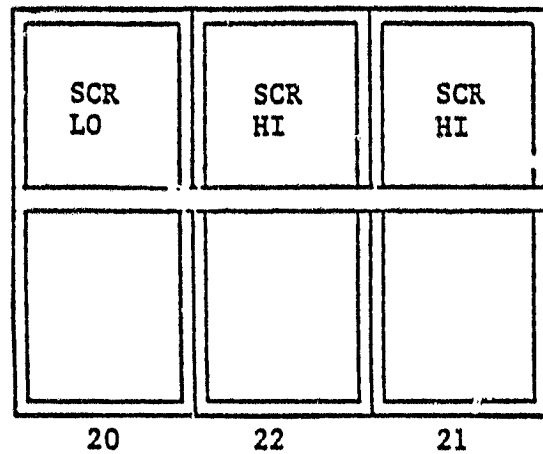


Figure 14. Component arrangement: Recommended changes, units 20-22

The suggestions for component arrangement in both the original and final design are based upon the criteria used in the human factors analysis. There was a lack of information for performing this part of the ERBS MOR workstation design analysis, for several reasons. First and foremost was the low priority assigned to the task by the working group. Within the very short time allotted for the analysis, the most pressing issues were those regarding physical layout and to a lesser degree, environment. Therefore, the discussion on component arrangement was minimal. There was no time set aside during the meetings between the GMU human factors analysts and ERBS working group to address this area. Thus, the recommendations are made without the benefit of the valuable feedback of the working group. The suggestions are also made in the absence of a task analysis. A task analysis of daily operations would answer questions such as: Where is the operator most likely to sit within his/her station? In front of the KCRT, the monitor, or in the middle? Assuming the operator sits exclusively in front of the KCRT, it would be advantageous to place the KCRT adjacent

to the communications panel, thus decreasing reach distance. If the operator sits directly in front of the monitor, then the monitor should be adjacent to the communications panel to decrease reach distance. It was assumed that the operator sits in between the two, an assumption reinforced by informal conversations with current MOR personnel. If this positioning is accurate and if mobile chairs are provided, reach distance will no longer be an issue.

In summary, the analysis of component arrangement is a valuable one despite the problems encountered in conducting it. It is based on explicit human factors criteria and raises several interesting questions and significant issues. Another approach to component arrangement would require investigation of the feasibility of stacking terminals within console racks. Further consideration of component arrangement is recommended and can only benefit the overall ERBS MOR workstation design.

## DISCUSSION

Comparison of the proposed methodology and the case study immediately reveals the wide discrepancy between a rigorous research methodology and the applied approach necessitated by ERBS MOR time constraints. Examination of some comparative examples will be made to illustrate the extent of this discrepancy and to support recommendations based on the case study. Discussion will focus on timing, ambiguities, analytical process, and other sub-topics.

Timing. Whereas the suggested general method provides for a series of onsite observations prior to any attempt at analysis, the timing of the actual analysis required concurrent observation and assessment. Time constraints created pressures to provide human factors analyses and rationales on short notice. These pressures were exerted from at least two directions, the on-going schedule of the project with its specific deadlines and the time required for completing documentation of human factors analyses. A chronology of GMU's observations and analysis is provided in Appendix G.

Commencing the human factors analysis at the stage of design review, with no opportunity for prior involvement in planning, tended to create a difficult situation for everyone. Human factors analysts were put in the position of either accepting the originally proposed design or criticizing it and alienating its developers. Under the circumstances, it might be considered remarkable that it was possible to identify any areas of flexibility in the initial meeting. The entire human factors effort was unintentionally jeopardized by the late entry of human factors considerations into ERBS MOR workstation design.

It should, perhaps, be noted that there is nothing particularly unusual about the timing of this human factors analysis. Unfortunately, it has been the typical situation

for human factors analysts to be consulted at advanced stages in design development in industrial and business settings. This practice has resulted in less than the maximal benefit that can be achieved from a complete, top-down systems approach to design. When equipment has already been procured and design of the workplace has reached the point of initial review, it is highly probable that a human factors analysis cannot result in optimal workstation design. It is just too late for much more than some retrofitting to occur. The analysis can have some impact where flexibility is still possible, but it is severely constrained by undesirable "givens" which might have been avoided by consideration of human factors from the earliest phase of planning (DeGreene, 1970; Swain, 1962).

**Recommendation: Plan for early consideration of human factors.**

Areas of Ambiguity. The originally proposed design was presented for review before the human factors analysts had an opportunity to develop a conceptual framework of system goals and criteria. It is possible and likely that others who attended this presentation had discussed goals and criteria, at least within their own perspectives; if there was any previous exchange of ideas or formal discussion of goals and criteria that cut across divisions of technical responsibility, it did not include the GMU analysts. In any case, the proposed design was presented in very definite terms, leaving the impression that all decisions had been made. Only after lengthy discussion did it become evident that changes might be made in some areas. The next step was the development of an explicit set of standards on which to base an analysis.

Determination of system goals was fairly straightforward, but identification of criteria for achieving these goals was another matter. Although human factors criteria were readily apparent to the analysts, there seemed to be additional criteria of value to



various Goddard personnel involved in the development of workstation design. If those representatives of other perspectives were being asked to consider human factors at this point in design development, it appeared advisable for human factors analysts to reciprocate by taking as comprehensive an approach as possible. Accordingly, an attempt was made to include additional, non-human factors criteria that could be inferred from the proposed design and from informal, individual discussions with project developers. Thus, provision of a clear view into the MOR from the hall windows and use of existing cabling were evaluated in developing benefits/limitations analyses of alternative designs.

As the assessment of possible designs proceeded, the problem of shifting criteria arose repeatedly. The criterion of minimal distraction to the commander came to assume paramount importance, for example, although it had not been mentioned during the initial design review meeting or implied by the original design. Throughout the evolution of the design, various criteria seemed to gain or lose significance, emerging suddenly or disappearing entirely from consideration. For example, limitations due to cabling length disappeared at some point as a constraint on design and were no longer included in the analysis after the second design review meeting. It is evident that an early discussion and ranking of human factors and other criteria would have expedited the entire analytical process.

In addition to shifting criteria, other areas of ambiguity included the rationale for the number of operator positions, the range of possible re-configurations of equipment, and the feasibility of making changes in positions of doors. Because of these ambiguities it was difficult to answer the recurring question of exactly what human factors benefits would be achieved by each of the possible combinations of variables, a question that could be investigated by further research of the kind envisioned for the Goddard Human

Engineering Laboratory. Additionally, varying levels of participation by key decision-makers contributed to the extension of the design-evolution process. The success of cooperative efforts such as workstation design depends on identification of significant decision-makers and their regular attendance at planning and review sessions.

It is likely that many of these ambiguities could have been dealt with if the human factors analysis had begun at a much earlier design phase. A team approach to planning new projects should routinely involve the participation of at least one human factors analyst in all phases of system development. Adherence to the steps in the proposed general method will help to integrate considerations of human factors with development of hardware and software and result in a higher level of compatibility among these major system components.

**Recommendation:** Develop a team approach to project planning.

Analytical process. A basic requirement for a rigorous human factors analysis is full availability of information relating to equipment, staffing, and patterns of activity within the MOR. Human factors tools such as task analysis, link analysis, and simulation can provide a basis for workstation design, but they will not achieve an adequate level of accuracy unless human factors analysts know as much about the project, in conceptual terms, as the project developers. If human factors analysts are included in the planning process from the beginning, their knowledge of the project will accrue naturally as a result of their full participation. However, if a human factors effort is not integrated with overall project development from an early phase, every effort must be made to inform analysts about changes in numbers of positions, requirements for equipment, and contingency planning. Human factors analysts share the responsibility to make sure that every appropriate question is raised and answered. The use of human factors tools, of

course, depends on time being built into the design-development schedule. The potential contribution of human factors research to planning will be realized only when full provision is made for that research to occur. Adequate time is essential.

In the case of ERBS MOR workstation design, the human factors analysis relied on onsite observations, informal discussions with appropriate personnel at Goddard, and guidelines in the human factors literature. Time did not permit the use of other methods of quantification. In attempting to provide balanced analyses of alternative designs, the benefits and limitations of each design were assessed in relation to human factors and other criteria. This kind of analysis essentially provides an explicit overview of tradeoffs associated with each proposal. In the absence of less subjective results that could have been obtained from more empirical techniques, the highest level of objectivity possible in this case is represented by the benefits/limitations analysis included in the text and the appendices.

**Recommendation: Allow time to conduct research.**

Climate of co-operation. Generally, Goddard personnel were extremely cooperative and receptive to the idea of considering the capabilities and limitations of the people who work in the command-and-control environment. As indicated during past and present observations, operations personnel, in particular, perceive human needs as receiving comparatively less attention than equipment needs (Mitchell, 1981). This perception has a negative effect on morale, absenteeism, turnover, and overall job satisfaction, with all of these indicators having implications for job performance. Most personnel involved in ERBS MOR workstation design understand that attention to the human qualities of the workplace will directly or indirectly benefit human performance in the workplace. There were, however, some negative reactions to the human factors

analysis described in this report. The resistance was limited to only a few people but was strident in tone and obstructive to the analytical process.

Effective application of human factors principles requires a flexible approach emphasizing what can be done with physical and human resources, rather than a negative approach repeatedly stressing what cannot be done. At a facility such as Goddard, with its enormous capabilities in so many areas, it is counterproductive to insist, for example, that a particular door cannot be moved to accommodate a direct, non-distracting traffic pattern through the MOR. (During the process of design iteration it sometimes seemed that a specific door could or could not be moved depending upon who suggested the move.) Moreover, it is counterproductive to argue that needed changes in physical layout cannot be made because equipment installers dislike having to re-position components. Understandably, there are crucial issues relating to physical resources and realistic limitations on what can be done, but the ultimate success of the mission can only benefit from serious and thoughtful consideration of its human factors aspects. Representatives of management, systems engineering, and human factors perspectives need to function in co-operation in order to ensure a balanced work station design.

**Recommendation: Management, systems engineering, and human factors representatives should function in co-operation.**

Systems approach. A human factors issue that deserves greater attention is that each person involved in a project needs to be provided with a clear understanding of his/her role within the project-as-a-system. Whether they are equipment installers, operators, or managers, workers need to know how mission success depends on their performance and how their tasks relate to the work of others. The equipment installer, for example, is surely capable of understanding why he/she is being asked to re-position components, not just because of some whim but because the new layout will contribute to

the success of the mission. If no effort is made to explain, the worker's frustration will be understandable. Time spent in explanations of this kind is likely to result in increased morale, motivation, and sense of team effort.

A systems approach is also needed in project documentation. Requirements and provisions for person-to-person interaction, both formal and informal, need to be described adequately in technical documents, not only for purposes of human factors analyses, but also for their informational value to operators and managers. Documentation should focus on the interrelationships among jobs as well as on the enumeration of individual tasks.

In groups of people who work together intensively over extended periods of time, a network of interpersonal relationships is a natural development. The human-as-a-resource approach to management suggests the manipulation of workstation design to best accommodate both formal and informal group dynamics (Mitchell et al., 1982). Attention to the elements of workstation ambience, as outlined in pages 12 - 13 of this report, should provide further support for group dynamics and result in enhanced job satisfaction (MIL-STD-1472C, 1981; NUREG-0700, 1981; Seal & Sylvester, 1982; Seminara et al., 1977). The more humanly compatible the environment can be made, the higher will be morale and motivation; in turn, performance will benefit.

**Recommendation:** Take a systems approach to ensure compatibility of hardware, software and the human component.

Reflections on Success. The GMU human factors analysts appreciate the enthusiastic verbal feedback they have received from operations and project personnel. However, it is necessary to attempt some quantification of results. Table 2 provides a general overview of trends toward greater consideration of human factors in ERBS MOR workstation design. The originally proposed design was rated low on human factors

ORIGINAL PAGE IS  
OF POOR QUALITY

Table 2. Evolving designs ranked on human factors and other criteria.

Criteria (in order of emergence)	Alternative MOR Workstation Designs						
	Proposed Design	II	IIA	IIB	III	IV (final)	
human interaction	F	E	E	E	G	G to E	
human-machine interaction	P	G	G	G	F	F to G	
traffic flow	P	G	G	G	F	G	
maintenance	G	F	F	G	F to G	G	
access to documentation	F	P*	P*	P*	P to F*	F to G*	
view from hall windows	G	F	F	F to G	G	F to G	
use of existing cabling, doors	E	P to F	P to F	P to F	P	P	
consistency with standard layout	E	F	F	F	F	P	
minimal distraction to commander	F	P	P	P	F	G to E	

P = Poor      G = Good

F = Fair      E = Excellent

\* Console-top storage is recommended.

criteria and high on other criteria. Over the course of design evolution, human factors criteria tended to receive more attention, with the final design rated quite high on ease of human interaction, ease of human-machine interaction, ease of traffic flow within and through the MOR, and ease of maintenance. Although validation of these ratings would require submission of all designs to a panel of other human factors analysts, every effort has been made to maintain objectivity.

To venture into the realm of the non-quantifiable, the analysis has been successful to the extent that it has conveyed a sense of the importance of human factors considerations to Goddard personnel whose reservations about human factors have been addressed; it has also been successful to the extent that it has supported those who adhere to a strong human factors position. The analysis has been successful if it has resulted in any constructive re-thinking about the need to consider the human component of command-and-control environments.

The ultimate impact of the analysis will be measured in the extent to which ERBS MOR workstation design achieves the basic human factors criteria. If the final design is implemented, some attempt at comparative evaluation might be made between a traditional MOR and the ERBS MOR. Measures such as operator satisfaction, error rates, response times, and levels of stress might be employed to evaluate the success of ERBS MOR workstation design in enhancing human performance.

**Recommendation:** After final design implementation, conduct comparative evaluation of MORs.

## SUMMARY AND FUTURE APPLICATIONS

ERBS MOR Workstation Design. The human factors analysis documented in this report focused on the physical layout of the ERBS MOR, on other environmental considerations such as lighting, temperature, and noise, and on the arrangement of components within console racks. Specific recommendations contained in this report are based on the human factors principle stating that the total work environment must be as compatible as possible with human capabilities if operators are to function as required over extended periods of time. The human factors approach is rooted in demonstrable links between environmental variables, motivation, and job performance. The general recommendation is to provide for human requirements in command-and-control environments in order to reduce operator error.

Application of this approach has produced a revised workstation design (Figure 6), and the process of analysis has generated thoughtful, explicit consideration of human factors issues. The revised design, if implemented and evaluated, can function as a starting point for workstation design in future real-time support applications at Goddard. The analytical process and the proposed methodology can also serve as guides for future human factors analysis of workstation design at Goddard, both in terms of what to do and what to avoid doing.

Integration of Human Factors Analysis. A continuing question involves the timing of a human factors effort for any Goddard project: At what point or points in the design process should human factors analysts review and respond to proposals? Broadly speaking, a human factors analysis must be integrated into all planning and review cycles of project development. Representing the various technical, human factors, and management perspectives, a co-ordinating group could be established to oversee a new



project from its inception through implementation, evaluation, and modification. An early entry of human factors considerations would allow sufficient time for observation and research as recommended in the proposed general method.

Additionally, the earliest possible attention to human factors is essential if the uncertainties and issues described in the present case study are to be recognized and addressed. In discussions of goals and criteria, for example, key decision-makers might employ the Delphi technique (Cascio, 1978) to arrive at a ranked set of criteria against which to assess alternative designs. Application of this technique would essentially involve sequential rounds of discussion and ranking of proposed criteria, ending with some degree of mutual understanding and consensus on the rankings. The group as a whole would then be in the position to evaluate proposed designs within a commonly held conceptual framework, not one that had been imposed by one particular interest group.

A systems approach to any new project is recommended. Systematic concentration on the design as a whole, as compared to design of the components, is necessary if the project is going to achieve mission goals with minimal error and need for modification (Williams, 1982). In addition to providing for a human factors analysis of workstation design, a total systems approach would include human factors analysis of staffing, training, allocation of functions, evaluation, and system maintenance (DeGreene, 1970).

On-going Attention to Human Factors. It is easy to assume that human factors will no longer need attention once a new system or project has been operational for some time. Once the system has gone into its maintenance phase, however, regular re-evaluation of environmental and human concerns must occur. At the very least, maintenance of a safe, pleasant, and comfortable environment requires flexible scheduling of replacement and repair as furniture, carpeting, or tiling begin to show wear. On a higher level, commitment to a humanized environment is the first step

toward maintenance and enhancement of human morale and motivation, with accompanying reduction in stress and fatigue. If error-free performance is the ideal, then on-going human factors research and review must occur throughout all phases of project development and implementation. The Goddard Human Engineering Laboratory will provide a much-needed facility for study of human requirements in command-and-control environments. As these requirements are better documented in settings at Goddard, and as they become better integrated into overall system requirements, future applications will benefit.

## REFERENCES

- Bailey, R.W. Human Performance Engineering: A Guide for System Designers. Englewood Cliffs, NJ: Prentice-Hall, Inc., 1982.
- Cascio, W.F. Applied Psychology in Personnel Management. Reston, VA: Reston Publishing Co., 1978.
- Cakir, A., Hart, D.J., & Stewart, T.G.M. Visual Display Terminals. New York, NY: John Wiley and Sons, 1980.
- DeGreene, K.B. Systems Psychology. New York, NY: McGraw-Hill, 1970.
- Department of Defense. Human Engineering Design Criteria for Military Systems, Equipment and Facilities. Washington, D.C.: Department of Defense, May 1981, MIL-STD-1472C.
- Jones, R.J., Jonsen, G.L., & Van, C.C. Evaluation of control station design: The crew human engineering software system. Proceedings of the Human Factors Society 26th Annual Meeting, 1982, 40-43.
- LeCocq, A.D. Selecting a color monitor for an interactive graphics system used to design integrated circuits. Proceedings of the Human Factors Society 26th Annual Meeting, 1982, 160-163.
- McCormick, E.J., & Sanders, M.S. Human Factors in Engineering and Design (Fifth Edition). New York: McGraw-Hill, 1982.
- Mitchell, C.M. Human-Machine Interface Issues in the Multisatellite Operations Control Center-1 (MSOCC-1). NASA Technical Memorandum 83826, August 1981.
- Mitchell, C.M., Stewart, L.J., Bocast, A.K., & Murphy, E.D. Human Factors Aspects of Control Room Design: Guidelines and Annotated Bibliography. NASA Technical Memorandum TM 84942, 1982.
- Moe, K. Overview of Human Factors Work in the ERBS Mission Operations Room. NASA/GSFC Informal Memorandum, 1982.
- Moe, K., & Weger, C. ERBS Human Factors Analysis: A Case Study. Proceedings of the Human Factors Considerations in System Design Symposium, 1982, 291-300.
- Seal, D.J., & Sylvester, G.E. Design applications for optimizing the working environment of the software employee: A case study. Proceedings of the Human Factors Society 26th Annual Meeting, 1982, 302-306.
- Seminara, J.L., Gonzalez, W.R., & Parsons, S.O. Human Factors Review of Nuclear Power Plant Control Room Design, Palo Alto, CA: Electric Power Research Institute, March 1977, EPRI NP-309, Project 501.

Seminara, J.L., & Parsons, S.O. Human Factors Methods for Nuclear Control Room Design. Vol. 2: Human Factors Survey of Control Room Design Practices. Palo Alto, CA: Electric Power Research Institute, Nov. 1979, EPRI NP-1118, Project 501-3.

Swain, A.D. System and Task Analysis, A Major Tool For Designing the Personnel Subsystem. Albuquerque, NM: Sandia National Laboratory, 1962.

U.S. Nuclear Regulatory Commission. Guidelines for Control Room Design Reviews. Washington, D.C.: Nuclear Regulatory Commission, Sept. 1981, NUREG-0700.

Williams, R.D. A systems analysis approach to office automation. Proceedings of the Human Factors Society 26th Annual Meeting, 1982, 302-306.

Worrall, W. Whatinthehellis "human factors". NASA/GSFC Informal Memorandum, 1982.

APPENDICES

## APPENDIX A: STATUS REPORT ON ERBS HUMAN FACTORS ANALYSIS

ERBS MOR Workstation Design Issues  
George Mason University  
September 16, 1982

### Areas of Flexibility

- o Physical layout
  - limited flexibility, existing layout maximizes side-to-side communication
  - plus or minus 4 feet of movement with existing cabling
  - components within console groups can be rearranged, but several conditions must be met
- o Lighting
  - each half of room can be independently controlled
  - existing arrangement of lights will be used
  - dimmer switches can be installed
  - incandescent ceiling spotlights can be installed with dimmer switches
  - shades or blinds can be installed on hallway window to cut glare from hallway lights
  - glare-free louvres for fluorescent lamps are available
  - anti-glare filters for the CRT screens have been ordered
  - a hood over the flat console top can be used to diffuse the light
  - individual "cockpit lights" can be installed
- o Acoustics
  - acoustical tiles can be installed on the ceiling, and partly down the walls
  - static free, industrial strength carpeting can be installed on the floor and partly up the wall to meet the tiling

PRECEDING PAGE BLANK NOT FILMED

INTENTIONALLY BLANK

- o Temperature and ventilation
  - existing ventilation system will be used
  - air conditioning is the only temperature control available
  - carpeting on the floor will help warm the room
- o Furniture and equipment
  - existing flat top consoles will be used, requiring a 3 foot clearance from the back for maintenance purposes
  - mobile, easily adjustable chairs can be used
  - a table can be included to provide extra workspace
  - existing bookcases and tape racks will be used for documentation storage
- o Keyboards
  - plexiglass covers are available to prevent accidental activation
  - the IDT terminal requires a thick cable to the keyboard allowing very little flexibility
  - the ISC terminals have ribbon cables connecting to the keyboards allowing limited movement

#### Areas of Constraint

- o KCRTs and monitors will be rack mounted in existing consoles
- o Some equipment already exists or has been ordered
- o The color printer must be within 25 feet of the graphics unit
- o A minimum of 3 feet must be clear behind racks for maintenance
- o Trade offs must be made regarding most issues

APPENDIX B: ERBS MOR WORKSTATION DESIGN,

PRESENTED ON SEPTEMBER 24, 1982

George Mason University

Working Assumptions:

o Goals of the system:

- maintenance of spacecraft's health and safety
- optimization of data-collecting process

o Criteria for Workstation Design: Physical layout

—ease of human interaction

Rationale: Relative ease of voice and sight communication, especially in the case of an anomaly or emergency, will facilitate performance (Bailey, 1982).

—ease of human-machine interaction

Rationale: If operators can view all displays with relative ease and have rapid access to all units, performance will benefit (Bailey, 1982; NUREG-0700, 1981).

—ease of traffic flow within and through the MOR

Rationale: Short paths with few or no corners and no obstacles between units will contribute to timely performance of duties and to safety in the MOR; longer paths around corners and obstacles will increase human response time, fatigue, and frustration. A direct path through the MOR is preferable to a more indirect path for the same reasons (NUREG-0700, 1981).

—ease of maintenance (ML-STD-1472C, 1981)

Rationale: All units, except the Trilog printer, require three feet of clearance in back.

o Horseshoe design as "ideal"

—description: a U-shaped design, with the command center in the curved position at the head of the U

—Rationale: This design maximizes achievement of all criteria.



--Recommendation: closest possible approximation of this design, within the existing constraints (McCormick & Sanders, 1982; NUREG-0700, 1981; Seminara & Parsons, 1979)

#### Benefits/Limitations Analyses:

##### Present Design:

###### o Benefits:

- allows for side-to-side communication between command operator and shift analyst.
- provides for ease of maintenance, although there appears to be less than three feet of clearance behind unit 1.
- provides ease of access to documentation for command operator and shift analyst.
- provides a clear view of units 1-5 and 14-19 from the hall windows.
- makes use of existing cabling, lighting, doors and physical dimensions of the combined rooms.
- is consistent with traditional MOR layout.

###### o Limitations:

- raises barriers to communication between operators in front half of room and those in back half.
- results in segmented human-machine interaction, especially access to strip charts and visual access to other displays.
- requires relatively angular, long pathways for traffic patterns within the MOR; addition of a work table adjacent to unit 13, as suggested, will lengthen the path between front and rear doors.

##### Design II:

###### o Benefits:

- increases opportunities for human interaction.
- increases possibilities for human-machine interaction, including access to strip charts from command center and visual access to other displays
- eases traffic flow within and through the MOR.

—a work table could be added at either end of units 14-19 without disrupting the flow of traffic.

—provides for viewing units 1-5 and 6-13 from the hall windows

o Limitations:

—provides five feet between units 6-13 and units 14-19 rather than the eight feet recommended in guidelines.

—results in lack of clearance behind units 1, 21, and 22.

—may require different cabling paths.

—has backs of units 14-19 and 20-23 facing hall windows, but a standing observer can see over most of these units.

—reduces access to documentation from operator's position unless documents are stored on console tops.

Design IIA:

o Benefits:

—provides for increased, integrated human interaction while maintaining the original side-to-side relationship between the command operator and shift analyst.

—provides for increased human-machine interaction, including access to strip charts and to other displays.

—allows unobstructed traffic flow within the MOR; passage between the front and rear door 2-4 feet to the right.

—provides for ease of access behind most units.

o Limitations:

—provides five feet between units 6-13 and units 14-19 rather than the more preferable eight feet.

—results in narrow access for maintenance behind units 8, 21, and 22.

—requires different paths for cabling.

—does not provide for a work table, except possibly in the left, rear corner.

—has backs of units 6-13 and 20-23 facing hall windows, but there is still a relatively clear view of units 1-5 and 14-19.

Design IIB:

o Benefits:

- retains benefits of IIA: increased opportunities for person-to-person and human-machine interaction, unobstructed traffic flow, and general ease of maintenance.
- additionally, moving the tall strip charts (units 21 and 22) against the left wall and the Trilog printer (unit 23) to the left, rear corner provides adequate space for a work table near the command position and should reduce any detrimental effect of noise from the printer.
- improves ease of maintenance behind units 8 and 20.
- improves ease of traffic flow through the MOR with change in position of rear door.
- improves the view of units 1-5 from the hall windows.

o Limitations:

- maintenance constraint makes it necessary to provide less than the optimal space between units 6-13 and 14-19.
- requires different paths for cabling.
- has backs of units 6-13 and 20-22 facing hall windows.

References

- Bailey, R. W. Human Performance Engineering: A Guide for System Designers. Englewood Cliffs, N.J.: Prentice-Hall, 1982.
- Department of Defense. Human Engineering Design Criteria for Military Systems, Equipment and Facilities. Washington, D.C.: Department of Defense, May 1981, MIL-STD-1472C.
- McCormick, E. J., & Sanders, M. S. Human Factors in Engineering and Design (5th Edition). New York: McGraw-Hill, 1982.
- Nuclear Regulatory Commission. Guidelines for Control Room Design Reviews. Washington, D.C.: Nuclear Regulatory Commission, Sept. 1981, NUREG-0700.
- Seminara, J. L. & Parsons, S. O. Human Factors Methods for Nuclear Control Room Design. Vol. 2: Human Factors Survey of Control Room Design Practices. Palo Alto, CA: Electric Power Research Institute, Nov. 1979, EPRI NP-1118, Project 501-3.

## APPENDIX C: BENEFITS/LIMITATIONS ANALYSIS, DESIGN III

ERBS MOR Workstation Design  
George Mason University  
September 27, 1982

Design III (as agreed upon at meeting of 9/24/82):

o Benefits:

—human interaction: This design maximizes interaction between the command operator and shift analyst; some voice and sight communication is possible between the commander and the support operator at units 6-7; the strip chart position is well integrated for purposes of person-to-person interaction; addition of a table adjacent to unit 20 provides for ease of interaction.

—human-machine interaction: The command operator and shift analyst have immediate access to each other's display screens; the self-contained support group position reduces the possibility of auditory interference with communications at the command and shift analyst locations; the printer is as close as possible to its driver, the graphics unit, while allowing for a walkway to the rear door; the printer is as far away as possible from the command position, resulting in minimal interference or annoyance due to the noise of the its operation; strip charts are easily accessible from the command position; there is no longer a need for eight feet of space between units 6-13 and 14-19.

—traffic flow: Compared to the originally proposed layout, this design reduces the length and angularity of paths within the MOR for positions 1-19 and 20-23; in general, personnel have fewer obstacles to avoid; ease of access to the hallway is provided for support staff (units 6-13) for purposes of caucusing on possible solutions to problems, with minimal distraction to the commander.

—maintenance: Ease of maintenance is generally provided.

—storage of documentation: Since operators will not need to see over units 1-19, documentation can be stored on these console tops in built-in shelving; ample space for tape racks is located in the left, rear corner; existing shelving behind units 6-10 can be retained.

—view from hall windows: Design III provides a clear view of all video displays from the right of unit 20.

ORIGINAL PAGE IS  
OF POOR QUALITY

o Limitations:

—human interaction: Person-to-person voice and sight communication is limited between the command/shift positions and the support operators who are, however, present only ten percent of operational time.

—human-machine interaction: Support operators do not have visual access to displays at positions 1-19, and command/shift operators do not have visual access to displays at positions 6-13; noise from the strip charts may be distracting to the commander.

—traffic flow: If the rear door remains in its current position, the path through the MOR will be excessively angular and long, requiring avoidance of corners and obstacles; if the door can be moved, the path will be shorter, with fewer obstacles and corners, thus enhancing safety and the timely performance of duties; access to tape racks in left, rear corner requires personnel to walk around the end of unit 19, into the corner, and back around again (if frequent access to the tape racks is not necessary, this limitation may not be a problem).

—maintenance: In addition to tight access to unit 1, there may be less than three feet behind unit 20. This possibility may not be a problem if most strip chart maintenance can be handled from the front.

—view from hall windows: The backs of units 20-22 face the hall windows. Blockage of the view has, however, been minimized by placing the tall strip charts (21 and 22) as close to the left wall as possible.

## APPENDIX D: BENEFITS/LIMITATIONS ANALYSIS, DESIGN IV

ERBS MOR Workstation Design  
George Mason University  
October 11, 1982

### Design IV (final):

#### o Benefits:

—human interaction: This design maintains side-to-side communication between the command operator and the shift analyst; contributes to the integration of personnel into a unified working group in which no one is totally isolated; and allows for adequate voice and sight interaction between command/ shift operators and support operators without causing undue distraction to the commander. Addition of a work table in the front, left corner provides a place for conferring before and after a pass.

—human-machine interaction: The commander and shift analyst have visual access to displays other than their own individual monitors and KCRTs; operators at units 9 and 12 are provided with some visual relief in comparison to the original design and to Design III where they would be able to see only their own displays; access to strip charts is improved for operators at units 6-9.

—traffic flow: Moving both doors to the new positions near the room's south wall greatly improves traffic flow through the MOR, reducing the possibility of distraction to the commander; support operators have improved access to the center of the MOR; the length and angularity of job-related routes have been reduced for some personnel.

—maintenance: Ease of maintenance is provided behind all but one unit.

—storage of documentation: If documentation is stored on console tops for units 1-5, 10-12, and 14-19, ease of access will be maintained, shelving for units 6-9 might be provided next to the pillar behind unit 6, and/or drawers in the strip chart units might be used for this purpose.

—view from the hall windows: Although units 6-12 are perpendicular to the hall windows, most displays can be seen from various vantage points. Visibility could be improved by installing a viewing ramp in the hall.

ORIGINAL PAGE IS  
OF POOR QUALITY

ORIGINAL PAGE IS  
OF POOR QUALITY

o Limitations:

—human interaction: There is a barrier to communication between support personnel at units 10-12 and those at units 6-9; support operators sitting closest to the hall windows have limited possibilities for voice or sight communication with command/shift operators; positioning of the table in the front, left corner requires MOR personnel to walk behind the commander, resulting in possible distraction. (If the table is not used during a pass, this limitation may not be a problem.)

—human-machine interaction: Support personnel at units 10-12 do not have easy access to strip charts; support operators farthest away from the center of the room (those sitting closest to the hall windows) have low likelihood of visual access to command/shift displays, but this positioning improves upon that of the original design which provided these operators with no visual access to other displays; location of the printer in the left, rear corner may result in some distraction to the commander due to the noise of its operation. (If use of the printer is not required during a pass, this limitation will be a problem only if printing operations are not completed before a pass begins.)

—traffic flow: New location of doors means that some personnel have longer job-related paths to exit the MOR, e.g., support operators near the hall windows are likely to encounter the greatest number of obstacles and the most angular paths, while location of the printer requires its operator to take a long, angular route within the MOR.

—maintenance: Unit 10 has no room for access in back; however, since this is a communications panel, it may be maintainable from the front.

—storage of documentation: Current shelving under hall windows will have to be removed; some rearrangement of storage racks will be necessary.

—view from hall windows: Installation of a viewing ramp would improve the view, which is partially blocked by units 6-12.

- o Summary: Of all the workable layouts considered, Design IV does the best job of achieving human factors criteria, including minimal distraction to the commander, while accommodating itself to the physical dimensions of the room and meeting maintenance requirements.

ORIGINAL PAGE IS  
OF POOR QUALITY

APPENDIX E: BENEFITS/LIMITATIONS ANALYSIS, IDEAL DESIGN

Benefits:

—human interaction: This design facilitates possibilities for voice and sight communication among all personnel, especially in the event of an emergency; it promotes a sense of group involvement, a sense of working together; it maintains the side to-side relationship between the commander and shift analyst; the addition of a glassed-in booth to enclose the table and printer provides a location for spontaneous meetings of MOR personnel and limits distraction to the commander.

—human-machine interaction: This design provides visual access to all operations (monitors, KCRTs, and strip charts) from all positions; in comparison to a design that isolates operators behind their own consoles, this design provides visual relief; it promotes cross-training of MOR personnel; noise is reduced by isolating the printer.

—traffic flow: A direct path across the south end of the MOR minimizes traffic passing behind the commander; this design greatly reduces the number of angular paths within the MOR, in comparison to the original proposal; spaces between units 1 and 13 and between units 5 and 14 provide alternate routes for access to storage along the north wall.

—maintenance: Ease of maintenance is provided for all units.

—storage of documentation: Frequently used documentation can be stored on console tops since there is no need to see over consoles; adequate space for documentation is provided around the perimeter of the room.

—view from hall windows: Because the view is largely blocked by units 6-13 and their console-top storage, small groups of visitors might be invited to view operations from the glass booth without disturbing MOR personnel. If feasible, addition of a viewing ramp in the hall would provide visual access to MOR operations.

Limitations:

—human interaction: The possibility of auditory overload has been considered. MOR personnel advise, however, that only one person should be speaking at any given time during a pass. Speaking should be in moderate tones, with only one incoming or out-going message at a time.

—human-machine interaction: The support operator and shift analyst are required to leave their positions for physical access to strip charts and printer, respectively.

—traffic flow: Some angular routes are necessary within the MOR, particularly for access to documentation stored along the walls; positioning of the doors isolates personnel at north end of MOR.



ORIGINAL PAGE IS  
OF POOR QUALITY

—maintenance: None.

—storage of documentation: Access to less frequently used documentation requires short trips within the MOR; console-top storage might be unsafe if not secured adequately.

—view from hall windows: The view is blocked by units 6-13 and console-top storage; it might be possible to install a raised platform or ramp for better viewing from the hall.

APPENDIX F: ENVIRONMENTAL ISSUES, BENEFITS ANALYSIS

Handout II  
ERBS MOR Workstation Design Issues  
George Mason University  
September 24, 1982

Lighting—The existing system will be used. Several actions can enhance the system from a human factors viewpoint.

- o Install incandescent ceiling spotlights over the individual workstations with a centralized "dimmer switch" control.

Benefits: provides extra available light; allows the human some control over the environment, affecting motivation and in turn performance, and helps to reduce glare. Glare on CRT screens from overhead fluorescent lights should be avoided. Glare can cause operator error, is visually fatiguing, annoying, and influences performance.

- o Use shades, blinds, or neutral density film on the back window which is a source of glare.

Benefits: reduces glare on the CRT screens that affects performance.

- o Anti-glare filters for the CRT screens will be used; glare free louvres for the fluorescent overhead lights can be used; and a hood over the flat console top can be used.

Benefits: All of these measures will cut down on the amount of glare. They also help diffuse the light within the room.

Acoustics—There will be several sources of noise within the MOR, e.g., strip charts, color printer, voice communications, normal conversation, and possibly noise from the equipment room when the door is open.

- o Install acoustical tiling on the ceiling and partially down the wall.

Benefits: Excess sound is absorbed; echoes are eliminated ridding the MOR of possibly distracting noises. This also helps create a positive ambience leading to better morale, job satisfaction and performance.

- o Install static-free industrial strength carpeting on the floor and partially up the wall to meet the tiling.

ORIGINAL PAGE IS  
OF POOR QUALITY

Benefits: Carpeting serves two functions; it absorbs noise and helps insulate against cold temperatures. It also helps create a positive ambience.

Temperature and Ventilation—The existing system will be used. Some human factors enhancements can be made.

- o Install carpeting.

Benefits: As expressed on the previous page, this will help insulate against the cold temperatures.

- o The extra space within cable holes should be insulated.

Benefits: Because of the lack of individual MOR heating units, every step should be taken to insulate against sources of cold air. Safety and comfort levels (no lower than 65°) should be maintained. The environmental temperatures also affect morale, job satisfaction, and in turn, performance.

Furniture and Equipment—Additions and enhancements within the MOR can be made.

- o Existing flat top console racks will be used requiring a 3 feet clearance from the back for maintenance purposes; rearranging the racks and repainting them would be beneficial.

Benefits: As discussed earlier, physical layout can positively affect several aspects of performance. Clean, freshly painted racks make the environment visually pleasing, affecting morale, job satisfaction and performance.

- o Mobile, easily adjustable chairs should be provided.

Benefits: This is one of the most important pieces of equipment in the MOR. The operator spends all of his time seated and needs the most comfortable chair available. Adjustability allows for individual control. Good seating reduces fatigue, and increases comfort, reducing chance for error and positively affecting performance.

- o Include a table.

Benefits: This will provide extra workspace. At present the keyboards occupy most of the available work space on the consoles. Additional space would be a plus.

- o Available bookcases and tape racks.

ORIGINAL PAGE IS  
OF POOR QUALITY

Benefits: Provides adequate documentation storage that is accessible.

- o Install a bulletin board strip between the acoustical tiling and the carpeting on the wall.

Benefits: Provides the operator with space to tack and hook things on the wall

Communications—Phone communications and voice communications will be used.

- o Flexibility in phone sets is available, both hand and head sets can be used.

Benefits: Provides the operator with a choice allowing for individual control and leading to job satisfaction. Performance is also positively affected.

- o Additional remote phone jacks can be installed.

Benefits: Provides every working position with easily accessible communication. Awkward working positions are avoided and adequate communication coverage is insured.

Keyboards—Both the IDT and the ISC terminals have keyboards that can not be deactivated.

- o Use plexiglass covers when the keyboard is not in use.

Benefits: Prevents accidental activation.

APPENDIX G: CHRONOLOGY OF COMMAND-CONTROL OBSERVATIONS  
AND ANALYSIS OF ERBS MOR WORKSTATION DESIGN

George Mason University

- July 26-28, 1982 Observe operations at Solar Mesosphere Explorer (SME) facility, University of Colorado, Boulder, Colorado.
- Sept. 1, 1982 Attend informal review meeting; discuss possible areas of flexibility and constraint in proposed design.
- Sept. 8-9, 1982 Observe in Data Operations Control (DOC).
- Sept. 16, 1982 Attend Human Factors Group seventh monthly meeting: Status Report on ERBS Human Factors Analysis (Appendix A); discuss several alternate workstation layouts with contract monitor (Karen Moe, Code 502).
- Sept. 22, 1982 Observe operations in Dynamics Explorer (DF-A) Mission Operations Room; discuss human factors issues with MOR personnel; discuss draft analysis of ERBS MOR workstation design with contract monitor.
- Sept. 24, 1982 Attend second informal review meeting; present analysis of ERBS MOR workstation design (Appendix B) and deliver Handout II: ERBS MOR Workstation Design Issues (Appendix F).
- Oct. 5, 1982 Observe in DE-A and DE-B MORs; continue discussion of human factors issues with MOR personnel.
- Oct. 12, 1982 Attend Human Factors Group eighth monthly meeting; present an oral status report on ERBS MOR workstation design; deliver Benefits/Limitations analysis of Design IV (Appendix D) to contract monitor.
- Dec. 16, 1982 Present overview of final report to Human Factors Group ninth monthly meeting.

PRECEDING PAGE BLANK NOT FILMED

PAGE 82 INTENTIONALLY BLANK