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EVALUATION OF
HUMAN ENGINEERING DESIGN STANDARD
(MSFC-STD-267A) IN THE DESIGN OF
MANNED SPACE VEHICLES

by

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Final Report

Standardization of
Human Engineering Design Criteria Task

Under

NASA Grant NGL-01-008-001

The University of Alabama in Huntsville
Division of Graduate Programs and Research
Research Institute
P. O. Box 1247
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FORWARD

This Final Report is submitted in compliance with National Aeronautics and Space Administration Grant NGL-01-008-001, from the Marshall Space Flight Center to the University of Alabama in Huntsville. The report is published in two volumes:

Volume 1 - Final Report

Volume 2 - Appendices

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- The questionnaire survey respondents

1.0 MAJOR CONCLUSIONS AND RECOMMENDATIONS

The major conclusion is that MSFC-STD-267A is unsuitable for the design of future spacecraft. This conclusion was reached on the basis of the analyses described in other sections of this report. The method recommended to alleviate this situation is a complete revision and update of MSFC-STD-267A. This revision, however, does not appear feasible in light of budget, time, and other program constraints within NASA. Therefore, an interim solution is proposed with subsequent phases for reaching this ultimate objective:

1. NASA initiate an interim revision/reformating of MSFC-STD-267A commensurate with the recommendations made in the rewritten sample section and other sections of this report. The primary reference documents used in the literature review (Section5.2)shall provide the zero-gravity supplement which should be published with this revision.

2. After the revised MSFC-STD-267A has been published, a section-by-section rewrite should be initiated. This revision should reflect results of a thorough analysis of recent research findings. This revision of the document could be published in sections to reduce costs and lead time.

3. The final step in the process is to implement a plan to periodically maintain the documentation in a current form. This phase should include the identification of research requirements to augment available research documentation.

TASK 1 - REVIEW AND CRITIQUE OF MSFC-STD-267A

The major conclusion of the item-by-item review and critique of MSFC-STD-267A is that the standard has several problems which tend to make it difficult to use and to enforce. Ambiguities, conflicts, unenforceable requirements, and the lack of current data were cited as contributing to this problem. These problems are discussed in detail in Section 5.1 and are summarized below.

- MSFC-STD-267A was not intended to be a zero or reduced gravity standard and, therefore, does not contain any specific information applicable to space environments.

- MSFC-STD-267A has never been revised, and, therefore, has not kept pace with expanding technology. Considerable data are out-of-date (7.5%) and many voids exist with respect to advances made during the last six years.

- Conflicting data were found in a number of paragraphs in MSFC-STD-267A.

- Ambiguities and unenforceable requirements exist in 114 paragraphs out of a total of 1200 paragraphs.

- Sixty sections (5%) contain duplicate or repetitive data.

- Presentations of the data are not consistent with good human factor concepts. The material is presented in such a manner that it often discourages use of the document.

TASK 2 - REQUIREMENTS FOR A NASA STANDARD FOR FUTURE MISSIONS

Future missions were examined to identify requirements for a NASA human engineering standard. In addition, past and current spacecraft designs were examined to identify design precedents and to evaluate the degree of design standardization in NASA's existing spacecraft. The results of this task are discussed in Section 3.0. The major conclusion is that the need for greater standardization is vital to the success of future space missions. Specific study conclusions are listed below.

- The ability to change the astronaut (e. g. training and selection procedures) will be reduced in future missions compared to former missions.

- The psychological/physiological effects of extended duration missions is unknown.

- MSFC-STD-267A has little impact on MSFC managed programs resulting in conflicting design philosophies among the various contractors.

- Activities in future missions will increase in number, but not significantly in type of activity (mostly sequential operations).

- Crew selection, skills and training will change most significantly. Will be flying scientific personnel with short training programs.

- Habitability and social factors may be more significant on future missions than on past missions because of the reduced crew selection and training efforts and the lengthy Space Station missions.

- Psychological/physiological stress may be a significant factor in future missions because:

  o The short duration, shuttle-based missions will require high activity levels during short experiment data collection sessions.

  o The reduced selection and training programs may introduce more vulnerable personnel.

- Since there is evidence of human factors inconsistencies in former spacecraft, it can be concluded that human factors standards either were not used or were not effective. Since crew selection and training can no longer be relied upon to compensate for design inadequacies, a human factors standard for the future must be prepared.

- To provide data needed to design future spacecraft, a human factors standard would have to supply data on the following:

  o Man/Machine Function Allocation

  o Crew Station Design

  o Control/Display System Design

  o Environment

  o Crew Work Load Assessment

  o Lighting

- o Anthropometry and Human Capabilities
- o Maintainability

TASK 3 - REVIEW OF LITERATURE SOURCES

Nine major data sources were selected and reviewed to identify data that would enhance MSFC-STD-267A. The documents also provided insight into a variety of ways to present human engineering data. The primary sources were:

- One government-wide standard, MIL-STD-1472A.
- Four contracted studies and study collections (Serendipity Report, Lovelace Compendium, G.E. Handbook, Bioastronautics Data Book)
- Four General Handbooks (Morgan, Kubokawa, Army, and Navy Maintainability Guides)

The literature review is discussed in detail in Section 5.2. The major conclusion is that the data in these sources provide a sufficient data base to rewrite/reformat MSFC-STD-267A into an effective human engineering standard. Additional conclusions are listed below.

- More current information was identified in the reviewed sources.
- Several sources contained zero-gravity data which could be integrated into MSFC-STD-267A.
- A number of sources made a better use of figures, graphs and illustrative material.
- Data were isolated which would enhance specific sections of MSFC-STD-267A.
- MSFC-STD-267A would definitely be improved with the addition of data from all of the sources reviewed.

TASK 4 - SURVEY OF NASA/MSFC CONTRACTORS TO DETERMINE USEFULNESS OF MSFC-STD-267A

One hundred fifty questionnaires on human engineering design standards were distributed to NASA/MSFC contractors throughout the country. The results of the questionnaires are presented in Section 5.3. The major survey conclusions support the review and critique findings that MSFC-STD-267A is largely ignored by MSFC contractors and that the most significant problems with the standard are the inaccessibility and non-specificity of the data. Specific survey conclusions are listed below.

- MSFC-STD-267A is considered to be current as of five to eight years ago.

- Nearly half of human factors decisions are made above the designer's level.

- Management and designer resistance are the major factors in poor human engineering design.

- Company specific standards and other data books are used in spite of the fact that MSFC contractors are contractually obligated to comply to MSFC-STD-267A.

- Resistance of program managers is a primary reason for the lack of human engineering inputs into systems design.

- A human engineering standard, in order to be effective, must include provisions for circumventing the manangement and designer resistance factors in human engineering design.

- MSFC-STD-267A requires a general update and reformating of data. This update should include more graphic and less narrative data and be reorganized to increase the accessibility of the data.

- Either separate human engineering standards for applications should be used or a single government-wide standard with addendums for specific applications (spacecraft, submarines, etc.). A NASA-wide standard is preferred to separate center standards.

- The human engineering standard should be imposed in the Statement of Work and the contractor should be penalized for not meeting the standards.

- The standard should be limited to specific criteria with direct application to hardware design.

- The standard should contain design data and to a lesser degree analysis techniques and supporting rationale.

- MSFC-STD-267A is largely considered as a general human factors reference for use by human factors specialists.

- MIL-STD-1472A is considered to be a more valuable human factors data source than MSFC-STD-267A.

TASK 5 - RECOMMENDATIONS FOR IMPROVEMENT OF FORMAT AND ORGANIZATION OF MSFC-STD-267A

Utilizing the results of the review and critique, literature review, and questionnaire survey, recommendations were prepared for the format and organization of a revised standard. This task resulted in specific recommendations as to the layout, depth of data, illustration usage, references, retrieval methods and cross referencing. Specific conclusions are listed below.

- Both general and specific human engineering data must be provided to afford a variety of users data at a level of depth which is commensurate with their experience/training.

- Definitions should be provided of human engineering terms which may not be familiar to all users.

- Illustrations should be used wherever possible to augment or simplify narrative descriptions.

- Illustrations should be located in unambiguous proximity to the associated narrative.

- Reference should be cited where data sources are identifiable.

- Source "type" data should be provided to inform the user as to the origin of each requirement (i.e. research, design precedence, etc.).

- A retrieval logic diagram should be provided to assist the user in identifying and locating data.

- Standardized figure and table formats should be utilized to reduce confusion in interpretation.

- Up-to-date examples of current designs should be used.

- Cross-referencing should be employed throughout the standard to reduce search time and to assist in the identification of related data.

TASK 6 - SAMPLE SECTION REWRITE

A single section of MSFC-STD-267A was rewritten to implement the recommendations of this report. This sample section rewrite is presented and discussed in Section 7.0. It is felt that the sample section rewrite demonstrates that the recommendations presented in this report can be implemented, and do provide a viable means for presenting human engineering data in a standard.

2.0 INTRODUCTION

Marshall Space Flight Center Human Engineering Standard 276A, published in 1966, is a Human Engineering Standard for aerospace equipment. At that time most of the involvement of the Marshall Space Flight Center in vehicle design did not extensively involve on-orbit or zero gravity operations. Consequently, the document was directed primarily toward ground support equipment and spacecraft equipment that was to be assembled or maintained on the ground.

In this same time period the military counterpart to MSFC-STD-267A, MIL-STD-1472, was introduced. This standard was also primarily intended for ground operations and included only minimal zero gravity data. Since MSFC-STD-267A and MIL-STD-1472A were not completely redundant, both standards were imposed on a number of NASA contractors. As a result, considerable interest developed in combining or integrating the standards into a single document to reduce cost and increase efficiency and use.

A question of particular interest was the degree to which the two documents were congruent. In many cases both documents were imposed upon the same contractor. Feedback from some contractors suggested that the design requirements conflicted. At the same time, a growing body of data suggested that standards were ignored by design engineers. Human engineering specialists were indicating to their NASA counterpart that the documents were largely ignored due to their lack of enforceability. As a result, MSFC felt that a thorough review of the two documents was timely.

In May, 1971, The University of Alabama in Huntsville was awarded a grant (NGL-01-008-001) to conduct a study into standardization of Human Engineering Design Criteria. This study involved a seven task scope of work to be performed over a nine-month period.

The grant's major objectives were the following:

1. Compare MSFC-STD-267A and MIL-STD-1472A to determine the feasibility of consolidating these two documents into a single standard.

2. Review space station, space shuttle, and earth orbital research and application missions to identify what a design standard for these missions would have to provide.

3. Identify areas requiring additional definition and data sources which could augment existing data in MSFC-STD-267A and MIL-STD-1472A.

4. Determine methods of rendering the design standards more useful.

5. Review and critique MIL-H-46855 and MSFC-STD-391, and recommend methods of enhancing the useability of these documents.

6. Determine feasibility of developing standards which decrease weight and increase efficiency.

7. Determine what human factors standards should be provided MSFC contractors.

Soon after the study was initiated, it was decided that these basic objectives should be modified to provide a more meaningful product. Through conferences with the Contracting Officer's Represent ive and other interested NASA personnel a new scope of work evolved. As a result, the University of Alabama in Huntsville (UAH) submitted a proposal to change the scope of work of the grant and to extend the period of performance to 12 months.

The proposed modifications to the grant were accepted by NASA and a new scope of work was implemented. The revised scope of work contained the overall objectives of assessing the usefulness of MSFC-STD-267A in future NASA missions and in integrating methods to render the standard more useful.

The major differences between the original scope of work and the revised versions were that:

1. A comparison between MIL-STD-1472A and MSFC-STD-267A was deleted in favor of a detailed review of MSFC-STD-267A and its application to future missions.

2. An indepth review of other standards (e.g. MIL-STD-1472A) handbooks, textbooks, etc. was added to assess their usefulness in an update of MSFC-STD-267A.

3. A survey of NASA contractors and human engineering personnel was added to determine the usefulness of MSFC-STD-267A and to determine recommendations for improvement.

4. The rewriting of a single sample subsection was added to demonstrate recommendations resulting from the study.

The new study scope of work generated to accommodate the differences discussed above include the following tasks:

1. Thoroughly review MSFC-STD-267A to determine if MSFC-STD-267A is sufficient to meet present needs and recommend ways to improve

the standard. For example, this would include data needed regarding design parameters in reduced and zero-gravity environments as well as provisions for mixed crews, etc.

2. Review the role of the astronaut in space station, space shuttle, and RAM to identify requirements for a NASA Human Engineering Standard.

3. Survey the human engineering literature to isolate sources for initial data identified in tasks one and two. Candidate data sources were other Human Engineering Standards and other documents resembling standards, research findings, current studies, handbooks and text books.

4. Compare the additional data requirements identified in tasks one and two and data sources identified in task three to make recommendations for further research and simulation.

5. Conduct a survey of NASA MSFC selected contractors to determine the usefulness of existing standards and to receive their recommendations for improvement.

6. Evaluate and recommend new organizations/configurations for an up-dated standard.

7. Review MIL-H-46855 and MSFC-STD-391 and recommend methods of enhancing useability.

8. Rewrite a single sample subsection of MSFC-STD-267A to reflect the recommendations and data findings outlined in the above tasks.

It was not the purpose of the study reported here to evaluate or to define methods of implementing human factors principles in the design process. That is, it was not the purpose of this study to compare the relative requirements of standards and detail specifications; requirements for acknowledged human factors specialist's concurrence; ground-based simulations; mockups; etc. as methods of implementing human factors principles. Rather, it is to evaluate the effectiveness of MSFC-STD-267A and to recommend methods for improvement.

2.1 REPORT ORGANIZATION

This final study report is organized to afford the reader a summary of the general study findings in addition to the detailed data generated in each task. The study conclusions and recommendations are presented in Section 1.0. Section 2.0 describes the background and scope of the study. The role of man in future space missions and its impact on human engineering standards is discussed in Section 3.0.

The methodology employed in each major study task is described in Section 4.0 with results for each task presented in Section 5.0. The format/organization recommendations are described in Section 6.0 and illustrated in a sample section of a standard presented in Section 7.0.

Five appendices are included to provide raw data for several study tasks and the results of a critique of the NASA and military implementation documents.

3.0 ROLE OF MAN IN FUTURE MISSIONS

3.1 INTRODUCTION

A major objective of the present evaluation of MSFC-STD-267A was to assess its adequacy for design in future manned missions. To perform this evaluation it was necessary to: (1) Critique 267A and determine its impact on current vehicular design. (2) Determine anticipated changes in mission objectives, vehicles, etc. (3) Study the changing role of the astronaut in manned flights. (4) Delineate what specific standardized design data are needed and make recommendations.

In early manned missions the astronaut had a great deal of influence on the design of his spacecraft which was, for all practical purposes, a custom made vehicle. The emphasis on individualizing the vehicle was certainly justified during early missions in which the element of risk was so high. The element of pioneering-risk, however, decreases with each new success. Congress and the public are now demanding more scientific accountability in future missions. Consequently, greater emphasis is placed upon the accomplishment of scientific data gathering objectives. In terms of vehicle design, multi-purpose work stations are anticipated. Scientific work consoles will be utilized by a number of crewmen on rotating work-shifts. Individualized design under these conditions would be highly undesirable.

It is the purpose of this section to describe the effects of this changing involvement of man in each of the space programs from Project Mercury through the 1980's Space Station, and how these effects impact a human factors standard. The report begins with an assessment of the impact of existing standards and precedents on current design

(Section 3.2). Section 3.3 presents a discussion of the activities anticipated on future missions. Section 3.4 describes how future mission activities compare to former missions from Project Mercury to date. In Section 3.5, the requirements that future missions will impose on a human factors standard are implied by describing design decisions that will have to be made. Finally, Section 3.6 summarizes the findings of this review of future missions and projects their impact on a human factors standard.

3.2 IMPACT OF EXISTING STANDARDS ON CURRENT AND PAST DESIGN PRACTICES

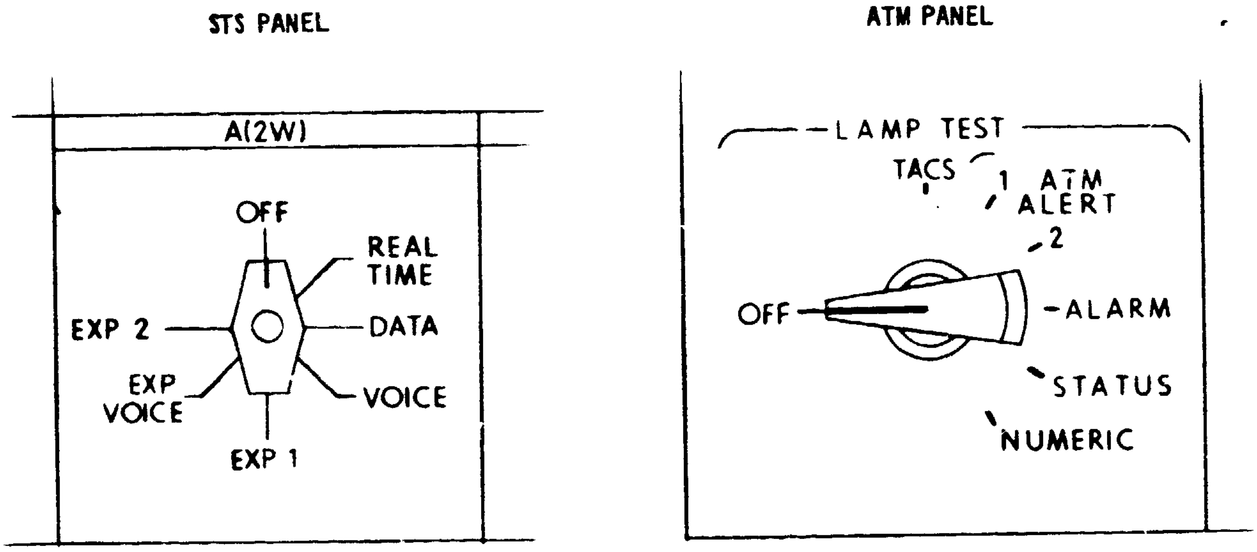
A brief review of the history of the U. S. manned space flights was instructive in revealing the logical augmentation of complexity in manned flights. As mission objectives, vehicle complexity, mission duration, etc. increase, so also did the demands upon the crew. More tasks of greater complexity were expected. Of particular interest were the design precedents which evolved as missions became more ambitious. For example, to what extent have these precedents resulted in standardization and commonality.

Throughout the Mercury, Gemini, and Apollo Programs severe time and scheduling constraints were obvious. In spite of these pressures, man-systems compatibility was certainly paramount in all three programs. This emphasis was apparent in Gemini in the development of docking and EVA technology. Emphasis on design compatibility was also evident in the Apollo Program encompassing such critical functions as Lunar Landing, Lunar Driving, Lunar Navigation, etc. The success of these programs has drawn international acclaim and will undoubtedly constitute the major historical event of the decade. The present evaluation of these vehicles in no way detracts from this achievement. Rather, as new programs evolve, with different emphases and constraints, reassessment is required to assure the same degree of success in future missions.

A review of the man/system design interface in Gemini and Apollo reveals NASA wide vehicle design precedents. Design preference was developed largely by individual astronauts in conjunction with the various contractors. As a result, commonality or standardization tend to be contract specific. Industry standards are used in preference to MSFC-STD-267A.

This conclusion can best be illustrated by examples. A revealing comparison is between the Skylab Structural Transition Section (STS) and the Apollo Telescope Mount (ATM) panels. These panels are in close physical proximity in Skylab and were developed by two different contractors each obligated to conform to MSFC-STD-267A. The same crewman will operate both panels.

ROTARY SWITCHES: Figure 3-1 depicts the rotary switches used in the STS and ATM panels. In addition to the obvious differences in switch shape, two different "off" positions are used on the two panels.

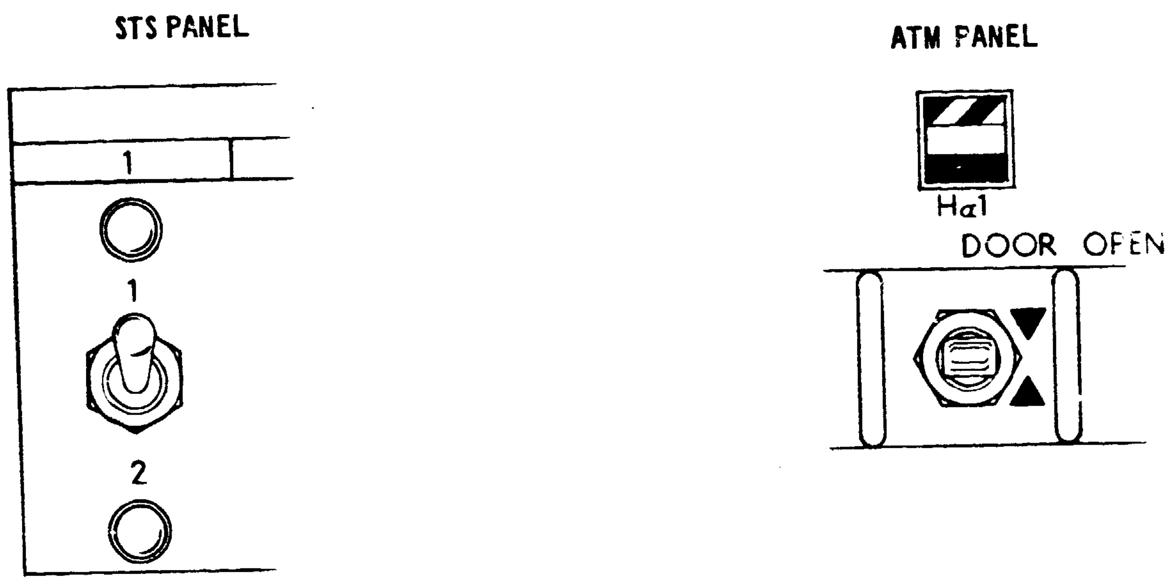


ROTARY SWITCHES

NOTE "OFF" POSITIONS

FIGURE 3-1

FUNCTION STATUS INDICATORS: A second example is the use of function status indicators. As shown in Figure 3-2, the STS panel uses status indicator lights where the identical function is performed on the ATM panel using a mechanical indicator.



FUNCTION STATUS INDICATORS

FIGURE 3-2

LABELING PHILOSOPHY: The differences in labeling between the two panels are illustrated in Figures 3-3 and 3-4. Grouping of switches is accomplished with boxes on the STS panel whereas the same function on the ATM panel is accomplished by bracketing. Different philosophies for the labeling of switch positions are also used between the two panels as illustrated in the figure.

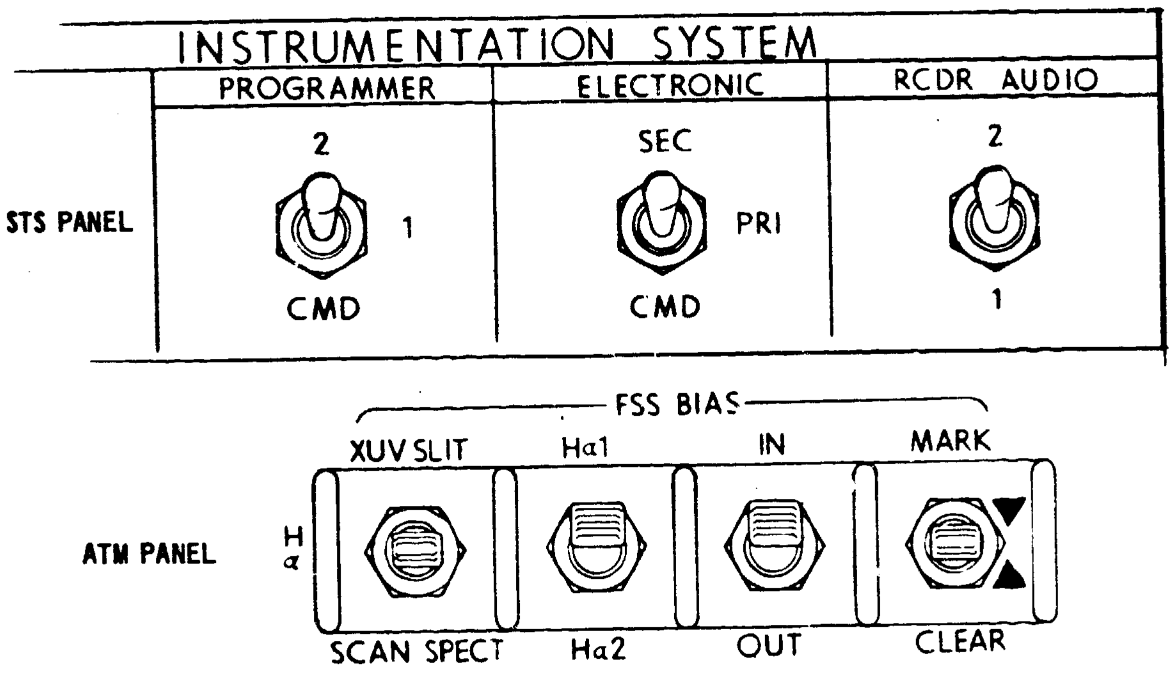


FIGURE 3-3 LABELING

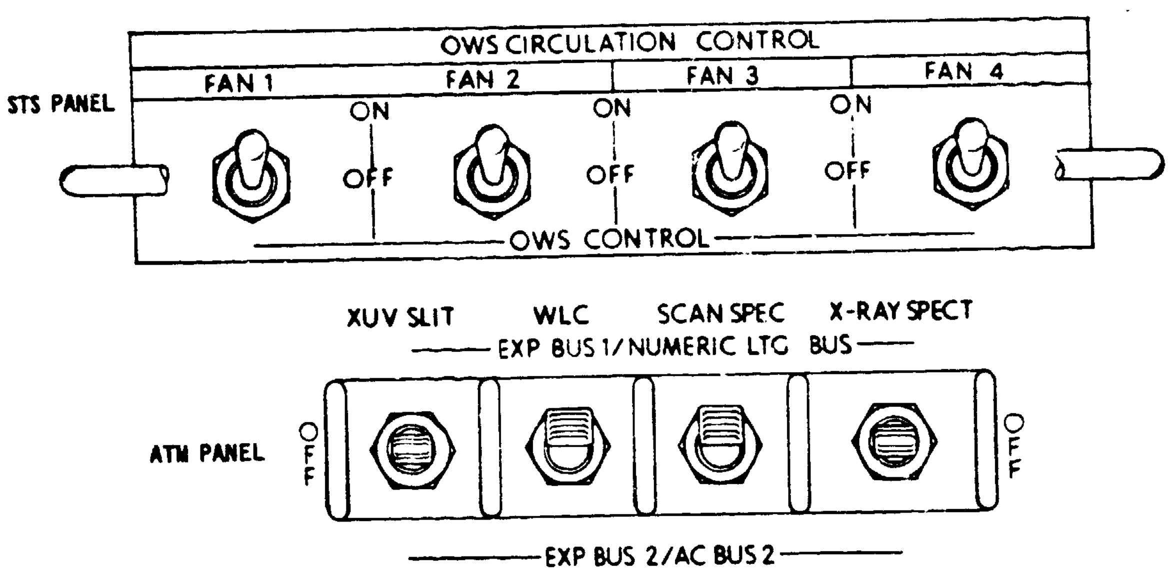


FIGURE 3-4 LABELING OF SWITCH POSITIONS

CONTROL GUARDS: Another example of design inconsistencies between the two panels is in the method of control guarding. As can be seen in Figure 3-5, the STS panel utilizes horizontal control guards, whereas the ATM panel utilizes vertical control guards.

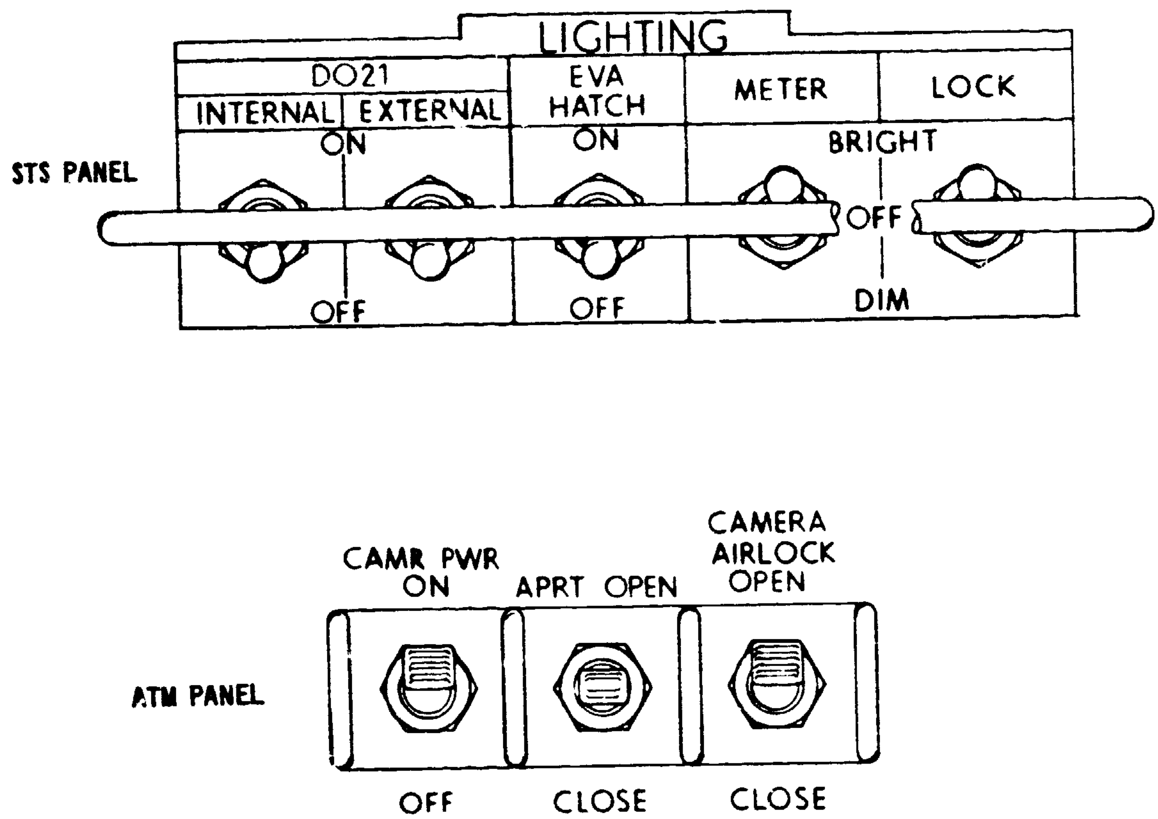
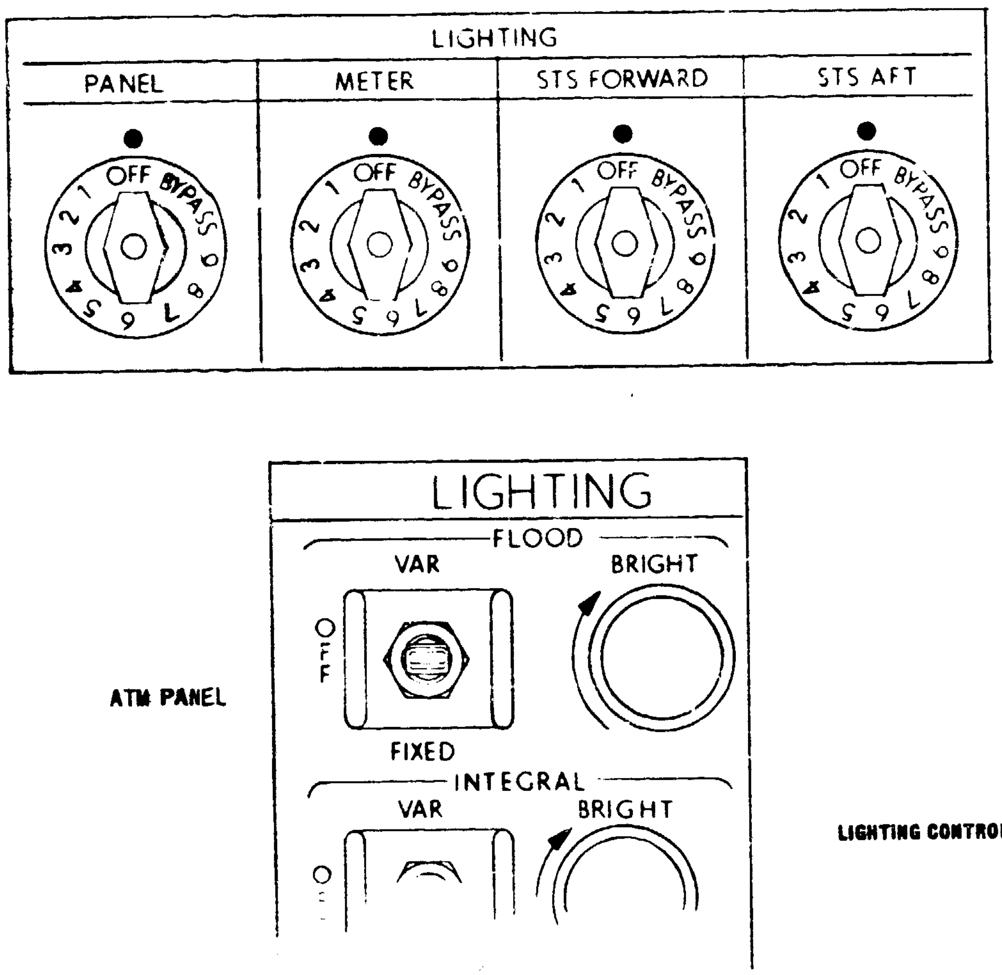


FIGURE 3-5 **CONTROL GUARDS**

SIMILAR FUNCTIONS: Figure 3-6 illustrates an example of how two identical functions (lighting levels) are accommodated by the different design philosophies on the STS and ATM panels.

STS PANEL



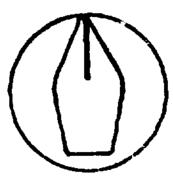
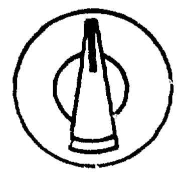
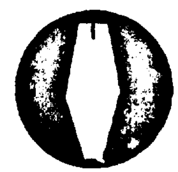
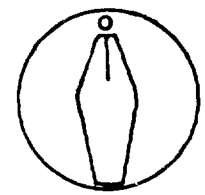
ATM PANEL

LIGHTING CONTROLS

FIGURE 3-6

A further revealing comparison is the design philosophies of past and current programs with the present definition of the Space Shuttle. Table 3-1 gives a summary of the design philosophies from Gemini through the planned Shuttle Program. The table clearly illustrates the contractor-specific nature of the design criteria and supports the conclusion that MSFC-STD-267A, as it presently exists, is not adequate for assuring design commonality in NASA's next generation spacecraft.

TABLE 3-1 SUMMARY COMPARISON

	GEMINI	APOLLO	SKYLAB		SHUTTLE	
			STS	ATM	MDAC	NORTH AMERICAN
TOGGLE SWITCH						
ROTARY SWITCH						
LABELING TECHNIQUES	boxes	bracketing	boxes	bracketing	boxes	bracketing

3.3 DETAIL ANTICIPATED CREW ACTIVITY SUMMARY

A recent study report entitled, "Flight Experiments on Work Performance,"[(1)] involved a detailed analysis of the activities anticipated for future space crews. Results of an analysis of operations required for the Space Station and NASA "Blue Book" experiments are reported.

Although this study was designed to generate requirements for an experiment program to test man's performance on the activities identified, the results will be useful here. Activities that are anticipated have been arranged in three major groups: Psychomotor (habitual level), Psychomotor (cognition required), and Cognitive. Table 3-2 presents the frequency of occurrence of the identified activities in each of sixteen task element categories within the three major groups. The task element categories are defined in Table 3-3.

By comparing this table with former space flights (see Table 3-4), it can be concluded that, although the spacecraft and experiment systems of the future are quite different from their predecessors, the types of activities required of the crew will not be. That is, the major percentage of activities involve sequential operations, etc., and the least involve decision making. This philosophy of utilizing men in orbit to activate and control preprogrammed systems is a continuation of the mission philosophy employed in current programs. Although some scientific decisions will be made in orbit, their occurrence is infrequent. The effects the anticipated activities will have on design and design standards are discussed in subsequent sections.

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(1) URS/Matrix Company, 1972.

TABLE 3-2

FREQUENCY OF OCCURRENCE OF EACH TASK ELEMENT
IN SPACE STATION AND EXPERIMENT MISSIONS

TASK GROUP/ELEMENT	PERCENT OF ACTIVITIES REQUIRING TASK ELEMENT
PSYCHOMOTOR (Habitual Level)	
BODY POSITION CONTROL	34%
MASS HANDLING AND TRANSFER	29%
SEQUENTIAL OPERATIONS	71%
LOCOMOTION AND MOBILITY	19%
FORCE EMISSION	29%
PSYCHOMOTOR (Cognition Required)	
MONITORING	57%
CONTINUOUS CONTROL	18%
COGNITIVE	
COMPARISON	32%
DEDUCTION	50%
ISOMORPHIC CODING	28%
PATTERN RECOGNITION	19%
VERBAL COMMUNICATIONS	15%
ESTIMATION	14%
SUBJECTIVE JUDGMENT	10%
INDUCTIVE REASONING	10%
DECISION MAKING	9%

TABLE 3-3

TASK ELEMENT DEFINITIONS

Psychomotor (Habitual Level)

- Body Position Control - Attaining a desired posture and maintaining one's body in a desired position.
- Mass Handling and Transfer - Controlling an article such as a cargo item while removing it from or placing it into a location, or transporting that item from one location to another.
- Sequential Operations - Step-by-step performance of preprogrammed sequence of activities.
- Locomotion and Mobility - Self-propelling one's body to a desired location and maintaining control over the path and rate of motion while moving.
- Force Emission - Exerting a controlled force on an object.

Psychomotor (Cognition Required)

- Monitoring - Observing the process of system operation (nominal and off nominal) through the review of status indicators such as caution and warning lights, flags, indicator lights, digital displays, meters, etc.
- Continuous Control - "Man-in-the-loop" control of system parameters such as control during landing,or pointing a stellar telescope at a selected star.

Cognitive

- Comparison (Physical Reference) - Determining the magnitude of some parameter (e.g., size, weight) of an object by relating it to a known object.
- Deduction - Drawing a conclusion based on a set of relevant and complete information for which the rules of deduction are known *a priori*.

TABLE 3-3 (continued)

Cognitive (continued)

- Ismorphic Coding - Translating a symbol(s) from one reference system to another.
- Pattern Recognition - Classification of a phenomenon or an event based on current data. The classification rules may be either deterministic or probablistic.
- Verbal Communications - Conversing with another individual through the verbal means.
- Estimation (Mental Reference) - Determining a magnitude of some parameter (e.g., size, weight) of an object without the aid of comparison with objects of known size.
- Subjective Placement - Selecting the input or output level of a system where no "optimum" level is defined, such as the brightness of indicator lights.
- Inductive Reasoning (Inference) - Generalizing from available data to develop principles or concepts.
- Decision Making - Selection of a course of action based on a determination of the course most likely to succeed. Such a course of action might be the selection of a scenario of activities for a given day.

3.4 CREW PARAMETERS

The emphasis on scientific accountability within the NASA Space Program for the 1970's and 1980's will significantly change the role of man in future missions (See Table 3-4). Rather than the specialized systems and highly qualified, highly trained astronauts of former programs, more versatile spacecraft and diversified crews will be used. The most dramatic change in future programs may well be in the areas of crew selection and training and on-orbit activities. The impact of these changes and of lesser changes in other areas is discussed below.

The increase in crew size expected on the Space Shuttle missions will not significantly impact flight crew operations since two highly trained men will be assigned these functions. However, Shuttle experiment crews and Space Station crews of up to ten men will have to set up, operate, and maintain equipment for periods of seven to ninety days. This large crew will probably be used on missions where continuous data taking or station-keeping will be required. In this case, crews will operate in shifts. This situation requires several men to operate the same equipment. To minimize the training time required for a number of crewmen operating the same equipment, it must be designed to meet the consistency and commonality principles of human factors.

One of the major factors which will impact future design is the variation in skill types of the crewmen. The scientific crewmen who will conduct Shuttle experiments and who will man the Space Station will not necessarily have both the engineering and piloting skills of Mercury, Gemini, and Apollo crewmen. This will very likely cause significant changes in the design of equipment.

Crew selection may change as drastically as crew skills. Scientific personnel who are selected on the basis of scientific criteria and physical condition (e.g., resistance to motion sickness, etc.) cannot necessarily be expected to be capable of performing under the stresses of the orbital environment as well as past crewmen. This holds in the sense that with less training and exposure to stressful environments, less habituation will occur.

Designers will have to design systems for operation by a less-select crew population than in former missions. More variability can be expected in all phases of crew behavior from psychomotor coordination to group social interaction.

The work/rest cycles of future missions will be less strenuous than former flights, thus presenting some advantages and disadvantages. This is especially significant in the extended duration Space Station missions where lower motivation levels are expected due to the length of the missions. Although crews should be more relaxed because of more conventional work/rest cycles, performance may be degraded by low moti vation levels, Considerable study of this area must be performed before its impact can be predicted. A most significant factor resulting in performance degradation in previous confinement studies has been boredom and monotony.

The reduced crew training activities on future missions augments the emphasis on consistency and compatibility in man/systems design. Crewmen, particularly experiment crews, will not spend years in training programs to compensate for design inconsistencies. Training can be expected to be conducted on a larger scale than previously, but over a shorter period of time. This will necessitate extensive design for ease of operation.

For example, the last two Apollo crews, (e.g., Apollo 15 and 16) have averaged eight years in the space program. To assume that future crews can invest this much time in specific orbital training and preparation may be unreasonable.

On-orbit acrivities is another crew area that is undergoing change. The increased number and diversity of functions assigned to crewmen can be expected to increase the difficulty of their tasks and of their training program. Increased numbers of functions are likely to be assigned to each crewman on future missions.

A major conclusion is that the degree to which man can be adjusted (i.e., selection, training, procedures, etc.) to accommodate NASA's next generation of spacecraft and missions may be <u>greatly</u> decreased in future missions. It is, therefore, necessary that NASA develop design standards and/or baseline hardware configurations to assure that spacecraft design will be compatible with the next generation crewmen.

Significant changes in crew selection and training are accompanied in future missions by changes in two factors which have not been discussed:

1. Habitability/social variables and
2. Psychological/physiological stress.

Since crew selection and training are expected to be less extensive than in former programs, some group interaction problems may arise. It is obvious that as mission duration increases, crew mix and social variables will assume increased significance.

Psychological/physiological stress assume an increased importance as compared to earlier flights. A major factor contributing to this is the crew selection and training process. The personnel who will participate in Shuttle flights may not be as resistant to the stresses of orbital flight as crew personnel to date. Measurable physiological changes have been documented in at least three major physiological systems due to prolonged exposure to zero-gravity. These changes have affected the muscular-skeletal system, the vestibular system, and the cardiovascular system. Various scientists (Chambers, Hardy, Gerathewohl, etc.) have expressed concern about the effects of long duration missions on astronauts. Chambers, for example, has discussed the stress produced by isolation and confinement in space. He concluded by warning that "...the effectiveness of man in space during prolonged confinement and exposure to disorientation can depend to a large extent on the success of physiologists and psychologists to mitigate the potentially degradative effect on perceptural motor and intellectual performance." (p. 288)

3.5 FUTURE DESIGN DECISIONS

The question of what type of human factors standard is needed for future vehicle design relates most importantly to the decisions which must be made in designing these vehicles. Using past programs as a basis, several major decision categories have been identified.

The requirements for each of these major categories are discussed below. Data on each of these topics which will allow firm design decisions to be made must be provided in a future standard.

Man/Machine Function Allocation:

The criteria upon which man or machine function assignments are made must be defined before interface hardware design can be initiated. The base of experience derived from past programs and ground-based studies appears to be adequate to establish these crucial criteria. The number and variety of functions required on future programs significantly exceeds those of the past, and as a result, impacts function allocation decisions. Some of the functions that must be analyzed and ultimately assigned to man or machine are:

- Interrogation of subsystem faults
- Control during docking operations
- Monitoring of experiment parameters
- Setup and calibration of equipment
- Launching of subsatellites
- On-orbit satellite maintenance
- Cargo handling

Crew Station Design:

Crew stations are expected to be similar to those of the Apollo and Skylab vehicles. Major control centers such as the Shuttle cockpit and Space Station command/control center are expected to be operated by two crewmen. Generally, the individual crew stations will afford complete redundancy of function so that a single crewman can operate the systems. Some of the features that are expected are:

- Two-man crew stations
- Zero-gravity restraint devices
- Sleeping quarters integrated into crew station couches (on shuttle)
- Zero-gravity maneuvering aids to allow ingress/engress of work sites.

Control/Display System Design:

Control/Display systems on future vehicles are expected to employ general-purpose components rather than the dedicated devices of the past. Crewmen will be maintaining and controlling larger, more complex systems than in the past which will require increased sophistication in control/display and computer systems. Keyboards are expected to provide most control functions while CRT's, diode displays, and transilluminated indicators will provide most display data. The control/display panel that is expected to present the most challenging design is in the Shuttle cockpit. This station will have to allow control of the vehicle during launch, orbital operations, re-entry, aerodynamic flight, and landing. Some of the design parameters that will have to be considered are:

- Display formats
- Information encoding
- Integrated versus dedicated controls for each application
- Integrated versus dedicated displays for each application
- Pictorial versus symbolic displays

Environment:

Basis environmental tolerances (atmospheric, radiation, vibration, noise, and thermal) currently used in space cabin design appear adequate for future vehicles. All current concepts for future vehicles include a 14.7 psia atmosphere of O_2 and N_2 which should alleviate many physiological problems encountered in the reduced pressure, O_2 atmosphere used to date. Pre-breathing time for extravehicular activity may also be reduced or eliminated if pressure suit technology continues to advance. Typical design considerations would include:

- CO_2 partial pressure limits
- Relative humidity range
- EVA prebreathing time
- Maximum contamination levels
- Temperature range
- Noise levels

Crew Workload Assessment:

The more diverse crews of future missions are likely to complicate the design task of estimating crew workload. Since more individuals (less rigidly selected and trained) will be operating the equipment, more variability can be expected in timelines and workload. These factors will not be able to be adjusted for each flight as they have to date, but must be commensurate with the entire population's capability. Some design considerations in assessing workload are:

- Information processing capacity
- Information type/density/format
- Perceptual capacities
- Task criticality

Lighting:

The lighting environment in future spacecraft is expected to be similar to that of current vehicles with the possible exceptions in the Shuttle cockpit and control/display panel lighting. Backlighting and edgelighting have received considerable interest as control/display panel lighting techniques. If used, floodlighting of these areas must be controlled in intensity and hue to avoid washout and to retain dark adaptation. Typical design items are:

- Ambient illumination levels and adjustment ranges
- Contrast values
- Color selection
- Illumination type (direct, indirect, diffused)

Anthropometry and Human Capabilities:

Since the 1980's population will be the users of the vehicles currently being designed, their anthropometric and physical capabilities data must be used in crew interface design. These data as well as corresponding female data must be provided in the proposed standard in raw data form or in design guidelines based on the raw data. Some design values that must be specified are:

- Force exertion values
- Reach envelopes
- Body size and shape

Maintainability:

Maintainability criteria must be defined for programmed, on-orbit maintenance of future vehicles. Although programmed, on-orbit maintenance is not anticipated for the Space Shuttle and Shuttle payloads, it is a realistic consideration for the Space Station. Typical design considerations include:

- Level of maintenance
- Accessibility
- Special tools
- Testing facilities
- Testing/malfunction isolation techniques
- Spares inventory

3.6 SUMMARY

Although the Mercury, Gemini, Apollo, and Skylab program vehicles were designed under existing human factors standards there is little evidence that the vehicle designs were affected by the standards. Several examples of design conflicts on the Skylab program were cited earlier in this report. Similar inconsistencies can be found on all spacecraft designed to date. Despite this fact, the U. S. Space Program has been remarkably successful. It may be instructive to investigate this apparent contradiction.

There are **four** obvious ways the situation described above could happen:

1. The human factors design standards were not used (or not enforced) in the design of the subject spacecraft.

2. The human factors design standards provide criteria which are easily misunderstood and easily satisfied even with poor designs.

3. Crew selection, training, and procedures combined with equipment redundancy and fail-safe features have compensated for design inadequacies.

4. Human performance on many tasks will be as proficient with or without the design standard.

The contractor questionnaire/survey results described in another section of this report can be used to support the hypothesis that existing standards were not used or not enforced (Number 1). The questionnaire and MSFC-STD-267A critique results both support hypothesis Number 2, that the stated criteria can be misunderstood and/or easily satisfied. Furthermore, the discussion in Section 3.1 of this report which describes crew selection and training in former programs certainly supports hypothesis Number 3, that the crew could compensate for many design inadequacies. Considerable research would be required to establish the performance levels with or without the standard (Number 4). Since all four hypotheses are supportable and there is no way to positively isolate causes of historical events, one must proceed as if all causes were significant.

The major conclusion derived from the role of man analysis presented above is that human factors design standards will be more important in future programs than they were in the past. This is largely based on increases in crew sizes, increases in vehicle autonomy, a change in the crew selection process, and reductions in training time. These factors indicate the hypothesis Number 3 cannot be relied upon to assure mission success. That is, we can no longer select and train men until they can compensate for design inconsistencies. If this is the case, we must attempt to alleviate the short-comings of current standards or generate new standards which will be useful for future design. Several other sections of this document suggest methods of accomplishing this goal.

4.0 METHODOLOGY

4.1 GENERAL INTRODUCTION

To accomplish the research goals a series of workable hypotheses was evolved. These research hypotheses structured the methodological approach to the tasks. The first order or primary questions were the following:

1. Is MSFC-STD-267A used by design engineers and if not, why not?

2. What aspects of the standard detract from its useability?

3. What factors detract from the standards enforceability?

4. Do the primary users of the standard (MSFC Contractors) confirm the results of the analytical evaluation?

The primary questions were further subdivided into secondary questions and were evaluated by means of an extensive analytical review of the standard, related standards, and relevant human engineering literature.

The secondary questions were as follows:

1. What data in MSFC-STD-267A have little impact because they are out of date (Task 1)?

2. What additional data are needed to render the document more useful (Task 1)?

3. What additional human engineering design data will be needed for future space missions such as space station, space shuttle, RAM, etc. (Task 2)?

4. Could additional standards currently in use enhance MSFC-STD-267A (Task 3)?

5. Could data in other sources, e.g. textbooks, handbooks, currently available be used to improve MSFC-STD-267A (Task 3)?

6. If better organized, would MSFC-STD-267A have greater impact (Task 6)?

7. How could the standards implementation documents, MSFC-STD-391 and MIL-H-48655, be improved (Task 7)?

8. What areas need additional research and simulation (Task 4)?

9. What would a sample section consist of if the results of the present grant effort were implemented (Task 8)?

10. What is the opinion of NASA/MSFC standard users toward MSFC-STD-267A and its effect on new design (Task 5)?

4.2 SPECIFIC METHODOLOGICAL APPROACH

The study tasks are arranged around the basic methodological techniques employed in each task. An analytical technique was employed in Tasks 1-4 and 6-8. Task 5 employed a survey technique.

Task 1 - Analytical Approach. A thorough item-by-item review was conducted to accomplish this task. Individual and group review sessions were conducted. Each item was evaluated to determine if it is up-to-date, relevant, useful, enforceable and ambiguous. The research team drew on their experience and knowledge of space vehicle design, human engineering, and basic literature in human factors.

Task 2 - Analytical Approach. Using NASA projections as to the nature of future manned missions and crew size/composition the changing role of the astronaut was assessed. A thorough evaluation of the psychological parameters affected by changes in future mission constraints was conducted. Particular emphasis was placed upon training time, typical crew operations, long and short term memory requirements, etc. The goal of the analysis was to determine the type of human engineering standard necessary to support futher design endeavors.

Task 3 - Analytical Approach. Nine basic source books of human engineering data including MIL-STD-1472 A, research reports, handbooks, and textbooks were carefully reviewed to determine what data each source contained which would enhance MSFC-STD-267A. These sources were selected not only because they obviously were relevant to space vehicle design, but also because they are presently used in design of spacecraft. Each section of these sources was reviewed and compared to data in MSFC-STD-267A to determine if the addition would augment MSFC-STD-267A. Handbooks, textbooks, standards, and databooks were intentionally selected to allow a review of a variety of formats for human factors data.

Task 4 - Analytical Approach. On the basis of the evaluation conducted in Task 1 of the deficiencies and problems existing in MSFC-STD-267A, and the requirements for future spacecraft as revealed in Task 2, MSFC-STD-267A was compared with the sources evaluated in Task 3 to determine whether the data needed to update MSFC-STD-267A were in existence. In addition to the nine primary sources reviewed, a thorough literature search was conducted in each of the major areas covered in MSFC-STD-267A. A preliminary evaluation was made in as many of these sources as possible to determine whether these sources included information that could be useful to MSFC-STD-267A. On the basis of these analyses, problem areas were identified and listed.

Task 6 - Analytical Approach. The ease of data was evaluated in Task 6. A thorough analytical review was conducted to determine how the data could be organized and/or configured to make the data more accessible to the design engineer. Several approaches were taken to derive an acceptable format.

Task 7 - Analytical Review. A thorough item-by-item review was conducted of the implementation documents used in the Military (MIL-STD-H-46855) and the implementation document employed by MSFC (MSFC-STD-391). Difficulties and problems in these implementation documents were evaluated, isolated and techniques were recommended for improving the useability of these documents.

Task 8 - Analytical Review. On the basis of the total study effort, a single sample subsection to MSFC-STD-267A was written. Effort was made in the construction of the section to implement the recommendations and data findings outlined in the study effort.

Task 5 - Survey Approach. In order to determine the usefulness of existing standards and to receive recommendations from the primary users of the document, a survey questionnaire was built and distributed to MSFC contractors. A secondary goal was to determine if the users opinions verified the results of the analytical review. On the basis of completion of Tasks 1 and 2, a survey questionnaire was built in accordance with standardized psychometric techniques. Every effort was made to assure that the questionnaire was methodologically sound.

A variety of survey questionnaire techniques were used including the Likert scaling technique, fixed choice testing, open ended questions, unstructured and structured, etc.

An effort was made to optimize the reliability and validity of the total questionnaire before its distribution. The 35 item questionnaire was pre-tested by administration to the local chapter of the Human Factors Society prior to its nationwide distribution.

5.0 RESULTS AND CONCLUSIONS

Section 1.0 provides the integration of the overall results and conclusions of the specific task elements, MSFC-STD-267A critique, literature review and survey results. This section discusses the results of each of those sections in more detail.

5.1 CRITIQUE/RECOMMENDATIONS OF MSFC-STD-267A REVIEW

5.1.1 Introduction

This section presents the results of a section-by-section review of MSFC-STD-267A. The report is divided into sections with each succeeding section covering the information in greater detail. Section 5.1.2 covers the general evaluation of the standard and recommendations for improvement. Section 5.1.3 presents specific findings of the item-by-item review. Tables 5-1 through 5-6 present in tabular form a complete listing of the specific type of problems discussed in Section 5.1.3. Table 5-7 lists those sections of MSFC-STD-267A that were found to be relatively free of problems. Item-by-item review data sheets of MSFC-STD-267A, including comments and recommendations can be found in Appendix A.

5.1.2 General Evaluation, Conclusions and Recommendations

A major purpose of this review was to assess the usefulness of MSFC-STD-267A and the degree to which it would enhance, hinder, or otherwise affect NASA hardware design if imposed upon contractors in the future. Additional objectives included investigating methods which would render the standard more useable and identifying areas requiring additional data. These goals were satisfied by an analytical section-by-section review of the standard with respect to future space missions.

The major conclusion reached from the review was that MSFC-STD-267A contains deficiencies which detract from its usefulness. Therefore, it will likely have little impact on future NASA space endeavors if imposed upon contractors in its present form. Designers will continue to ignore the standard for the following reasons:

(1) The standard was not intended to be a zero or reduced gravity standard and, therefore, does not contain specific information applicable to space environments.

(2) MSFC-STD-267A has never been revised and, as a result has not kept pace with the expanding technology. Considerable data are out of date (7.5%) and many voids exist with respect to advances made during the previous six years.

(3) Conflicting data were found in a number of paragraphs in MSFC-STD-267A.

(4) Ambiguities and unenforceable requirements exist in 114 paragraphs out of a total of 1,200 paragraphs in MSFC-STD-267A (9.5%).

(5) Sixty sections (5 %) contain duplicate or repetitive data.

(6) Presentation of the data is not consistent with good human factors concepts. The material is presented in such a manner that it often discourages use of the document.

(7) Irrelevant data were found in 39 sections (3%). Irrelevant data increase the volume of the standard, but not the quality. In fact, these data make it more difficult to extract useful information.

Only 142 sections (12%) of the total standard were found to be free from deficiencies. Therefore, MSFC-STD-267A requires a complete revision if it is to be the standard used in future space endeavors. This revision should include:

(1) The updating of MSFC-STD-267A to reflect the present state-of-the-art.

(2) The addition of zero or reduced gravity information.

(3) The elimination of ambiguities, uneforceable, irrelevant conflicting and repetitive data.

In addition, the revised standard should be reorganized to present the data in a format which encourages its use. Designers are accustomed to design handbooks and reference documents which present data in a logical format with maximum utilization of graphic, pictorial and tabular forms. Presentation of human factors data in such a manner would encourage the user to seek out the standard rather than to avoid it.

Another point that must be addressed is enforcement of the standard. The existing standard does not directly define how its requirements are to be enforced, but makes reference to MSFC-STD-391, "Standard Human Factors Engineering Program Plan." This document describes among other things, the enforcement criteria (MSFC-STD-391 is considered in more detail in Appendix C).

It is recommended that this document continue to define the enforcement criteria and that MSFC-STD-267A be restricted to actual human factors requirements. Improvement can be made to MSFC-STD-267A to aid enforcement by eliminating unenforceable wording and stating the requirement in a more definite manner.

As pointed out earlier, one of the main deficiencies of MSFC-STD-267A is its lack of current data. When MSFC-STD-267A was published in 1965, it contained human factors data that reflected the state-of-the-art at that time and has fallen into disuse due to not staying current with the expanding technology. To alleviate this situation in the future, it is recommended a single source be established to continuously review new human factors literature, techniques, and applications and periodically update the human factors standard.

If the above recommendations were incorporated, MSFC-STD-267A could become a useful standard and would have a positive impact on future NASA space endeavors.

5.1.3 Specific Findings

5.1.3.2 Data Applicable to Space Environments

One major deficiency is the fact that MSFC-STD-267A was not intended to be a zero or reduced gravity standard and, therefore, supplies little data specifically related to the space environment. For example, MSFC-STD-267A does not include astronaut anthropometric data, space qualified tools, EVA lighting, lunar lighting, space visual acquisition problems, mobility and stability aids, zero "g" workspace layout considerations, pressure suits, extravehicular activities and the limits placed on man's capabilities by reduced or zero gravity. All of these areas are important when considering man's abilities to function under zero or reduced gravity constraints and when designing hardware for his use. The data furnished in the standard are oriented toward hardware designed for a one "g" environment, however, it contains some general information which applies to both earth and space.

Additional data pertaining specifically to space environments should be extracted from reports on simulated space experiments or actual space flights and be incorporated into MSFC-STD-267A. A number of useful reduced gravity sources which contain information that would enhance MSFC-STD-267A were found during the literature review (5.2).

5.1.3.2 Current Data

Another major deficiency which detracts from the standard is the lack of current data. MSFC-STD-267A was published September, 1966. The data may have been current at that time, however, it is presently out dated. For example, the illumination section does not give consideration to electroluminescent techniques for panel lighting which are now in common usage.

In comparing the anthropometry data of MSFC-STD-267A to that of MIL-STD-1472A, it was noted that nearly all the data are in conflict. The reason for the conflict is that the data in MIL-STD-1472A are based on studies by the military in 1964, 1966, and 1967. The average stature height in 1967 was nearly an inch greater than that of Hertzberg's population in 1950, as reported in MSFC-STD-267A.

Another example may be found in Section 5.1.6.4.2, which addresses the use of shape coded knobs. The alternative knob shapes illustrated in this section are not representative of those used today. Although shape coding has not been used extensively in spacecraft, it would be simple to update these charts for possible selection in the future.

A number of areas were identified during the review in which more recent data are available (Table 5-1). These areas along with additional data sources are delineated in Section 5.2, Literature Search Recommendations.

5.1.3.3 Conflicting Data

A small percentage of the sections reviewed were found to be internally contradictory as well as conflicting with data from other sources. For example:

The definition of "Brightness Contrast" in the illumination section contradicts itself.

> 5.6.1.5.1 <u>General</u> - Brightness contrast is the term used to denote variation in the brightness of the object being observed. It is expressed as a percentage (reflected light/delivered light) or as an amount of reflected light (foot-lamberts). A good example is the use of black print on white paper. As a percent of an amount, brightness contrast is derived as follows:
>
> $$\frac{B_1 - B_2}{B_1} \times 100 = \text{contrast}$$
>
> B_1 = brighter of two contrasting areas
>
> B_2 = less bright of two contrasting areas

It should be noted that the formula given is not an expression for reflected light over delivered light, and conflicts with the definition above. The formula is the presently accepted definition.

The access opening requirement of 5.5.2.8 and Figure 65 of the workspace section conflict.

> 5.5.2.8 <u>Access Openings</u> - Access openings and hatches for personnel shall be determined from Figure 65. The absolute minimum in dimensions for various access openings shall be as follows:

(a) Rectangle vertical access openings and hatches shall be 18 inches square.

The minimum in Figure 65 is given as 24 inches X 12 inches.

(b) Circular horizontal access openings and hatches shall be a minimum of 18 inches in diameter.

The minimum in Figure 65 is given as 24 inches.

(c) Horizontal rectangular access openings shall be an absolute minimum of 18 inches wide and 15 inches high.

Conflicts are also prevalent in the control section such as Table III near the end of that section. This table conflicts with the minimum control size dimensions stated in earlier paragraphs. For example, in Table III, Page 50, a diameter for a round knob is given as .125. In Paragraph 5.1.3.9.3 (b), a minimum of .375 is quoted.

Conflicts such as these make the standard extremely frustrating to use and reduce the credibility of design values given. Additional sections containing internal conflicting data are listed in Table 5-2.

5.1.3.4 Ambiguities and Unenforceable Requirements

Terms such as "when possible," "whenever possible," "where possible," "where required" are used throughout the standard. These statements tend to negate the requirements by leaving the final choice to the designer. With many contractors designing NASA equipment, the same requirement could be and is interpreted in numerous ways. It is suggested that qualifying statements of this nature be deleted from the standard. The deletion of qualifying statements would make the standard stronger and more enforceable, but may also tend to reduce the designer's prerogative. To overcome this disadvantage, provisions should be made by which the designer may obtain deviations from the standard when innovation, performance or cost warrants it. If deviations are necessary, they should be coordinated with the responsible government agency through a formal deviation request. This would insure that appropriate human factors principles are designed into equipment, and deviations made only if trade-off considerations benefit the overall program.

Throughout the standard there are statements which are ambiguous and general in nature. The information density of these statements is very low and will have little or not effect on the hardware design. Several examples are presented below.

5.8.4.2.6 Adjacent components - Adjacent components shall not be damaged while the repaired unit is being repaired or maintained.

5.4.4.3.12 Feel of control - The controls used shall contain the minimum force consistent with proper "feel" condition.

5.2.3.1.2.1 Legend Indicator Light Applications - Legend lights shall be used in reference to simple indicator lights unless design considerations demand otherwise.

5.7.2.1.9 Gloves - Glove surfaces shall be such that it provides an adequate gripping surface.

5.3.3.8 Priority - Controls and displays location. Priority shall be given to location of controls and displays that will be used most often. The choice shall depend upon the functional requirements such as reading distance, angle of view, illumination, presence of other instruments and methods of actuation of related controls.

5.3.4.3.1.3 Equipment component response - Without the intermediary of some display mechanism and where the feedback is direct to the sensory modalities, the movement of controls shall be the same as when displays are provided.

Ambiguous statements, such as those above, add very little to the standard and should be converted to more quantitative requirements or eliminated completely. Additional sections that contain ambiguities and unenforceable requirements are listed in Table 5-3.

5.1.3.5 Repetitive Data

A distracting trait of MSFC-STD-267A is the manner in which the same type or similar information is presented in a number of places in a slightly different manner, such as:

> 5.1.3.11.3 Displacement - Displacement of detent positioning knobs will be as follows:
>
> (a) Minimum displacement (between adjacent detents) for visual positioning - 15 degrees.
>
> 5.1.3.11.5 Other requirements - Other requirements of detent knobs will be as follows:
>
> (a) No more than 24 switch positions will be incorporated into one detent positioning knob.
>
> 5.1.3.8.1 Application -
>
> (a) The number of knob positions shall be between 3 to 24. Speed and accuracy of setting and checking are sacrificed with too many settings.

These three statements effectively impose the same requirement on the designer.

5.8.4.3.1 <u>Code Interchangeable Units</u> - All interchangeable units shall be coded (keyed) so that it is physically impossible to insert a wrong unit.

5.8.4.3.8 <u>Standard Orientation</u> - Components of the same or similar form but of different functional properties should be mounted with a standard orientation through the unit, but should be readily identifiable, distinguishable and not physically interchangeable.

The intent of 5.8.4.3.1 is covered in 5.8.4.3.8 along with more information.

5.5.1.1 <u>General Criterion</u> - The selection of appropriate dimensions for the design of equipment that will be operated or maintained by personnel shall be considered as a critical factor in the success of the equipment. The basic principle to be observed shall be the designing of equipment to suit the operator instead of selecting operators to fit the equipment.

5.5.1.4.1.2 <u>Accommodation</u> - To accommodate the variation in size of the potential users of equipment, the designer shall attempt to provide for the greatest range of users from smallest to largest.

The two statements above convey the same information in two different ways.

After reading the same data over numerous times with only slight variation, the reader loses sight of the main point. When this happens he will likely tend to ignore the document entirely. Additional sections listed in Table 5-4 should be rewritten to alleviate this problem.

5.1.3.6 Presentation of Material

The organization of many sections is somewhat disjointed. Much of the material is presented in a fragmented manner, making it difficult to understand and to extract useful information. Many minor criteria are given similar paragraph status as more important criteria, such as:

5.8.6.2	Size of accesses
5.8.6.2.2	Number of accesses
5.8.6.2.3	Supplementary accesses
5.8.6.2.4	One-hand accesses
5.8.6.2.5	Specific one-hand access
5.8.6.2.6	Two-handed access
5.8.6.2.7	Specific two-hand access

The major and most important information contained in these sections can be found in 5.8.6.2.4 and 5.8.6.2.6. Sections 5.8.6.2.5 and 5.8.6.2.7 are merely a repeat of data found in 5.8.6.2.4 and 5.8.6.2.6 respectively. The number of accesses, 5.8.6.2.2, is actually another subject that should be covered in more detail at the same level as 5.8.6.2. Organization and structuring in this manner increases the user's confusion factor and makes it difficult for him to use the standard.

In many place the same data are presented in tables, figures and written form which could complement each other, but the relationship between the various presentations is not clearly shown. Figure 65, on Page 224, illustrates two of six work space positions on the top half of the page, and illustrates access requirements on the bottom half of the page (the figure is labeled "work space requirements (access)"). The remaining four work space positions appear two pages later in Figure 66, on page 226.

Another example is Table XV on Page 187, which contains values for measurements of various body dimensions and also the increment for heavy winter clothing. The Figure (53) which gives the points of measurement for Table XV appears five pages later on Page 192. Table XV makes no reference to the location of its associated figure. In addition, the table is not labeled as to the date of the data or the sample population. The remaining increments for clothing data are discussed two pages after Table XV in Table XVII, on Page 189.

In the section on arm and hand access (5.8.6.2.4 - 5.8.6.2.7) duplicate data, apparently derived from various sources, are presented in three different ways:

(a) Tabular form depicting the minimal space required.

(b) Tabular form depicting the mean and range values of the various criteria.

(c) Narrative form depicting the minimal criteria.

The use of three distinct forms for presenting the same data tends to confuse the user.

The data should be analyzed to determine the best of the three. In this case, a tabular form giving minimal criteria appears to be the best way to present the data.

Additional areas with the same problem are listed below:

Subject	Minimal Requirements	Mean and Range	Narrative
Tube replacement	Fig. 99	Table XXXIII	5.8.6.2.5a 5.8.6.2.5d
Pliers & wire cutters (only tables are used but in different formats)		Table XXXIV Table XXXVII	
Screwdrivers	Fig. 99	Table XXXVII Table XXXVIII	5.8.6.2.5g
Two-handed reach	Fig. 100 Fig. 101		5.8.6.2.6 5.8.6.2.7

Much of the material in MSFC-STD-267A is presented in short, concise statements. Brevity has the advantage of not hindering the reader with voluminous material, however, the standard at times is brief to the extent that it is difficult to interpret the meaning of many statements. For example:

> 5.8.4.3.6 Unit Removal - Units shall be removable along a straight or slightly curved line rather than through an angle.

This statement could mean many things to different people while the same subject covered in Reference Number 8 gives an example to show exactly what it means.

> 5.8.9.3.4 Mounting - Heads of mounting bolts should come up to the work surface.

What does it mean? How is the human factors involved?

> 5.8.9.3.5 Threaded nut plates - Threaded nut plates shall be used when several bolts are to be fastened on one surface and where positioning and holding nuts may be difficult.

What is a threaded nut plate? What is considered one surface? Reference Number 8 and Number 9 have a better explanation of the same topic with illustrations to avoid confusion. In sharp contrast to the brief statements described above, much of the data contained in the standard is voluminous, large number of words are used to describe information that could be presented better in tables. For example, the discussions of the various lighting techniques in the section on illumination could be summarized in a single table providing a brief description of each technique delineating the advantages and disadvantages of each method. This would provide the user with quick access to the data and promote usage of the standard.

Studies conducted by Meister[1] indicate a designer's preference for data presented in graphic/pictorial format than in tabular form. The least preferred method for data presentation was the paragraph or verbal form. Much of the data in MSFC-STD-267A are presented in a manner which opposes designer preference. Although the standard need not necessarily adhere to designer's preference in all cases it would be advantageous to present the data in a form the designer would be most prone to utilize.

Additional sections containing material presentation problems are listed in Table 5-5.

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1 "The Utilization of Human Factors Information by Designers," Meister, Farr, Human Factors Journal, February, 1967.

5.1.3.7 Irrelevant Data

Several areas were found in which the information density of the document was lowered by providing the designer with data irrelevant to human factors design. For example:

> 5.5.1.5.2 Reliability on Anthropometric data - When groups are actually measured for anthropometric data, the sample size shall be a minimum of 50 persons in order to insure reliablity of data.
>
> 5.4.1.4.6 Testing - It is possible to test several of the larger muscle groups and obtain a good overall picture of the individuals strength.
>
> 5.4.1.4.8 Exercise - The exercise of one limb will increase the strength of the contralateral limb.

Information of this nature tends to increase the difficulty of finding data required to perform a given design task and as a result the user will turn to more useful sources and tend to ignore MSFC-STD-267A. Additional sections containing irrelevant data are listed in Table 5-6.

Table 5-1

Out-of-Date Data

Sec #	Title
5.1	Control criteria
5.1.2.1.2	Tasks requirements
5.1.2.1.3	Information requirements for the operator
5.1.2.1.4	Work space requirements
5.1.2.2.1.2	Foot controls
5.1.2.2.2	Rotary versus linear controls
5.1.3.2.1	Application
5.1.3.2.2	Size
5.1.3.2.3	Displacement
5.1.3.2.4	Resistance
5.1.3.4.2	Continuous thumbwheels
5.1.3.4.4	Other features
5.1.3.5.1	Application
5.1.3.5.2	Size
5.1.3.6.2	Size
5.1.3.6.3	Displacement
5.1.3.6.4	Resistance
5.1.3.6.5	Other requirements
5.1.3.7.1	Application
5.1.3.7.2	Size
5.1.3.7.4	Resistance
5.1.3.7.5	Separation
5.1.3.8.1	Application
5.1.3.11.2	Size
5.1.3.11.3	Displacement

Table 5-1, Continued

Sec #	Title
5.1.3.11.4	Resistance
5.1.3.12.2	Size
5.1.3.13	Handwheels
5.1.3.14.2	Size
5.1.3.14.3	Displacement
5.1.4	Other controls
5.1.5.2.1	Effect accidental actuation
5.1.5.3	Optimum spacing between controls
5.1.5.6.2	Groups of levers
5.1.6.4.1	Type of shape coding
5.1.6.5	Sizing coding
5.1.6.6	Mode-of-operation coding
5.2.1	Display design considerations
5.2.2.3	Meaningful information form
5.2.2.5	Logical display layout
5.2.2.11	Failure of displays
5.2.2.14	Brevity
5.2.2.17	Abstract symbols
5.2.3.1	Transilluminated indicators
5.2.3.1.2.2	Legend light lettering
5.2.3.1.2.3	Other considerations
5.2.3.2.2	Color banding (zone marking)
5.2.3.2.3	Scale design
5.2.3.2.4	Pointer design
5.2.3.3.2.1	Design requirements
5.2.3.3.3	Other type indicators
5.2.3.5.1	Application
5.2.3.5.2	Design requirements

Table 5-1, Continued

Sec #	Title
5.2.3.7.1	Application
5.2.3.8	Other display types
5.2.4.2	Label spacing
5.2.4.4	Label readability and legibility
5.2.4.5.1	Label size
5.2.4.5.2	Panel label style
5.2.4.5.3	Panel label placement
5.2.4.6.2	Graduation mark dimension
5.2.4.6.3	Numerical progression markings
5.2.5.2.2	Number of available colors
5.2.5.2.3	Color meaning
5.2.5.3	Position coding
5.2.5.4	Shape coding
5.3.2	General requirements
5.3.3.4	Functional grouping
5.3.3.6	Examples of simple panel layout arrangements
5.3.3.7	Example of complex panel layout arrangements
5.3.3.8	Other display types
5.3.4.4.1.3	Associated meaning
5.3.4.4.1.4	Rotary display (with rotary control)

Table 5-1, Continued

Sec #	Title
5.4.1.1.1.3	Value of force exerted
5.4.1.1.2.2	Value of force exerted
5.4.1.1.4	Maximum torque for two hands
5.4.1.2.2	Value of force exerted
5.4.1.3	Strength of various body members
5.4.1.4	Facts relating to human strength
5.4.1.4.2	Sex
5.4.2.1.1	Physical size (bulk)
5.4.2.1.7	Handling or gripping surface
5.4.3.1	Requirements
5.4.4.3.6	Signals channels
5.5.1.3.1	Range
5.5.1.4.2.7	Increment for hand wear
5.5.1.6.1	Application
5.5.2.3.2.2	Control reach
5.5.2.11.3.1	Angle
5.6.1.5.2	Requirements
5.6.1.6.2	Requirements
5.7.1.3	Cold and performance
5.7.1.5.2	Convective cooling
5.6.2.1	Localized vibration
5.6.2.2.1	General

Table 5-2

Conflicting Requirements

Sec #	Title	Conflicts with
5.4.2.1.7	Handling or gripping surface	5.8.7, size and weight of removable units
5.5.1.3.5	Trade-offs	5.5.1.3.1, Range
5.5.2.3.1	Display height	Figure 60
5.5.2.3.2.2	Control reach	Figure 60
5.5.2.7.1	General	Figure 56
5.5.2.8	Access openings	Figure 65, conflicts within sections
5.6.1.5.1	General	5.6.1.5.1 General
5.6.1.6	Brightness ratio	5.6.1.6, brightness ratio
5.6.3.1.4.2	Exposure limit variations	Figure 78
5.6.3.1.4.3	Damage risk criteria	Figure 76
5.8.1	Maintainability Definition	3.1.46
5.8.6.2.4b	One-hand access, Fig. 79, Table XXXIV, XXXV	Table XXXVIII
5.8.6.2.5	Specific one-hand access	Figure 99, Figure 100
5.8.6.2.6	Two-hand access	5.8.6.2.6
5.8.6.2.7	Specific two-hand access	Figure 100
5.8.11.6	Handle location (item g)	Figure 104

Table 5-3

Ambiguities/unenforceable requirements

Sec #	Title
5.1.3.9.4	Displacement
5.1.3.10.1	Application
5.1.3.10.2	Feedback
5.1.3.10.4	Displacement
5.1.3.11.1	Application
5.1.3.14.1	Application
5.1.5.2.3	Need for blind positioning
5.1.5.2.5	Simultaneous use of controls
5.1.5.5	Size consistency
5.1.5.6.1	Ganged controls
5.1.6	Control coding
5.1.6.3	Color coding
5.1.6.4	Shape coding
5.1.6.4.1.1	Class A
5.1.6.4.2	Selection and use of coded shapes

Table 5-3, Continued

Sec #	Title
5.4.1.1.1	Seated body position
5.4.1.1.3	Maximum torque for one hand
5.4.1.1.4	Maximum torque for two hands
5.4.1.2.2	Value of force exerted
5.4.1.3	Strength of various body members
5.4.2.1.1	Physical size (bulk)
5.4.2.1.2	Frequency of move
5.4.2.1.3	Horizontal distance
5.4.4	Human reaction time
5.4.4.2.2	Two or more senses
5.4.4.2.3	Intensity
5.4.4.2.5	Stimulus change
5.4.4.2.6	Alerting or warning signal
5.4.4.2.8	Signal discrimination
5.4.4.3.3	Simplicity of response
5.4.4.3.4	Number of signals or choices
5.4.4.3.5	Signal rate
5.4.4.3.9	Feedback
5.5.1.3.3	Exclusive dimensions
5.5.1.4.1	Human variability
5.5.1.4.1.1	Extent of variability

Table 5-3, Continued

Sec #	Title
5.5.1.7.2.1	Vertical reach seated
5.5.1.7.2.2	Horizontal reach seated
5.5.1.7.2.2.3	Infrequently used devices
5.5.1.7.2.3	Forward reach standing
5.5.1.7.2.4	Overhead reach standing
5.5.1.7.2.5	Unrestrained seated reach envelope
5.4.3.1	Requirements
5.5.1.8.1.2	Movement at the joints of the hand and arm
5.5.1.8.1.3	Movement at the joints of foot and leg
5.5.1.9	Estimation of correlated measures
5.5.2.2.1	Traction
5.5.2.2.3	Equipment surfaces
5.5.2.3.1	Display height
5.5.2.3.3	Clearance
5.5.2.4.6	Desk tops
5.5.2.10.1	Mobile workspace requirements
5.5.2.11.3.3	Treads and risers
5.6.1	Illumination
5.6.1.4.3	Indirect glare
5.6.1.5.2	Requirements
5.6.1.7.4	Direction of contrast between an object and its immediate background
5.6.1.8.4	Inadvertent illumination

Table 5-3, Continued

Sec #	Title
5.6.3.1.1.1	Necessary exposures
5.6.3.4.2	Procedures
5.6.3.5.1	Use
5.6.3.7.3	Length of exposure
5.7.1.2	Heat and performance
5.6.2.2.1	General
5.6.2.2.2	Short term exposure
5.6.2.2.3	Long term exposure

Table 5-3 , Continued

Sec #	Title
5.8.4.1a	Unitization
5.8.4.1c	Unitization
5.8.4.1e	Unitization
5.8.4.3.2	Array
5.8.5.4.1a	Equipment design
5.8.5.4.15	Multiple units
5.8.5.4.16	Two-man maintenance
5.8.9.1	Standardization
5.8.9.2	Design considerations
5.8.9.3.7	Latch Lock
5.8.12.3	Case size
5.8.14.7	Protection
5.8.3.2	Reliability of components
5.8.4.2.3	Space for test equipment
5.8.4.2.6	Adjacent components
5.8.4.3.7	Extensions
5.8.4.4	Operating conditions
5.8.4.4.1	Protective garments
5.8.4.4.2	Environmental Factors
5.8.7.8	Lubrication
5.8.9.3.1	Slot design
5.8.9.3.2	Wrenching clearance
5.8.9.3.3	Bolt length
5.8.9.3.4	Mounting

Table 5-3, Continued

Sec #	Title
5.8.13.1	Wires
5.8.14.1	Disconnect
5.8.15	Test points
5.3.3.1	Function and efficiency
5.3.3.2.1	Display location
5.3.3.3	Control and display relationship
5.3.4.1	Requirements
5.3.4.3.1.3	Equipment component response
5.3.4.4.1.1	Operator orientation
5.3.4.4.2.1	Operator orientation and associated meaning
5.3.4.4.2.4	Associated up-down meanings
5.2.2.1	Ease of reading
5.2.2.6	Minimum lag in status change feedback
5.2.2.7	Error-free features
5.2.3.2	Scale indicators
5.2.3.3.2	Counter wheels
5.2.3.4.2	Design requirements
5.2.5.2.4	Color aid in display search
5.1.2.1	Selection analysis
5.1.2.1.1	Function of the control
5.1.2.2.1.1	Hand controls
5.1.3.4.1	Application
5.1.3.5.5	Other requirements
5.1.3.9.1	Application
5.1.3.9.2	Feedback

Table 5-4, Continued

Sec #	Title
5.4.1.4.4	Static and dynamic strength
5.4.2	Weight lifting and carrying
5.4.2.1.6	Limb and body support
Table XIII	
5.4.4.2.4	Number of receptors
5.4.4.2.3	Intensity
5.4.4.2.10	Time uncertainty
5.4.4.2.6	Alerting or warning signal
5.4.4.3.7	Proper control-display relationship
5.3.1	Control-display relationship Panel layout
5.4.4.3.8	Anticipatory information
5.4.4.2.6	Alerting or warning
5.5.1	Anthropometry
5.4.3.1	Requirements
5.5.1.4.1.2	Accomodations
5.5.1.1	General Criterion
5.5.1.4.2.1	Increment for clothing
Table XV	
5.5.1.7.1.1	Kneeling
Table XVIII	
5.5.1.7.1.2	Crawling
Table XVIII	

Table 5-4, Continued

Sec #	Title
5.5.1.7.1.3	Prone Position
Table XVIII	
5.5.1.8.1	General
Figure 58	
5.5.2.1.3	Safety
5.5.2.1.1	Decision factors
5.5.2.5	Sit or stand operations
5.5.2.4.1	Slope and surface
5.6.1.2	Distribution
5.6.1	Illumination
5.6.1.7.1	Contrast of object
5.6.1.5.2	Brightness requirements
5.6.1.4.1	General
5.6.1.7.2	Brightness visual field
5.6.1.7.3	Size and brightness of object
Table XXVII	
5.6.3.2	Temporary hearing loss
5.6.3.1.1	General
5.6.3.3	Permanent hearing loss
5.6.3.1.1.2	Absolute limit

Table 5-4

Repetitive Data

Sec #	Title
5.8.4.2.2	Large components
5.8.4.2.5	Throw-away assemblies
5.8.5.4.3	Accessibility
5.8.5.4.5	Unit removal
5.8.5.4.15	Multiple units
5.8.5.4.16	Two-man Maintenance
5.8.4.3.1	Code Interchangeable units
5.8.4.3.8	Standard orientation
5.8.5.4.7	Edge Protection
5.7.3.2.2	Access Safety requirements
5.8.5.4.8	Safety
5.7.3.2.5	Safety Equipment and devices
5.8.11.3	Curvature of Handles
5.8.11.4	Handle dimensions
5.8.12	Covers and cases
5.8.5	Access
5.8.12.8	Corners
5.8.5.4.7	Access edges

Table 5-5

Organization/Format

Sec #	Title
5.1.1	Control requirements
5.1.2.2	Selection of control mode
5.1.2.2.1	Use of limb
5.1.2.2.4	Control identification
5.1.3.2.5	Other requirements
5.1.3.3	Rocker arm switch
5.1.3.6.1	Application
5.1.3.9.3	Size
5.1.3.10.3	Size
5.1.3.12.1	Application
5.1.3.12.4	Other requirements
5.1.3.13.1	Application
5.1.3.13.4	Other requirements
5.1.3.14.4	Resistance
5.1.3.15.1	Application
5.1.5	Spacing of controls
5.1.5.2	Spacing factors
5.1.6.4.1.2	Class B
5.1.6.4.1.3	Class C
5.2.2	Selection and design criteria
5.2.2.4	Feedback information
5.2.2.8	Consistency of placement
5.2.2.9	Usable within specified operating conditions
5.2.2.15	Abbreviation

Table 5-5, Continued

Sec #	Title
5.2.3.1.1.1	Application
5.2.3.1.2.1	Application
5.2.3.1.3	Master lights
5.2.3.1.4	Critical indicator location
5.2.3.1.5	Brightness
5.2.3.2.1	Application
5.2.3.2.5.1	Circular fixed scale (moving pointer)
5.2.3.2.5.3	Circular fixed scale (fixed pointer)
5.2.3.2.5.4	Straight moving scale (fixed pointer)
5.2.3.3.1	Application
5.2.3.4.1	Application
5.2.3.6.1	Application
5.2.3.6.2	Design requirements
5.2.3.7	Cathode ray tubes
5.3	Control-display interaction
5.3.1	Control-display relationship: panel layout
5.3.3	Panel layout criteria
5.3.3.2.1.1	Ambiguity
5.3.3.5	Sequential grouping
5.3.3.11	Combined controls
5.3.3.12	Positional restrictions
5.3.4	Control-display movement
5.3.4.2	Application
5.3.4.3	General Criteria
5.3.4.3.1	Movement of control
5.3.4.3.1.1	Operator's position

Table 5-5, Continued

Organization/Format

Sec #	Title
5.4.1	Human strength Capabilities
5.4.1.1.1.3	Value of force exerted
5.4.1.1.2.2	Value of force exerted
5.4.1.1.3	Maximum torque for one hand
5.4.1.4	Facts relating to human strength
5.4.1.4.7	Increase and decrease strength
5.4.2	Weight lifting and carrying
5.4.2.1.5	Relationship to body
5.4.2.1.8.3	Thigh carry
5.4.3.1	Requirements
5.4.4.2.6	Alerting or warning signal
5.4.4.2.11	Auditory signals
5.4.4.3	Operator and decisional characteristics
5.4.4.3.10	Comfort
5.4.4.3.11	Noise level
5.4.4.4.2	Other factors
5.5.1	Anthropometry
5.5.1.4.1.1.	Extent of variability
5.5.1.4.1.3	Corrections for slump
5.5.1.4.2	Clothing and personal equipment
5.5.1.4.2.2	Heavy winter clothing
5.5.1.4.2.3	Street and winter clothing
5.5.1.4.2.4	Increments for heavy clothing
5.5.1.4.2.5	Increments for shoes
5.5.1.4.2.6	Increments for head gear

Table 5-5, Continued

Organization/Format

Sec #	Title
5.5.1.6	Static human body dimensions
5.5.1.6.1	Application
5.5.1.6.2	Standard deviation
5.5.1.7	Dynamic human body dimensions
5.5.1.7.1	Working positions
5.5.1.7.2.2.1	Push buttons
5.5.1.7.2.2.2	Lever controls
5.5.1.7.2.2.4	Reduction of reach
5.5.2	Work space
5.5.2.1	General considerations
5.5.2.1.2	Posture change
5.5.2.2.2	Slope
5.5.2.3.2	Control dimensions
5.5.2.3.2.1	Precise controls
5.5.2.4.2	Panel height
5.5.2.7.1	General
5.5.2.10.2	Kneeling work space
5.5.2.10.3	Stooping work space
5.5.2.10.4	Squatting work space
5.5.2.10.5	Supine work space
5.5.2.10.6	Prone work or crawl space
5.5.2.10.7	Kneeling crawl space

Table 5-5, Continued

Organization/Format

Sec #	Title
5.5.2.11.1.1	Incline decision factors
5.5.2.11.1.4	Preferences
5.5.2.11.2	Ramps
5.5.2.11.4.1	Width
5.5.2.11.4.2	Treads
5.5.2.11.6	Platforms and work stands
5.5.2.11.6.1	Platforms
5.5.2.14	Environmental toxicity
5.6.1.1	Foot-candle provision
5.6.1.3.1	Direct light
5.6.1.3.2	Indirect light
5.6.1.3.3	Diffused light
5.6.1.3.4	Semi-indirect light
5.6.1.8.2	Determination of dark adaption time
5.6.3	Noise
5.6.3.1.2.1	Differences
5.6.3.1.2.3	Damage risk criteria
5.6.3.7.1	General
5.6.4.9.1	General
5.6.4.9.2.3	Criteria
5.6.3.9.3.2	Computation
5.6.3.9.4.4	Alternate methods
5.6.3.9.4.2	Computation

Table 5-5, Continued

Organization/Format

Sec #	Title
5.7.1.	Temperature
5.7.1.1.1	Factors
5.7.1.1.2	Comfort zone
5.7.1.2.2	Long term exposure
5.7.1.2.3.1	Without protective clothing
5.7.1.4	Humidity and performance
5.7.1.5	Air movement
5.7.1.5.3	Humidity
5.7.1.5.4	High temperature humidity
5.6.2.2.1	General
5.6.2.3.2	Performance decrements

Table 5-6,

Irrelevant Data

Sec #	Title
5.4.1.4.5	Muscle tissue
5.4.1.4.6	Testing
5.4.1.4.8	Exercise
5.4.2.1.6	Limb and body support
5.4.4.2.1	Single (one) sense
5.4.4.2.7	Irrelevant signals
5.4.4.3.1	Training emphasis
5.4.4.3.2	Amount of training
5.4.4.3.12	"Feel" of control
5.5.1.3.2	Inclusive dimensions
5.5.1.4.2.7	Increment for handwear
5.5.1.5	Determination of anthropometric data
5.5.1.5.1	Validity of anthropometric data
5.5.1.5.3	Standardization of anthropometric data
5.5.1.8	Range of movement of body members
5.5.2.1.4	Equipment
5.5.2.11.1.2	Angle
5.5.2.11.1.4	Preferences
5.5.2.11.3.2	Strength
5.5.2.11.5.7	Handgrip
5.5.2.11.6	Platforms and work stands

Table 5-6, Continued

Irrelevant Data

Sec #	Title
5.5.2.13	Design of equipment for remote handling
5.5.2.13.1	Prime equipment
5.5.2.13.2	Tools
5.5.2.13.3	Remote viewing equipment
5.6.3.1.1.2	Absolute limit
5.6.3.4.11	Control at source
5.6.3.4.1.2	Control elsewhere
5.6.3.5.2	Type
5.6.3.6	Acoustic reflex
5.6.3.8	Physiological effects of noise
5.7.2	Clothing
5.6.2.3.1	General
5.6.2.4.2	Other methods
5.1.5.1	General
5.2.4.3	Label orientation
5.2.4.5.4	Functional group title
5.3.3.2.1.2	Blocking

Table 5-7
D ca found to be acceptible

Sec #	Title
5.0	Detailed Requirements
5.1.2	Control section
5.1.3	Types of control
5.1.3.1	Requirements
5.1.3.2	Toggle switches
5.1.3.4	Thumbwheels
5.1.3.4.3	Descrete thumbwheels
5.1.3.5	Push buttons (finger actuated)
5.1.3.5.3	Displacement
5.1.3.5.4	Resistance
5.1.3.6	Push buttons (foot)
5.1.3.7	Legend switch
5.1.3.7.3	Displacement
5.1.3.7.6	Barrier height (from panel surface)
5.1.3.7.7	Other requirements
5.1.3.8	Knobs
5.1.3.9	Multiple rotation knobs
5.1.3.9.5	Resistance (torque)
5.1.3.10	Fractional rotation knobs
5.1.3.10.5	Resistance
5.1.3.11	Detent positioning knobs
5.1.3.12	Cranks
5.1.3.12.3	Displacement
5.1.3.13.2	Displacement
5.1.3.13.3	Resistance
5.1.3.14	Levers
5.1.3.15	Pedals

Table 5-7, Continued

Sec #	Title
5.1.3.15.2	Size
5.1.3.15.3	Displacement
5.1.3.15.4	Resistance
5.1.3.15.5	Other requirements
5.1.5.2.2	Hindrance of personal equipment
5.1.5.4	Limited space availability
5.1.5.6	Special cases
5.1.7	Control movement coding
5.2.	Display criteria
5.2.2.2	Accuracy of reading
5.2.2.10	Special displays
5.2.2.12	Function label
5.2.2.13	Units of measurement
5.2.2.16	Trade marks
5.2.3	Types of displays
5.2.3.1.1	Simple type indicator lights
5.2.3.1.2	Legend indicator lights
5.2.3.1.6	Coding
5.2.3.2.5	Types of scale indicators
5.2.3.3	Digital readout indicators
5.2.3.4	Printers
5.2.3.5	Plotters
5.2.3.6	Time displays
5.2.4	Labelling and marking criteria
5.2.4.1	Labelling association
5.2.4.5	Panel Labelling

Table 5-7, Continued

Sec #	Title
5.2.4.6	Marking criteria
5.2.4.6.1	Application
5.2.5	Display coding
5.2.5.1	Display coding requirements
5.2.5.2	Color coding
5.2.5.2.1	Color coding requirements
5.2.5.2.1.1	Advantages of use
5.2.5.2.1.2	Disadvantages of use
5.3.3.10	Separate panels
5.3.3.13	Panel hardware
5.3.4.4	Specific criteria
5.3.4.4.1	Rotary controls
5.3.4.4.2	Linear controls
5.3.4.4.2.2	Vertical plane
5.3.4.4.2.3	Horizontal plane

Table 5-7, Continued

Sec #	Title
5.4.1.2	Leg strength
5.4.2.1	Factors to consider
5.4.2.1.4	Vertical distance
5.4.2.1.8	Other methods of carry
5.4.2.1.8.1	Back carry
5.4.2.1.8.2	Thigh carry
5.4.4.1.1	Senses used
5.4.4.1.2	Selection
5.4.4.2	Signal (stimuli) characteristics
5.4.4.4.1	Limbs used
5.5.1.1	General criterion
5.5.1.2	Decision factors
5.5.1.3.2	Inclusive dimensions
5.5.1.3.4	Adjustable items
5.5.1.7.2	Functional arm reach
5.5.2.2	Walking surface requirements
5.5.2.4.2.1	Console height
5.5.2.4.3	Arm reach
5.5.2.4.4	Writing surface
5.5.2.4.5	Knee room
5.5.2.4.7	Seating height
5.5.2.6.2	Passage width
5.5.2.6.3	Clearance
5.5.2.7	Horizontal work surfaces
5.5.2.7.2.1	Standing operations
5.5.2.9	Doorways

Table 5-7, Continued

Sec #	Title
5.5.2.11	Work space inclines
5.5.2.11.1	General requirements
5.5.2.11.1.3	Angle of incline
5.5.2.11.3	Stairs
5.5.2.11.3.4	Length of flight
5.5.2.11.3.5	Rails
5.5.2.11.4	Stair ladders
5.5.2.11.4.3	Handrail
5.5.2.11.5	Ladders
5.5.2.11.5.1	Angle
5.5.2.11.5.2	Between several levels
5.5.2.11.5.3	Fixed ladders
5.5.2.11.5.4	Cages
5.5.2.11.5.5	Rungs
5.5.2.11.5.6	Portable ladders
5.6.1.4.1	General
5.6.1.4.2	Direct glare
5.6.1.8.1	General
5.6.1.8.3	Dark adaptation time versus system time
5.6.1.8.5	Protection of low illuminated areas

Table 5-7, Continued

Sec #	Title
5.6.3.4.1	General
5.6.3.9.2.1	General
5.6.3.9.2.2	Computation
5.6.3.9.3.1	General
5.6.3.9.3.3	Criteria
5.6.3.9.4.3	Criteria
5.7.1.3.4	Wind chill
5.8.3.3	Component Arrangement
5.8.4.1b	Unitization
5.8.4.2.4	Placement of Structural Members
5.8.4.3.9	Mounting
5.8.4.3.10	Meters
5.8.5.4	Access requirements
5.8.5.4.4	Interference
5.8.5.4.12	Access covers
5.8.5.4.13	Rear Access
5.8.6	Location of access
5.8.6.2.2	Number of accesses
5.8.7.1	Unit size and weight
5.8.9.3	Specific design considerations
5.8.9.5	Cover fasteners
5.8.9.5.2	Standardization
5.8.12.1	Orientation
5.8.12.5	Opening
5.8.13.5	Input-output cables
5.8.13.6	Receptacles for test cables
5.8.14.3	Test and services

5.2 LITERATURE SURVEY

5.2.1 Introduction and Summary

A review of current literature was conducted to identify sources which contain data relevant to human performance and the man/machine interface, that might be appropriate for a standard such as MSFC-STD-267A. During the review, a number of sources were identified that not only contained additional data that could be added to MSFC-STD-267A, but also presented the data in a manner more conducive to use by technical personnel.

The review began with a survey of current literature, to identify potential sources. Nine references, which represented a variety of source types (i.e. standards, textbooks, handbooks, etc.), were selected as primary sources and were subjected to a detailed section-by-section comparison with MSFC-STD-267A. The nine primary sources are listed below:

1. MIL-STD-1472A
   Human Engineering Design Criteria for Military
   Systems, Equipment and Facilities
   May, 1970

2. A Descriptive Model for Determining Optimal Human
   Performance in Systems
   Serendipity Associates
   October, 1966
   TR-29-66-34

3. Human Engineering Guide to Equipment Design
   Joing Army-Navy-Air Force Steering Committee
   Morgan, Cook, Chapanis, et al.
   1960

4. Compendium of Human Responses to the Aerospace Environment
   Lovelace Foundation for Medical Education and Research
   November, 1968
   NASA-CR 1205

5. Data Book for Human Factors Engineers, Vol. I
   C. Kubokawa, NASA, Ames Research Center
   November, 1969
   NASA-CR 114271

6. Handbook of Human Engineering
   Design Data for Reduced Gravity Conditions
   General Electric Co., Valley Forge Space Technology Center
   NASA Contract NAS8-18117
   October, 1971
   NASA-CR 1726

7. Bioastronautics Data Book
   Webb Associates
   1964
   NASA Sp-3006

8. Engineering Design Handbook
   Maintainability Guide for Design
   U. S. Army Materiel Command
   August, 1967
   AMDP-70 6-134

9. Maintainability Design Criteria
   Handbook for Designers of Shipboard
   Electronic Equipment
   NAVSHIPS 94324 0367-048-0010
   March, 1965

Secondary sources were examined to determine if they would be applicable if MSFC-STD-267A were revised. The results of that review were compiled into a bibliography in Appendix B.

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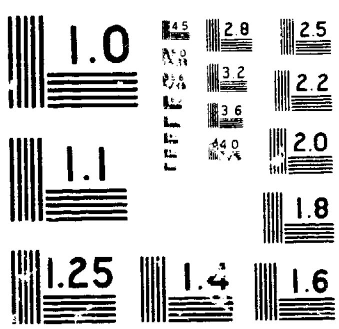


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS - 1963

The section-by-section comparison of the nine primary references with MSFC-STD-267A revealed several points of interest.

(a) Standard Evolution

Human factors standards in the 1950's merely stated that the contractor should have his designs reviewed by a Human Factors Engineer and imposed a few general requirements on the design. From this beginning, Human Factors Standards have evolved into documents which contain more specific criteria. The references are results of this evolutionary process. They are not all standards per se, but each makes a contribution toward the goal of incorporating human factors criteria into equipment design.

(b) Purpose and Intent

All nine references have as their general objective the presentation of human factors data, information and criteria that will afford optimal equipment designs with respect to man-machine interfaces and interactions. The specific approaches to reach that objective are somewhat diversified.

MSFC-STD-267A and MIL-STD-1472A are both standards whose intent is to provide engineering principles and practices for use in design of equipment. MSFC-STD-267A is concerned with large earth launch booster systems while MIL-STD-1472A is oriented toward military systems. Each attempts to present the material in a standard format which gives direct requirements rather than handbook or textbook type material.

The Serendipity Report, the G.E. Handbook, the Lovelace Compendium, and the Bioastronautics Data Book are directed toward man's role and activities under orbital conditions. They concentrate more on a comprehensive coverage of human responses to the space environment and man's performance capabilities under these conditions. In each case, they consitute a collection of data, from research endeavors, simulation studies and actual space flights, available at the time of publication. Their stated intent was not to provide the discrete requirements of a standard or specification, but to provide overall quantitative data that would aid in planning future space missions while providing human factors data to the equipment designer.

The Human Engineering Guide to Equipment Design is more of a handbook in that it contains textbook-type material along with general human factors data and specific requirements for given situations. This document was the result of a Joint Army, Navy, and Air Force endeavor to provide a guide in human engineering which the designer could use as a handbook.

The Data Book for Human Factors Engineers lies between the standards, handbooks and reports. It contains more specific data than a handbook, but it is too general in places to be considered a standard. Its stated intent is to present data most used by practicing human factors engineers into one convenient portable reference. The data contained in this document are, therefore, a collection of data from other sources.

The objective of the Army and Navy Maintainability Handbooks is to ensure optimum maintainability of equipment used by the armed services. To this end, they consider the complete maintainability situation including approaches and techniques, overall program goals and plans, maintainability interaction with other design disciplines, specific Army and Navy working environments and human factors data. Much of the information contained in the references are not directly related to human factors, but they were chosen for this review because the other seven references do not provide extensive maintainability human factors data.

When comparing the nine references and MSFC-STD-267A, one must be aware of the fact that they were published in different years and had different purposes and objectives. The publication date and purpose of each of the nine primary references are listed below.

1960: Human Engineering Guide to Equipment Design
Joint Army-Navy-Air Force Steering Committee
Purpose: Handbook

1964: Bioastronautics Data Book
NASA
Purpose: Collection of reduced gravity data.

1965: Maintainability Design Criteria Handbook for Designers of Shipboard Electronic Equipment
U. S. Navy
Purpose: Overall maintainability guidelines, including human factors.

1966: MSFC-STD-267A
Human Engineering Design Criteria
NASA
Purpose: Standard for large earth launch vehicles.

1966: A Descriptive Model for Determining Optimal Human Performance in Systems.
NASA
Purpose: Collection of reduced gravity data.

1967: Engineering Design Handbook
Maintainability Guide for Design
U. S. Army
Purpose: Overall maintainability guidelines including human factors.

1968: Compendium of Human Responses to the Aerospace Environment.
NASA
Purpose: Collection of reduced gravity data.

1969: Data Book for Human Factors Engineers
NASA
Purpose: Collection of most used HFE data.

1970: MIL-STD-1472A, Human Engineering Design Criteria for Military Systems, Equipment and Facilities.
Tri-Services
Note: Prior issue was Sept. 1966
Purpose: Standard for military systems.

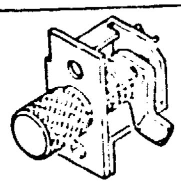
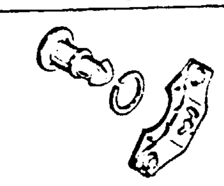
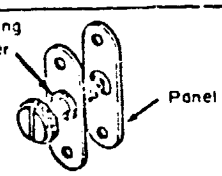
1971: Handbook of Human Engineering Design Data for Reduced Gravity Conditions
NASA
Purpose: Collection of reduced gravity data.

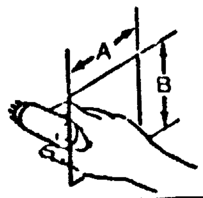
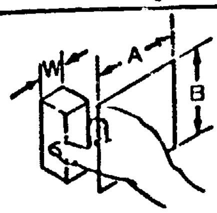
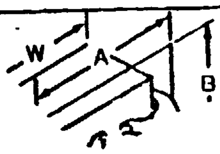
(c) Data Presentation

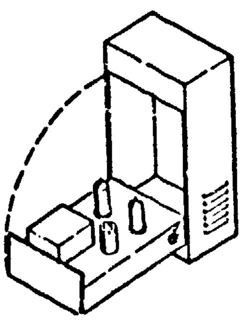
All nine references reviewed made extensive use of pictures, figures, charts, and tables to reinforce the narrative information. Three basic methods were used. First, the narrative was written in a given order with illustrations somewhat randomly placed, apparently at the convenience of the publisher. Under the second method, a number of narrative requirements were placed on one page followed by a full or nearly full page of illustrations. In the third method, the narrative discussion was placed within the illustration itself in tables or located near the picture it was discussing.

MSFC-STD-267A utilized all the above methods in a somewhat random manner, with little consistency. In a few sections the illustrations were found as much as four pages away from the associated narrative. This approach makes it somewhat difficult to find pertinent data within the standard.

The method used in reference nine was considerably different from that used in the other references. The format used in reference nine consists of a combination of the following: a picture of hardware or concept under discussion, a description of the hardware or task, the advantages and disadvantages of the given technique, human factors considerations, and dimensional data. The specific combination of these approaches varied with the concept under discussic as shown below.

Type	Description	Maintainability Considerations
	Adjustable pawl fastener As knob is tightened the pawl moves along its shaft to pull back against the frame 90° rotation locks, unlocks fastener	1. No tools required
	"Dzus" type fastener with screwdriver slot Three piece 1/4 turn fastener. Spring protects against vibration. 90° rotation locks, unlocks fastener	1 Tools may be required. 2 Should not be used for front panel fasteners or in structural applications. Preferred type for light weight panels other than front panels
	Wing head, "Dzus" type 90° rotation locks, unlocks fastener.	1. No tools required 2. Should not be used for front panel fasteners or in structural applications. Preferred type for light weight panels other than front panels.
	Captive fastener with knurled, slotted head The threaded screw is made captive by a retaining washer	1. Tools may be required 2. Operating time depends on number of turns required

Opening Dimensions	Dimension (In Inches) A	B	Maintenance Task
	4.8	5.0	Grasping small objects (less than 2 1/2" diameter).
	W+1.75	5.0**	Grasping large objects (more than 2 1/2" wide).
	W+3.0	5.0**	Grasping large objects with two hands, with hands extended through openings up to fingers.

Example	Description	Advantages	Disadvantages
	Hinged chassis. Can be hinged on side, top, or bottom.	1. Easy access from top or bottom of chassis.	1. Dust plate must usually be removed for access to front of chassis. 2. Open equipment requires excessive space. 3. Difficult access to both top and bottom of chassis at same time. 4. Chassis and parts can be damaged by dropping panel heavily.
	"Book" type opening. Parts on either side [illegible]	1. Easily accessible from [illegible]	

In the example above, one can see this technique for data presentation is easy to use. This method or one similar to it should be adopted for MSFC-STD-267A.

(d) Similar Data

Much of the data found in each reference was similar to that in MSFC-STD-267A and in other references. In some cases, the data were exactly the same, with the same illustrations and figures. Each new document, of course, uses past references as a data base.

The most obvious example of similarity was between MSFC-STD-267A and MIL-STD-1472A. At least sixty-percent of the requirements in each document are either identical or convey the same message. Consequently, both contain the same weaknesses and deficiencies as described in Section 5.1.

When comparing the two standards with Morgan, et al Guide to Equipment Design, one finds a good portion of the requirements of MSFC-STD-267A and MIL-STD-1472A in the guidebook. Taking into consideration the fact that the guidebook was published before either of the other two, this would indicate the standards may have used the guidebook as a common reference.

The Data Book for Human Factors Engineering contains data extracted directly from MSFC-STD-267A and MIL-STD-1472A. More than half of that document comes directly from the two standards.

The Army and Navy Maintainability Guides contain data (about 25%) which is not identical to the standards and the Morgan et al Guide, but has the same basic intent. Again, this could be easily accounted for if the Morgan et al Guide were used as a data base for the other three documents.

The Lovelace Compendium, Serendipity Report, G. E. Handbook, and the Bioastronautics Data Book contain information on man's performance capabilities, some of which are similar to the data found in MSFC-STD-267A. Each of these references contains many similarities. However, there is little similarity between these references and the standards.

In conclusion, it appears that the Morgan et al Guide to Equipment Design was the base for references 1, 5, 8, 9, and MSFC-STD-267A, while the other references (2, 4, 6, and 7) were based on studies, simulations and actual space flights completed at their time of publication and, therefore, are similar in content.

(e) Differences

Although much of the data found in MSFC-STD-267A and the references is similar, each of the above documents contains data not found in the others. For example, approximately 20% of the data found in MIL-STD-1472A was not in MSFC-STD-267A and about 20% of the data found in MSFC-STD-267A was not in MIL-STD-1472A

The Lovelace Compendium, G. E. Handbook, Serendipity Report, and the Bioastronautics Data Book were intended to be references for space oriented human factors data. As a result, they contain data on man's performance and capabilities in the space environment. The data are more general in nature and encompass a large cross section of man's relationship to the space environment. These sources provide excellent reference material.

The main difference between the other references and the maintainability handbooks is the level of detail and type of information covered. MSFC-STD-267A considers all aspects of human factors concepts while the maintainability handbooks are concerned with a limited application of those concepts. Consequently, the maintainability handbooks contain much more human factors data relative to maintainability. This more comprehensive coverage includes complete sections on the topics of unitization and modularization, test points, test equipment, malfunction, identification techniques, and maintenance documentation.

The other major difference between MSFC-STD-267A and other references is the mode of data presentation. In general, MSFC-STD-267A makes less use of pictures and illustrations than the other references.

(f) Conflicts

One method of discouraging the use of human factors data is to impose upon contractors sources which contain conflicting data. Unfortunately, this is the case with MSFC-STD-267A and MIL-STD-1472A. Both of these documents are imposed upon NASA MSFC contractors. The controls and displays sections of the two documents conflict in the data provided for detent position knob movement resistance, minimum diameters for pushbuttons and maximum dimensions for legend switches. Conflicts were also found in the maintainability sections where the one-handed and two-handed access dimensional requirements differ. Weight lifting constraints of MSFC-STD-267A are more stringent for one man lifting than MIL-STD-1472A.

The conflict in one and two handed data mentioned above was also found to be a problem in other references. The Kubokawa-

Data Book and the G. E. Handbook support MSFC-STD-267A, while the Navy's Design Criteria is in conflict with MSFC-STD-267A.

Other areas of conflict between the reference data and MSFC-STD-267A are:

(1) Weight lifting requirements (Ref #5)

(2) Control/Display legend switch diameters (Ref #5)

(3) Control/Display letter size and style (Ref #5)

(4) Detent position knob data (Ref #5)

(5) Rotary knob design values (Ref #5)

(6) Handle dimensions data (Ref #8)

A general evaluation of these conflicts revealed that the differences are not large in magnitude and either criterion may be sufficient for design needs, but a more detailed evaluation will be necessary to fully resolve the problem. It is important to note, however, that no matter how minor the conflict, in many cases, the user cannot meet both requirements. This results in a question of credibility concerning the entire document.

(g) Additional Data Requirements

As previously discussed, the nine reference documents contain data that would augment MSFC-STD-267A and MSFC-STD-267A contains data that would augment the reference documents. The purpose of the review was to identify data that would enhance MSFC-STD-267A. In that light the paragraph-by-paragraph review of the documents noted only additional data that could be added to MSFC-STD-267A. Each of the data elements is discussed within the individual reference review sections, and a general review is presented in Table 5.2.1

(h) Data Retrieval

A major point emphasized by the various references on reduced gravity requirements was that despite the abundance of human factors data published, very little is in a form readily available to the designer. Each reference made efforts to alleviate this problem. The desired result has not yet been obtained. Although the reports contain considerable data, difficulties are still encountered in locating the data required for a specific design problem. One reason may be the similarity and redundancy of much of the data. A more appropriate solution to this problem is the flow diagram method suggested in the sample section rewrite (Section 7).

Each of the references reviewed, approached the subject of human factors slightly different. Some gave direct requirements and criteria while others presented available data, leaving the interpretation to the individual. The third approach was the typical textbook. In the standards themselves, a combination of the three techniques was used.

With all the data available in various forms, it is difficult for the designer to isolate the information to meet his specific needs. Some designers who are well informed in the field of human factors would not necessarily require the textbook material or the supporting data in each requirement. Others, who are not so well versed are in need of some detail.

(i) Current Data

The problem of providing the most recent data for use by contractors is not limited to MSFC-STD-267A. The fact that so many documents concerned with the same subject have been prepared indicates a need for more up-to-date information in the design of space vehicles. In addition to the references reviewed there are still untapped sources of data. Much of these data can be found in individual research studies, reports on current simulation activities and reports on recent Apollo flights.

TABLE 5.2.1: APPLICABILITY OF REFERENCE SOURCE DATA TO MSFC-STD-267A

Section Title	(1) 1472	(2) Serendipity	(3) Morgan	(4) Compendium	(5) Kubokawa	(6) G.E.	(7) Bioastr.	(8) Army Main	(9) Navy Main
Controls & Displays	High	Low	High	Low	Moderate	Low	Very Low	0	0
Maintainability	Moderate	0	High	Low	Low	Low	0	Very High	Very High
Human Capabilities & Responses	Low	High	Low	Very High	0	Very Low	Very Low	0	0
Anthropometry	Low	Low	0	Low	0	0	Low	0	0
Work Space	Low	Very Low	0	Low	Low	0	0	0	0
Environment (Illum., Vib., Noise, Temp.)	Low	High	0	Very High	0	0	0	0	0
Safety	High	Low	Low	High	0	0	0	Low	Low

5.2 MIL-STD-1472A, HUMAN ENGINEERING DESIGN CRITERIA FOR MILITARY SYSTEM, EQUIPMENT AND FACILITIES

5.2.2.1 PURPOSE AND BACKGROUND

MSFC-STD-267A and MIL-STD-1472A have as their purpose: the presentation of human factors engineering design principles and practices to be used in designing equipment for achievement of required human performance, increase man/equipment reliability and to provide a basis for design standardization in large earth-launch booster systems and military systems respectively.

Both standards evolved from early human factors criteria of the 1950's, which stipulated that the contractor submit his designs to a review by qualified government human factors engineers.

Some of the milestones in the development of today's human factors standards were the Army's "Human Factors Engineering for Signal Corps System and Equipment," of 1958 and its associated technical reports and handbooks, "Missile Systems Human Factors Engineering Criteria," dated October, 1961 (ABMA-STD-434); "The Human Engineering Guide to Equipment Design," Morgan, Cook, Chapanis, et al, 1963; "Missile System Human Factors Engineering Criteria," MIL-STD-1248, January, 1964; "Human Factors Engineering Design Standard for Missile Systems and Related Equipment," HEL-STD-S-3-65, September, 1965; "Human Engineering Design Criteria," MSFC-STD-267A, September, 1966; "Human Engineering Design Criteria for Military System," MIL-STD-1472, 9 February 1968; and MIL-STD-1472A, 15 May 1970.[1]

During this evolution phase, each new document used the preceding one as a basis for development. This would provide the rationale for the fact MSFC-STD-267A and MIL-STD-1472A possess many similarities.

5.2.2.2 SIMILARITIES

In general it was found that MSFC-STD-267A and MIL-STD-1472A are alike and contain identical or similar requirements. Each contains major sections on controls, displays, control/display integration, work space design, environment, maintainability and safety.

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(1) G. Chaiken, HFE Standards and Specifications Contract Monitoring, U. S. Army Human Factors Research and Developr .t, Fourteenth Annual Conference, October, 1968.

Within each of these major sections, subsections cover the same general topics. In numerous cases identical wording was noted. Indeed, one document could have been derived from the other.

Because of the similarity of information and mode of presentation, MSFC-STD-267A and MIL-STD-1472A possess some of the same strengths and weaknesses.

The discussion on MSFC-STD-267A in Section 5.1 pointed out that deficiencies exist which weaken its usefulness. These weaknesses include lack of current and reduced gravity data, conflicting data, ambiguities, and unenforceable requirements, duplicative and repetitive data and data presentation. The same problems appear to exist although to a lesser degree in MIL-STD-1472A.

5.2.2.3 DIFFERENCES

Although MSFC-STD-267A and MIL-STD-1472A are similar, each contains information not found in the other. For example, the maintainability section of MIL-STD-1472A, thirty-eight of its one hundred nine paragraphs contain data which would complement MSFC-STD-267A. Eighty-nine paragraphs of the 120 in MSFC-STD-267A, on the other hand contain information that would complement MIL-STD-1472A.

Depending on how the data are presented, one could show either standard has advantages over the other.

MIL-STD-1472A contains sections on Design of Equipment for Remote Handling, Small Systems and Equipment, Operational and Maintenance Cround Vehicles and Aerospace Vehicle Compartment Design Requirements which are not found in MSFC-STD-267A. Some of these data, particularly the section on Aerospace Vehicle Compartment Design, should be included in MSFC-STD-267A. MSFC-STD-267A does, however, contain data sections on clothing and human capabilities and responses not available in MIL-STD-1472A. The clothing data are rather limited, but the human capabilities and response data would be a useful addition to MIL-STD-1472A.

Formating and organization of the standards differ to some extent. MIL-STD-1472A sections on human capabilities and responses, anthropometry, work space, illumination, vibration, noise, and temperature are more enforceable, and have fewer conflicts.

The difference in formating/organization between MIL-STD-1472A and MSFC-STD-267A can best be illustrated by an example.

MSFC-STD-267A: The anthropometric data is presented in tables on Pages 187 and 188. The associated figures for the tables are on Pages 192 and 193. No reference is made in the table telling where to find the associated figures or that they even exist.

MIL-STD-1472A: The same data is presented much more clearly on Pages 89-95 of MIL-STD-1472A. It is presented in seven separate tables and associated figures corresponding to each of seven categories of measurements (standing body dimensions, seated body dimensions, etc.). Each category occupies one page with the tabular data at the bottom of the page and the associated figures immediately above.

A major problem has been to motivate contractors to use the standards. The presentation method of MSFC-STD-267A would detract rather than enhance its use, MIL-STD-1472A data presentation is clearer and more conducive to use.

Differences in the enforceability of the two documents are illustrated in the following example on work positions.

Work positions are addressed by the following section in MIL-STD-1472A:

5.7.4 Unusual Positions - The design for workspaces with shirt-sleeve environment for work to be accomplished in the squatting, stooping, kneeling, crawling, or prone positions, shall conform to the "preferred" dimensions shown in Table VI and illustrated in Figure 21. These unusual workspaces shall conform to the "Arctic" dimensions shown in Table VI whenever bulky outer clothing is required for environmental protection. In no case shall clearance dimensions be less than the minimum values specified.

In contrast, the same topic is addressed in MSFC-STD-267A by four sections:

5.5.1.7.1 Working Positions - Three working positions shall be considered as critical elements in the design of spatially restricted areas where the ground support personnel often perform their tasks. These are the kneeling, crawling, and prone positions. (Morgan, 2) XR-S-2.

5.5.1.7.1.1 Kneeling - Measurements for the kneeling position shall be taken with the knees and feet together, fist clenched and on the floor in front of knees, arms vertical, and head in line with the long axis of the body as shown in Figure 55. Kneeling dimensions for the 5th, 50th, and 95th percentile shall be obtained from Table XVIII. (Hertzberg, 9) XR-S-1

5.5.1.7.1.2 Crawling - Measurements shall be made with subject resting on his knees and flattened palms, arms and thighs vertical, feet extended, and head in line with the long axis of the body as shown in Figure 55. Crawling dimensions for the 5th, 50th, and 95th percentile shall be obtained from Table XVIII. (Hertzberg, 9) XR-S-1

5.5.1.7.1.3 Prone Position - Measurements shall be made with subject lying in prone position with feet together and extended, arms extended forward, and fists clenched as shown in Figure 55. Prone position dimensions for the 5th, 50th, and 95th percentile shall be obtained from Table XVIII. (Hertzberg, 9) XR-S-1

Not only did MSFC-STD-267A use four paragraphs to relay the same information as MIL-STD-1472A, but the enforceability of MSFC-STD-267A is questionable. MSFC-STD-267A conveys what working positions should be considered; how to take measurements for the kneeling, crawling, and prone positions and various percentile dimensional data for the kneeling, crawling, and prone positions. MIL-STD-1472A, on the other hand, conveys the same information and gives preferred dimensional data which is required in designing work spaces. The more definite requirements of MIL-STD-1472A lend themselves to enforcement while the general statements of MSFC-STD-267A do not.

5.2.2.4 CONFLICTS

Conflicts exist between the two documents which require further evaluation to resolve. The following examples were found in the control and display sections.

- Several quantities in 1472A's detent positioning knobs section disagree with those in MSFC-STD-267A. MIL-STD-1472A specifies a minimum resistance of 1 in. - lb. and a maximum resistance of 6 in. - lbs. MSFC-STD-267A establishes values of 12 in. - oz., minimum of 48 in. - oz. maximum.

- The minimum diameters for pushbuttons specified by MIL-STD-1472A is 0.385 in. while MSFC-STD-267A states 0.5 in. This value should be evaluated and the desirable dimension defined.

- Maximum dimension for legend switches stated in MIL-STD-1472A is 1.5 in. MSFC-STD-267A gives a maximum of 1.25 in. This dimension should be evaluated and the appropriate value selected to eliminate the conflict

The maintainability sections also contain conflicts with respect to the one and two handed access data. The format and tables used to present the data are identical, but the dimensional numerical data differ. Again, one must consider MIL-STD-1472A was updated in May 1970 while MSFC-STD-267A was released in September 1966, therefore, MIL-STD-1472A may contain more recent data. Further investigation is needed to resolve this problem.

3

The weight lifting constraints of MSFC-STD-267A are more stringent than those found in MIL-STD-1472A. MIL-STD-1472A allows one man to lift more weight than does MSFC-STD-267A. This whole area needs to be explored to determine the proper requirements.

5.2.2.5 PARAGRAPH-BY-PARAGRAPH COMPARISON

The following paragraphs deal with each major section of MSFC-STD-267A and the comparison of that specific section with its counterpart in MIL-STD-1472A.

Controls and Displays

The controls and displays sections of MSFC-STD-267A and MIL-STD-1472A are similar in content. However, MIL-STD-1472A contains considerable data not found in MSFC-STD-267A, while MSFC-STD-267A contains some data not in MIL-STD-1472A, but to a more minor degree. The two documents conflict as pointed out in the discussion above, but it would appear MIL-STD-1472A is more up-to-date.

The examples below illustrate the type of data elements found in MIL-STD-1472A that would enhance MSFC-STD-267A.

- Toggle Switch Controls, 5.4.3.1.3
  Virtually all the type of control sections of MSFC-STD-267A could be supplemented by data from MIL-STD-1472A. For example, data from MIL-STD-1472A, Section 5.4.3.1.3, on channel guards, lift-to-unlock switches, could be included in MSFC-STD-267A. MIL-STD-1472A data on dimensions, separation and resistance of thumbwheels needs to be added to MSFC-STD-267A, since these items are not discussed.

- Push Buttons, 5.4.3.1.2
  MIL-STD-1472A, Section 5.4.3.1.2, establishes a maximum value for foot operated push button displacement. This value should be integrated into MSFC-STD-267A.

- Discrete Rotary Selector Switches, 5.4.2.1
  In the area of rotary selector knobs, MIL-STD-1472A specifies the preferred shape of rotary knobs. MSFC-STD-267A does not establish this. MIL-STD-1472A also specifies moving pointer, fixed scale rotary controls, while MSFC-STD-267A allows use of moving scale, fixed pointer knobs.

- Linear Controls, 5.4.2.3
  MIL-STD-1472A specifies a maximum height for rotary knobs which should be incorporated into MSFC-STD-267A, Section 5.1.3.9. The MIL-STD-1472A figure in those same sections also is a useful illustration of three basic types of knobs.

- Cranks, 5.4.2.3.2; Handwheels, 5.4.2.3.3; Levers 5.4.3.2.1
  The cranks, handwheels, levers and pedals sections of MSFC-STD-267A could be augmented by the more complete data provided in MIL-STD-1472A, sections 5.4.2.3.2, 5.4.3.3, 5.4.3.2.1, and 5.4.3.2.2 respectively. The tabular format used in MIL-STD-1472A is much more useful than MSFC-STD-267A's format. MIL-STD-1472A also discusses isometric controls which MSFC-STD-267A does not.

- Selection, 5.4.1.1
  The MIL-STD-1472A data on control operation under various "g" - loading should be added to MSFC-STD-267A.

- Prevention of Accidental Activation, 5.4.1.7
  The MIL-STD-1472A requirements on control guarding against inadvertent actuation would also be a useful addition to MSFC-STD-267A.

- Auditory Displays, 5.3
  A major shortcoming of MSFC-STD-267A is in the area of auditory displays. Small sections are provided in the Safety, Noise, and Human Capabilities and Human Responses Sections, but these are not adequate. MIL-STD-1472A, on the other hand, devotes an entire major section to the subject. The data from MIL-STD-1472A would be very useful additions to MSFC-STD-267A.

- Scale Indicators, General 5.2.3.1
  In the area of transilluminated indicators, data from MIL-STD-1427A on positive feedback would be useful. This section states a requirement for feedback to indicate a "positive" action, such as "system ready" or "system on" rather than a negative action. MIL-STD-1472A also gives data on grouping of transilluminated indicators and other design information.

- Scale Indicators, 5.2.3
  To supplement the selection table provided in Section 5.2.3.2 of MSFC-STD-267A, MIL-STD-1472A, Section 5.2.3, could be considered. This table provides selection criteria for scale indicators versus counters versus pointers versus flags for various applications.

- Linear Scales, 5.2.3.1.4
  MIL-STD-1472A, Section 5.2.3.1.4 states a requirement for linear scale indicators while MSFC-STD-267A, Section 5.2.3.2 does not treat the subject.

- Coding 5.2.3.10
  In the area of scale zone marking, MIL-STD-1472A presents pattern codes, while MSFC-STD-267A specifies only color banding.

- Pointers, 5.2.3.1.7 and Horizontal and Vertical Straight Scales, 5.2.3.2.4
  Information from two sections of MIL-STD-1472A would be useful to the Pointer Design Section. Section 5.2.3.1.7 of MIL-STD-1472A gives contrast values for pointers and requirements for calibration information not interfacing with display information. MIL-STD-1472A, Section 5.2.3.2.4 specifies the location of pointers within horizontal and vertical displays.

- Moving-Pointer, Fixed Scale Indicators, 5.2.3.2
  The Circular Fixed Scale Section of MSFC-STD-267A could be augmented by the data provided in MIL-STD-1472A, Section 5.2.3.2. MIL-STD-1472A states that numbers be oriented upright and that no more than two coaxial pointers be provided on a single display. Neither of these items is discussed in MSFC-STD-267A. MIL-STD-1472A also establishes a minimum separation between ends of the scale at 10°. MSFC-STD-267A states that this separation should be 1.5 times the major scale interval.

- Cathode Ray Tube Displays, 5.2.4
  MSFC-STD-267A, Section 5.2.3.7, on Cathode Ray Tubes provides no quantitative data for design. MIL-STD-1472A, Section 5.2.4, gives data on signal size, scope size, viewing distances, ambient illumination.

- Large-Scale Displays, 5.2.5; Flags, 5.2.6.5
  The 5.2.3.8 Display Section of MSFC-STD-267A is brief and only lists displays that are not discussed in MSFC-STD-267A. MIL-STD-1472A provides two sections which could be included in this section. Section 5.2.5 establishes requirements for large-scale displays for group observation, while Section 5.2.6.5 discussed indicator flags.

- Functional Grouping, 5.1.2.1.1
  Section 5.1.2.1.1 of MIL-STD-1472A states requirements for the size and color of functional borders which could be added to MSFC-STD-267A, Section 5.3.3.4.

- Control Displays Ratio, 5.1.4
  MIL-STD-1472A gives considerably more data than MSFC-STD-267A on control/display movement relationships. Section 5.1.4 of MIL-STD-1472A establishes criteria for control/display ratios, but does not provide quantitative values given in other references.

Maintainability

With respect to maintainability, one would have a difficult time trying to determine which standard is better. Each contains similar information and covers the same topics. In this section, MIL-STD-1472A suffers from the same deficiencies as MSFC-STD-267A, described in Section 5.1.

The two documents conflict in two sections. The dimensional data of the one and two hand access requirements sections are presented in tables which appear to be the same but differ quantitatively. The one man weight lifting constraints of MSFC-STD-267A are more stringent than MIL-STD-1472A, and conflict in a number of places.

Both documents contain information the other lacks. However, MSFC-STD-267A does contain additional information that could be applied to MIL-STD-1472A. MIL-STD-1472A had virtually no additional requirements that were not covered in MSFC-STD-267A. However, MIL-STD-1472A covers many topics in more detail than MSFC-STD-267A, as shown by the following examples.

- Design for Maintainability, General 5.9.1
  This section covers general requirements which are not found in MSFC-STD-267A covering the area of special tools, standardization, malfunction identification and clothing constraints. Each would be helpful if added to MSFC-STD-267A.

- Adjustment Controls, 5.9.3
  MIL-STD-1472A includes adjustment control criteria essential to good design which are not found in MSFC-STD-267A, such as knobs versus screwdrivers for frequent adjustments, blind adjustments, adjustment reference scales for feedback, control limits, sensitive adjustment guards or supports to prevent inadvertent disturbance and hazardous location precautions.

- Delicate Components, 5.9.2.3
  MIL-STD-1472A covers delicate component locations which should be added to MSFC-STD-267A.

- Large Parts, 5.9.4.2
  The "large part access" requirement of MIL-STD-1472A is not covered in MSFC-STD-267A, and should be added to Paragraph 5.8.4.2 of that document to insure full access requirement coverage.

- Rollout Racks, Slides or Hinges, 5.9.12.6
  The information on rollout racks, slides and hinges in MIL-STD-1472A is similar to that in MSFC-STD-267A, although it does present the data in different words. Neither document covers the information adequately, but if the two were combined some improvement would result.

- Use of Tools and Test Equipment, 5.9.4.3
  The same basic information is presented in MSFC-STD-267A under visibility. The two do differ in wording and a combination of the two would provide some improvement.

- Relative Accessibility, 5.9.4.5
  High Failure Rate Items, 5.9.4.6
  Covers or Panels, 5.9.12.12
  Frequency of use 5.9.12.13
  High Frequency Access, 5.9.12.14
  All these MIL-STD-1472A sections and the data in Sections 5.8.5.4.3, 5.8.5.4.5, 5.8.5.4.15, 5.8.5.4.16 of (cont.)

MSFC-STD-267A cover various criteria for determination of relative accessibility to a given component or area. Each provides useful data, but is not all inclusive. The combination of all nine sections into one would provide better coverage of the subject.

- **Visual Access, 5.9.9.5**
  The information in MSFC-STD-267A, Section 5.8.5.4.6 is similar to that of MIL-STD-1472A. MSFC-STD-267A defines an order of preference not given in MSFC-STD-267A. MSFC-STD-267A has the advantage over MIL-STD-1472A in that it utilizes a picture to show what is desired.

- **Labeling, 5.9.9.3**
  MSFC-STD-267A indicates instructions relating to the unit covered should be on or adjacent to the hinged door. MIL-STD-1472A covers the same topic, but goes deeper into when labeling is needed, where it should be, and how it should be presented.

- **Labeling (weight) 5.9.11.3.1.2**
  The labeling requirements for two men or mechanical lift found in MIL-STD-1472A, Section 5.8.7.3 should be added to MSFC-STD-267A. MSFC-STD-267A does have tighter lifting constraints than MIL-STD-1472A and the subject should be reviewed to determine which is best.

- **Captive Fasteners, 5.9.10.3**
  Number of Turns, 5.9.10.8
  Both MSFC-STD-267A, Sections 5.8.9.2 and 5.8.9.3.6 and MIL-STD-1472A cover the area of the number of turns allowed for opening of captive fasteners and the required constraints, but each in a different manner. The two should be combined into one.

- Accessibility (Fasteners) 5.9.10.6
  The MIL-STD-1472A requirement for fastener accessibility is not in MSFC-STD-267A and should be added to Section 5.8.9.3.2.

- Handles and Grasp Areas 5.9.11.4
  The MIL-STD-1472A handle information on nonfixed handles (5.9.11.4.3) grasp surface (5.9.11.4.4), handle and grasp area force requirements (5.9.11.4.6) would enhance MSFC-STD-267A if added to the handle and grasp area section.

- Self-Supporting Covers, 5.9.9.2
  Braces, 5.9.12.9
  MSFC-STD-267A provides more information on covers and cases than MIL-STD-1472A, but MIL-STD-1472A does consider data on braces and hinged units not in MSFC-STD-267A.

- Cable Clamps 5.9.11.3
  Both MSFC-STD-267A and MIL-STD-1472A provide the same information concerning the method of securing long cables, however, MIL-STD-1472A presents the information in a more concise and understandable manner. The 1472A data could replace Section 5.8.13.2 of MSFC-STD-267A.

- Identification, 5.9.13.9
  The cable identification requirements of MIL-STD-1472A are not in MSFC-STD-267A, Section 5.8.13.7 and should be added.

- Drawer Modules 5.9.14.10
  Simplicity 5.9.14.11
  MIL-STD-1472A covers data not in MSFC-STD-267A, Section 5.8.14.1, with respect to connectors used on modules mounted in drawers and electronic equipment plug-in connectors. This data would be helpful if added to MSFC-STD-267A.

- Connectors 5.9.14
  MSFC-STD-267A and MIL-STD-1472A try to convey the same connector alignment information, but MIL-STD-1472A is more concise and understandable. Section 5.9.14 alignment data of MIL-STD-1472A should be used in Section 5.8.14.4 of MSFC-STD-267A.

- Test Points 5.9.15
  Test Equipment 5.9.16
  Failure indications and Fuse Requirements 5.9.17
  MIL-STD-1472A has additional test point and test equipment information above that covered in 267A, Section 5.8.15. More specifically, test point adjustment location criteria, test cable locations, equipment storage and instructions, indicator fuse data and a MIL-STD reference for test point markings.

Human Capabilities and Responses

MIL-STD-1472A does not have a specific section devoted to Human Capabilities and Responses.

Anthropometry and Workspace

The anthropometry and workspace data in both MSFC-STD-267A and MIL-STD-1472A are similar, but the illustrations and tables used in MIL-STD-1472A are more concise and easier to understand. The following data in MIL-STD-1472A should be added to MSFC-STD-267A:

- Anthropometry 5.6
  The data in MIL-STD-1472A with respect to standing and seated body dimensions, breadth and depth dimensions, circumference and surface dimensions, head and face dimensions, and foot dimensions and age and weights is more current than MSFC-STD-267A

- Anthropometry 5.6 (continued)
  and should be incorporated into MSFC-STD-267A. The MIL-STD-1472A data given was taken from U.S. Army personnel (1966) and U. S. Air Force officers flying personnel (1967) while the MSFC-STD-267A data is more dated.

- Kick Space 5.7.1.1
  The kick space dimensions for cabinets and consoles are not covered in MSFC-STD-267A.

- Handles 5.7.1.2
  MSFC-STD-267A does not consider handle criteria like that found in MIL-STD-1472A. This data should be added to MSFC-STD-267A.

- Work Space 5.7.1.3
  The operator and maintenance floor space, work area depth and lateral work space requirements of MIL-STD-1472A should be added to Section 5.5.2.1 of MSFC-STD-267A.

- Unusual Positions 5.7.4
  MIL-STD-1472A, Figure 21 and Table VI provide data and and illustration of a standard console. This information would be helpful in Section 5.5.2.4 of MSFC-STD-267A.

- Horizontal Wrap-around 5.7.6.1
  MIL-STD-1472A gives an illustration of a typical horizontal wrap-around console not found in MSFC-STD-267A, along with dimensions and recommended use.

<u>Illumination, Vibration, and Noise</u>

In these areas MIL-STD-1472A has little to offer that is not already in MSFC-STD-267A. The one data element found in MIL-STD-1472A and not in MSFC-STD-267A is the table on Pages 121-123. This Table

(VIII) provides specific task illumination requirements, both minimum and recommended limits for each task or type of work area.

Temperature and Clothing

In these two areas MIL-STD-1472A has nothing to contribute to MSF -STD-267A. In fact MSFC-STD-267A has a clothing section not covered in MIL-STD-1472A.

Safety

MSFC-STD-267A and MIL-STD-1472A generally have an equal amount of requirements in the Safety Section, but only around twenty-one (21) percent are common. Th following items in MIL-STD-1472A were not found in MSFC-STD-267A.

- Safety Labels
  MIL-STD-1472A, Section 5.13.2, requirements for labeling cover five elements, see below, not covered by MSFC-STD-267A. They would be helpful if added to MSFC-STD-267A, Section 5.7.3.1.6

  (a) Center of gravity and weight locations
  (b) Weight capacity of weight bearing equipment
  (c) Jacking and hoisting points
  (d) No step labels
  (e) Electrical receptacle markings

- Safety Labels
  The MIL-STD-1472A, Section 5.13.3, requirements for identifying the contents and specific quantitative parameters of pipes, hoses and tubelines would enhance the data in 5.7.3.1.6 of MSFC-STD-267A.

- Emergency Exists
  The five second time limit on emergency exists, MIL-STD-1472A, Section 5.13.4.2, should be considered for MSFC-STD-267A, Section 5.7.3.2.5.

- Stairs
  The more specific requirements concerning skid proof surfaces, of MIL-STD-1472A, Section 5.13.4.3, would add to the data in MSFC-STD-267A, Section 5.7.3.2.5.

- Thermal Hazards
  The specific 120° contact and 140° equipment surface temperature requirements of MIL-STD-1472A, Section 5.13.4.6 should be added to MSFC-STD-267A Section 5.7.3.2.1.

- Interlocks and Alarms
  The locking devices for switches and controls, MIL-STD-1472A, Section 5.13.5.1, are not in MSFC-STD-267A and should be considered for use in Section 5.7.3.2.1 of that standard.

- Edge Rounding
  MIL-STD-1472A, Section 5.13.5.4, provides specific minimum radius for exposed corners and edges covered by a general statement in MSFC-STD-267A, Section 5.7.3.2.2.

- Safety Mesh
  The MIL-STD-1472A, Section 5.13.6.3, Safety Mesh requirement for platforms and floors would be useful in MSFC-STD-267A, Section 5.7.3.2.1.

- Electrical Hazards
  MIL-STD-1472A, Section 5.13.7.1, has a number of precautions to prevent electrical shock which are not in MSFC-STD-267A and would improve that document if added.

(a) Wire routing to prevent "hot" lead exposure
(b) Insulation of tools and test leads
(c) Plug and receptacle wrong insertation precaution.
(d) General grounding requirements
(e) Hand operated tools grounding criteria
(f) Electronic equipment safety provision reference specification.

5.2.2.6 SUMMARY

The review of MSFC-STD-267A/MIL-STD-1472A on a paragraph-by-paragraph basis found both documents contain similar information while each contains unique data, MIL-STD-1472A has much to contribute to MSFC-STD-267A with respect to additional data in the controls and display section, a moderate amount in the maintainability and safety sections, and little in the human capabilities and response, anthropometry, workspace, illumination, vibration, noise, temperature, and clothing sections.

MSFC-STD-267A was also found to contain information that would enhance MIL-STD-1472A, particularly in the human capability and response clothing and maintainability sections.

The MIL-STD-1472A formating and organization of data in the human capabilities and responses, anthropometry, Workspace, Illumination, Vibration, Noise, and Temperature sections have fewer conflicts and the data are more enforceable than MSFC-STD-267A.

Conflicts were found between the two documents in the maintainability, control and display sections that require further research to resolve.

It would be difficult to choose between the two documents. Each contains unique advantages and disadvantages. The optimum would appear to be the integration of the two documents. This would produce one document better than either one alone. However, as mentioned before, both documents contain deficiencies which detract from their use. These common deficiencies must be alleviated if the standards were to be combined.

5.2.3 DESCRIPTIVE MODEL FOR DETERMINING OPTIMAL HUMAN PERFORMANCE IN SYSTEMS - SERENDIPITY ASSOCIATES, OCTOBER, 1966

5.2.3.1 PURPOSE AND BACKGROUND

The initial objective of the Serendipity Report was "to present a sequence of activities which describes an effective strategy for determining man's role and carrying out the allocation of function decisions . . . in the development of any aerospace system," and second, "to present data necessary to support man's role and allocation decisions in a format which makes the data readily available as they are needed in the development process." (p. 23) MSFC-STD-267A on the other hand is a human factors standard devoted to presenting design principles and practices to be used in designing earth launch vehicle systems and associated hardware.

5.2.3.2 GENERAL COMPARISON

The Serendipity Report was oriented toward an approach to aid in finding man's optimal role in space programs. This was accomplished in the context of decision making with respect to allocation of functions to man or machine and provided a methodology by which man's role in space programs can be assessed in a systematic manner. The document is well done, providing considerable data concerning man/machine trade-off considerations, man's performance capabilities and attributes, the activities necessary for determining man's allocation to given functions and the sequence of task or activities one must follow to determine the role of man and function allocations. It contains data which could be used to improve MSFC-STD-267A, but the data are not presented in a form directly transferable to a standard.

The discussions on man/machine function allocation, thresholds and capabilities could be used to generate useful design criteria after they are developed into a standard type presentation. This is particularly true in the function allocation area where MSFC-STD-267A provides no design guidance.

The organization of the report differs considerable from the other references cited in this review. The bulk of the report is attached as an appendix. However, the data sheet format in the appendix makes locating particular data difficult. To alleviate this problem, Serendipity devised a system parameter by human parameter matrix, which provided data sheet numbers for parameters the user needed. After utilizing this system, one finds it quite convenient for locating the data.

The report makes extensive use of figures and tables to present data in a form which is easily retrievable. This technique is one which would further improve MSFC-STD-267A.

5.2.3.3 PARAGRAPH-BY-PARAGRAPH COMPARISON

The major sections of MSFC-STD-267A were compared, paragraph-by-paragraph with the information contained in the research report and the following data items were determined to be specifically applicable to MSFC-STD-267A.

CONTROLS AND DISPLAYS

Two items found in the research report should be added to the MSFC-STD-267A control and display section.

- Tracking controller characteristics and g vectors, Item 333.

  The two and three axis balanced and unbalanced controller data shown in Item 333 is not presently in MSFC-STD-267A.

- Controls for use in High g situations, Item 418.

  The information on control placement for use above 2 g acceleration forces is not in MSFC-STD-267A and should be added to Sections 5.1.3.14 and 5.1.3.15.

MAINTAINABILITY

The information contained in the report is not directly comparable to the type of data in MSFC-STD-267A. However, the report would be a useful reference when designing experiments for determining maintainability data.

HUMAN CAPABILITIES AND RESPONSES

The Serendipity Report is an excellent source of basic data which is not presently in MSFC-STD-267A. This specific information is applicable to the Human Capabilities, listed below, and should be added to MSFC-STD-267A.

- Reaction Time (P144)

  Reaction times and the factors influencing reaction time such as sex, age and sense modulity are reviewed.

- Basic Psychophysical Capabilities and Limitations (P134-137)

  The report provides a table on a survey of man's various senses and the physical energies that stimulate them. Included is the comparison of intensity ranges and intensity discrimination abilities.

- Frequency Ranges and Frequency discrimination abilities (p138)

  Frequency ranges of the senses are compared with frequency discrimination abilities in the areas of light wave length, sound and vibration.

- Characteristics of the Senses (p139-140)

  Limits of sense characteristics parameters of spectral range, spectral resolution, dynamic range, amplitude resolution, acuity, response rate, reaction time, stimulus, best operating range and useage are covered.

ANTHROPOMETRY AND WORKSPACE

Anthropometry data are rather limited in the report and MSFC-STD-267A contains much more data. The report, however, contains a table on female human body dimensions which is not treated in MSFC-STD-267A. In the workspace area the tables in Item 430 of the report provide typical crew area requirements for ti living module, laboratory, command area general area. In each case specific function, space utilization information is given along with space dimensional requirements. This data would be a useful addition to Sections 5.5.1 and 5.5.2 of MSFC-STD-267A.

ILLUMINATION, VIBRATION AND NOISE

The Serendipity Report contains a large amount of information that would be applicable to this section of MSFC-STD-267A in the following areas.

- Acceleration Nomenclature (Item 15, 16)

  Acceleration nomenclature is provided for various body positions, prone, supine and seated, should be added to Section 5.6 of MSFC-STD-267A.

- Oxygen Cost (Item 17)

  Daily oxygen cost in different earth and space environments at given functional activities are presented that show and compare the oxygen requirements in different environments. This data would be appropriate in Section 5.6 of MSFC-STD-267A.

- g Tolerance Variables (Item 18-22)

  Variables influencing man's physiological tolerance, maximum acceleration exposures endured by human subject, and data on acceleration exposure limits of humans in relationship to direction of body movements and aircraft maneuver are given in the report and should be added to 267A, Section 5.6.

- Factors Detected While Free-Floating (Item 289 a-e)

  Factors detected by humans when free-floating concerning, exhilaration, comfort, falling sensation, knowledge and control of limb positions and body positions are each considered with respect to light conditions, weightless conditions and a maneuver condition are not covered in Section 5.6 of MSFC-STD-267A.

- Real and Simulated Weightlessness (Item 278)

  Data of changes resulting from real and simulated weightlessness on metabolism, muscular skeletal system, cardiovascular system, sensations, performance and mechanical efforts would be useful in MSFC-STD-267A, Section 5.6.

- Lighting Requirements and Illumination Levels (Items 199, 205, 206, and 207)

  Illumination requirements not covered in MSFC-STD-267A, Section 5.6.1.1 for various tasks on space vehicles including visual acuity, threshold background, speed of vision, acceleration, accuracy, minimum requirements are covered in three tables.

- Whole Body Vibrations (Item 353)

  Data covering subjective ratings of sensations experienced during whole body vibrations as it effects individual portions of the body that should be covered under MSFC-STD-267A, 5.6.2.2.

- Tracking Performance During Jostle

  Two tables are included in which tracking performance errors and deviations under random vibration applications are present.

- Ear Protective Devices (Items 193 to 198)

  A series of figures and tables, not found in MSFC-STD-267A, Section 5.6.3.5, cover ear protection and the attenuation capabilities of various protective devices under given noise characteristics. Including the acoustic reflex of intra-aural muscles.

- Acoustic Reflex (Item 192)

  The reference provides a discussion of the use of acoustic reflex for noise protection including a table which presents the temporary threshold shifts with and without the acoustic reflex.

- Effects of Exposure to Noise (Item 170)

  The effect of exposure to noise as compared to quiet on human performance is discussed. The data, in tabular form should be considered for use in MSFC-STD-267A.

- Maximum Permissible Speech-Interference Levels (Item 171)

  Speech interference level data is provided as a function of distance and acoustic absorption for normal, raised, loud and shouting voice levels. This data would complement MSFC-STD-267A, Section 5.6.3.9.2.

TEMPERATURE AND CLOTHING

One table in the report deals with human impairment when performing manual tasks at critical temperatures. This is the only data on temperature in the report not found in MSFC-STD-267A.

The report does not cover specific clothing information that would be useful in MSFC-STD-267A.

SAFETY

The report contains data that could be used to verify safety requirements, but it does not deal directly with specific safety criteria of the type found in MSFC-STD-267A.

5.3.3.4 SUMMARY

The conclusion drawn from the review of the report in comparison to MSFC-STD-267A is as follows. The report contains a wealth of data and techniques which could be incorporated into MSFC-STD-267A particularly Appendix B as shown in the individual topic discussions.

The report, however, is oriented toward overall capabilities of man and not necessarily discrete items a standard requires. Therefore, if MSFC-STD-267A were to be rewritten it is suggested the report be used as a reference to check the standard requirements against ensure that they are accurate and complete, with the exception of anthropometry data which can be directly transferred to the standard.

5.2.4 HUMAN ENGINEERING GUIDE TO EQUIPMENT DESIGN/MSFC-STD-267A MORGAN, COOK, CHAPANIS, ET AL.

5.2.4.1 PURPOSE/BACKGROUND

Unlike MSFC-STD-267A, which is a human factors design standard, the Human Engineering Guide to Equipment Design was developed by Joint Armed Services to "provide a guide in human engineering which the designer can use in the same manner as handbooks in other areas to assist in solving design problems as they arise. The primary emphasis in the guide will be on recommended design principles and practices in relation to general design problems rather than on compilation of research data." (p. VII) The efforts of twenty-three major contributors and numerous others, over an eight year period went into the final document released in 1960.

5.2.4.2 SIMILARITIES

Although the Human Engineering Guide was written as a handbook and MSFC-STD-267A follows the format of a standard the data in each are similar and in many cases identical. MSFC-STD-267A, published six years after the guidebook, apparently drew heavily from the data contained in it. For instance, the cable requirements illustrated by Figures 9-19 and 9-24 of the guidebook are identical to those in Figures 106 and 107 of MSFC-STD-267A with minor exceptions.

As shown in the examples below, the narrative in both documents are similar.

Guidebook, 9.4.1

Covers and cases should be designed so that they can be lifted off the units rather than the units lifted out of them.

MSFC-STD-267A, 5.8.12.2

Cases shall be designed to lift off units rather than the units be lifted out of the cases.

5.2.4.3 DIFFERENCES

The main differneces between the two documents are organization and format. MSFC-STD-267A is organized into major sections which are further broken down into subsections, each of which contains additional subsections. Each subsection consists of one specific and brief requirement related to the overall section. In contrast, the guidebook is written in a narrative fashion using more narrative to cover the same basic material.

The guidebook contains considerable research data to support and clarify the design recommendations made while the standard is more limited to providing only design requirements.

Additionally, the guidebook contains instructional information similar to that of a textbook. For example, the methods of conducting functional, decision, activity, flow and job analysis were discussed in Section 1.2.1. The man-in-system design information of Section 1.3 covers variations among men, Gaussion distributions, measurement of errors, man's sensory capabilities, motivation and learning. These are a few examples of the textbook type material in the guidebook which are not generally applicable to a standard.

MSFC-STD-267A does have a definite advantage over the handbook in that it contains data on size and weight of units, lubrication techniques, maintenance tools and specific qualitative handle criteria not found in the handbook.

The handbook in turn makes more effective use of figures and pictures to illustrate requirements in a more understandable form than MSFC-STD-267A. An example of this is the pictures of roll out hardware, guide pins, and different types of fasteners.

5.2.4.4 PARAGRAPH-BY-PARAGRAPH COMPARISON

The paragraph-by-paragraph comparison of MSFC-STD-267A and the guidebook revealed unique data in each. The primary purpose, however, was to evaluate the guidebook to determine if it contains data which would enhance MSFC-STD-267A. These data are listed below.

CONTROLS AND DISPLAYS

The guidebook contains more data with respect to controls and displays than MSFC-STD-267A, as depicted by the examples below.

- Hand Controls, 6.3.2

  The guidebook provides quantified data on when to use hand controls which MSFC-STD-267A does not cover.

- Control Coding, 6.2.4

  The guidebook's Section 6.2.4 establishes a value on the relative sizes. MSFC-STD-267A, Section 5.1.6.4 on shape coding does not emphasize the usefulness of this coding technique. The guidebook, Section 6.2.4 gives a better dexcription of the technique and supplies nine standard aircraft codes.

- Auditory Presentation of Information, 3.0

  As found in other references, the guidebook provides an entire section on auditory displays. Chapter 3, of the text is devoted tothis topic, while MSFC-STD-267A does not provide any specific data on auditory displays.

- Printed Materials, 2.8

  The guidebook also discusses decals, checklists, labels, graphs, etc. which are not mentioned in MSFC-STD-267A. A section on these items could be included in Section 5.2 of MSFC-STD-267A.

- Combination/Integration of Displays, 2.1.4

  Guidebook discussion of combined or integrated displays in Section 2.1.4 could be added to MSFC-STD-267A, Section 5.2.3.

- Visual Coding, 2.4

  The display coding section of the guidebook is much more complete than Section 5.2.5 of MSFC-STD-267A.

Morgan gives eight different coding techniques in addition to a discussion of code selection considerations. (Section 2.4)

- Warning and Signal Devices, 2.5

  The guidebook provides a complete description of warning and signal devices compared to a single paragraph in MSFC-STD-267A, 5.2.2.10. Guidebook, Section 2.5 discusses the types of warning devices and the criteria for their selection.

- Design of Symbolis Indicators, 2.6.2

  The scale design criteria provided in the guidebook, Section 2.6.2 are considerably more complete than those in Section 5.2.3.2.3 of MSFC-STD-267A. For example, Morgan gives scale intervals, interpolation, numeral and letter size and scale layout. The guidebook describes color banding of scale indicators, and provides both color and shape codes (Section 2.6.2). MSFC-STD-267A only provides data on color codes.

- Design of Pictorial Indicators, 2.6.3

  Guidebook contains discussions on the design aspects of pictorial displays. This area is critically important in today's spacecraft, but it is not discussed in MSFC-STD-267A, 5.2.3.8.

- Cathode-Ray Tubes, 2.7

  As found in other references, significant data are available on cathode ray tubes. Guidebook, Section 2.7 gives quantified data for design of these displays. Section 5.2.3.7 of MSFC-STD-267A does not provide design data.

- Location of Shared Controls and Displays, 7.7

  Guidebook, Section 7.7 discusses requirements for displays that have to be monitored by two operators. These requirements would be useful additions to Section 5.3.3 of MSFC-STD-267A.

- Control Display Associations, 7.3.3

  Guidebook illustrations of relative positions of controls and displays on panels are much more meaningful than those given in MSFC-STD-267A, Section 5.3.3.6.

- Grouping Controls and Displays, 7.3.2

  Section 7.3.2 of the guidebook provides a more complete discussion of the advantages and applications af sequential and functional groupings. Data from this section could be integrated into Sections 5.3.3.4 and 5.3.3.5 of MSFC-STD-267A.

- Priority Positions, 7.3.1

  Section 5.3.3.8 of MSFC-STD-267A could be augmented by the priority data given in Section 7.3.1 of the guidebook.

Maintainability

Approximately twenty percent of the maintainability data in MSFC-STD-267A is similar to that found in the test guidebook and approximately the same percentage of the text data is found in MSFC-STD-267A.

The handbook provides more comprehensive coverage of the types of maintenance, maintenance criteria involving human factors, the main areas of human factors a designer should consider and a step-by-step approach the designer should follow to obtain specific maintainability design information concerninga given design.

As far as specific design criteria are concerned, both MSFC-STD-267A and the guidebook contain an equal amount. However, each contains unique data. For instance, both MSFC-STD-267A and the guidebook cover the areas of component location, mounting of units, fasteners, conductors and connectors. In each case, MSFC-STD-267A has data not found in the guidebook and the guidebook contains data not available in MSFC-STD-267A.

Listed below are those discrete items in the handbook which contain data not in MSFC-STD-267A.

- Overall Plan for Maintenance, 9.3.1

  The guidebook definition of maintenance types is more comprehensive than MSFC-STD-267A, Section 5.8.2.

- Design Schedule for Maintainability, 9.2

  Section 5.8.3 of MSFC-STD-267A makes an attempt to give general maintenance criteria and the information a designer should have to perform the task. The guidebook covers the topic more completely.

- Prime Equipment, 9.4.1

  The guidebook contains a few points on component locations that should be added to MSFC-STD-267A, Section 5.8.4.2, covering part mounting and wiring locations, subassembly interference and internal controls.

- Prime Equipment, Equipment Accesses, 9.4.1

  The guidebook has little on the subject of access requirements covered in 5.8.5 of MSFC-STD-267A, but does contain information that would be useful if added to 267A such as the tube orientation, access identification numbers and required tools.

- Designing for Maintainability, 9.4

  The roll out hardware and guide pin figures shown in the guidebook would help illustrate the points made in 5.8.4.3.3 and 5.8.4.3.4 of MSFC-STD-267A.

- Prime Equipment, Equipment Accesses, 9.4.1

  The size and shape information of MSFC-STD-267A Section 5.8.6 utilizes figures to illustrate the requirements. MSFC-STD-267A should do the same.

- Mounting bolts and fasteners, 9.4.1

  The hex head, fastener marking, thread controls, mounting surface space requirements and covers and cases fasteners requirements of the guidebook contain information in addition to that found in Section 5.8.9 of MSFC-STD-267A.

- Wire Connectors, 9.4.1

  The guidebook makes better use of illustrations to show wire terminal interfaces and physical constraints not shown in MSFC-STD-267A, Section 5.8.13.

- Connectors, 9.4.1

  The guidebook covers connector requirements with respect to coding, self locking catches, alignment pins, keying criteria, test point and connector integration not found in MSFC-STD-267A, Section 5.8.1.4.

- Test Points, 9.4.1

  Section 9.4.1 of the guidebook deals with the whole subject of test points not covered in MSFC-STD-267A, from test point arrangement to placement and labeling. The maintenance task cannot be efficiently performed without use of test points so that section should be added to MSFC-STD-267A.

- Test Equipment, 9.4.3

  Section 9.4.3 deals with another important factor of maintainability not adequately covered in MSFC-STD-267A. It begins with trade-off considerations with respect to built in, go-no-go, automatic and combined technique test equipment. This subject is only lightly covered in MSFC-STD-267A. The section then covers bench mock-ups to be used for checkout and repair, their advantages and recommendations for mock-up design.

- Maintenance Procedures, 9.4.4

  The last maintainability section, 9.4.4, of the guidebook provides information and techniques for development of maintenance procedures and manuals. This subject is not approached in MSFC-STD-267A. The most effective use of maintainability criteria in hardware design can be negated by not providing the maintenance personnel with effective documentation. It is, therefore, important to use the techniques described in Section 9.4.4, listed below. They should be added to MSFC-STD-267A.

- Format recommendations
- Routine check techniques
- Group analysis techniques for symptom patterns
- System data flow diagrams
- Half-split trouble shooting method
- Special test sequencing
- Trouble shooting approaches

Human Capabilities and Responses

The handbook contains very little data not in MSFC-STD-267A, the exception being the handbook discussion on man's sensory system and capabilities. This discussion covers: man's channel capacities, signal detection, tactile inputs, sensory interaction and multiple inputs.

The narrative is backed by tables giving specific data on:

Man's senses and physical stimulation

Stimulation versus intensity ranges

Discrimination abilities of these ranges

Frequency detectability range

Frequency discrimination abilities

5.2.4.5 <u>SUMMARY</u>

The Human Engineering Guide to Equipment Design unlike many textbooks is a collection of human factors data presented with narrative statements reinforced by numerous figures, tables and charts. This method of data presentation includes not only the basic data but gives the advandages, disadvantages, and design trade-off considerations.

The illustrations and section headings in the test are easily identified by their bold print and large labels. This renders the text material easy to retrieve.

In the areas of controls displays and maintainability, the guidebook covers the same topics as MSFC-STD-267A.

When the human capabilities and responses, anthropometry, workspace, illumination, vibration, noise temperature and clothing sections of MSFC-STD-267A were compared with the guidebook, little useful dada were found in the text that were not currently in MSFC-STD-267A or better covered in other references. The two documents did contain most of the same information in those sections with MSFC-STD-267A covering more material than the guidebook.

When the guidebook and MSFC-STD-267A are viewed in light of which encompasses the greatese amount of design data they both receive an equal rating. The optimum lies somewhere between or possibly a combination of the two documents utilizing the advantages of each.

Both would have one major disadvantage if imposed on contractors of future space programs. The data they contain are out-of-date. Therefore, the combination of the two documents would produce a better document, but it would still not meet the needs of today's state-of-the-art.

5.2.5 COMPENDIUM OF HUMAN RESPONSES TO THE AEROSPACE ENVIRONMENT LOVELACE FOUNDATION

5.2.5.1 PURPOSE AND BACKGROUND

The Lovelace Compendium is the response of Lovelace Foundation for Medical Education and Research (November 1968) to the NASA Office of Space Medicine request for a review of the human data available to engineers and life scientists, to develop design operational planning for manned spacecraft systems and operations.

"It soon became clear the environmentally induced degradation of human function and performance to be assumed by mission planners and system designers is very sensitive to mission-specific variables. It was therefore, felt that the first step in establishing a basis for future standards would be a comprehensive analysis of human responses to different environments with emphasis on the subtle pit-falls to be encountered in extrapolating to the space environment many of the data obtained from previous studies of the earth and atmospheric environments." (Page V.)

The Lovelace Compendium is divided into sixteen sections, each of which deal with one of the separate environmental categories listed below:

1. Microwave Radiation

2. Light

3. Ionizing Radiation

4. Magnetic Fields

5. Electric Current

6. Thermal Environment

7. Acceleration

8. Vibration

9. Sound and Noise

10. Oxygen-CO_2-Energy

11. Inert Gas

12. Pressure

13. Contaminates

14. Nutrition

15. Water

16. Anthropometry and Temporo-Spatial Environment

Each section follows the same general pattern, first describing the particular environment, its range and limits, then the effects of various environmental levels upon human functions and performance. As stated in the Lovelace Compendium, much of the information is directed toward individual writing specifications and standards. The intent was not to develop a design handbook per se, but a compromise between the specific needs of engineers and life scientists.

5.2.5.2 GENERAL COMPARISON

Like the Serendipity Report discussed above, the Lovelace Compendium was not directed toward the development of specific criteria for use in design standards. The Lovelace Compendium contains narrative descriptions on each of sixteen environmental topics along with figures, tables and graphs depicting quantitative data. It is written more toward an overall textbook type coverage of each topic backed by specific data, as opposed to the direction giving statements required by a well structured standard. For example, Section 2 on Light begins with the characteristics of the human eye, its construction and an operational description. It then describes in detail such things as the relationships between intensity (candles or Lumens) and illuminance units (Lumen/ft^2), conversion units commonly used in optics, conversion factors and visibility of stars. This is followed by vision in rendezvous and docking including subtopics on acquisition and range, braking and docking phase.

Section 3, on ionizing radiation, covers space radiation, again using a narrative form supported by figures and graphs.

The example below gives some insight into the type of information presented in section.

> "A phenomenon of special importance for satellite missions in near-Earth orbits is the so-called South Atlantic anomaly. It is a region where the mirror points of the trajectories of trapped protons in the inner belt dip down more closely to the Earth than at any other longitude, due to an asymmetry of the geomagnetic field. Dose rates below 1.5 g/cm^2 shielding come close to 100 mrads/hr at altitudes as low as 120 miles, as direct dose-rate measurements on the Gemini IV mission indicate. Since the point of intersection of a satellite orbit with the geographic continuously drifts westward due to the rotation of the Earth, any mission comprising a large enough number of revolutions passes through the anomaly on some orbits. Although the time of a single passage is less than 15 min and the accumulated passage time on a mission of many orbits remains well below 10 percent of the total time in orbit, the proton exposure in the anomaly accounts for more than 90 percent of the total exposure. The accumulated exposure in the anomaly will be a limiting factor for long-duration, low-orbital missions."

These data are good background material and should be used in the development of a standard, but must first be converted into a standard format and language.

Although most of the data found in the Compendium is similar to the above examples and will require conversion prior to use in a standard, some data were found that could be directly applied to the standard. An example can be found on Page 16-23 of Volume III. Here various work space dimensions of instrument consoles for seated and standing operators utilizing a table showing maximum or preferred dimensions for the 95th percentile of the USAF population are presented. Additional examples are covered in the paragraph-by-paragraph comparison.

5.2.5.3 PARAGRAPH-BY-PARAGRAPH COMPARISON

The areas of MSFC-STD-267A to which the Compendium has the greatest potential of contribution are the Human Capabilities and Responses, Anthropometry and work space, Illumination, Vibration, Noise, Maintainability and Safety. In these areas the Lovelace Compendium data are normally depicted in a narrative form and must be translated to standard language before use in any standard. Sections of MSFC-STD-267A which would be least affected by data in the Lovelace Compendium are the temperature, clothing displays and control sections. The Lovelace Compendium does contain data that would augment those sections, and MSFC-STD-267A provides more detailed coverage of the topics.

In comparison with the other references reviewed, the Lovelace Compendium provides the greatest coverage in Human Capabilities and Responses, Illumination, Vibration, and Noise. The following paragraphs reflect these observations.

Controls and Displays

The majority of the data in the Lovelace Compendium is not applicable to the control and display sections of MSFC-STD-267A, but several data items were identified which would be useful as supplemental data for MSFC-STD-267A.

- Side-arm Controllers, 16
  Pages 16-39 to 16-42 present forces exerted on side arm controllers for various controller angles. These data are not currently available in MSFC-STD-267A, Section 5.1.3.14.

- Color Code, Pigments and Indicator Lights, 2
  Pages 2-34 and 2-35 provide color coding pigment recommendations and color meaning data which could be added to MSFC-STD-267A, Section 5.2.5.2.

- Cathode Ray Tubes, 2
  As in other references, Lovelace Compendium presents a better treatment of cathode ray tubes than MSFC-STD-267A. Pages 2-87 to 2-91 provide design values on target size and background brightness versus probability of target detection. Section 5.2.3.7 of MSFC-STD-267A does not discuss the topic.

- Luminance Contrast, 2

  Page 2-15 gives formulas for luminance contrast between target and background not covered in MSFC-STD-267A.

MAINTAINABILITY

MSFC-STD-267A lacks data pertaining to reduced gravity environments. The Lovelace Compendium provides excellent coverage of this topic and man's capabilities during EVA.

The reference discusses problems that occurred during EVA of Gemini missions and evaluates the tether line and hand-held maneuvering units. These data along with the pressure suit considerations cannot be directly applied to a standard, but the mission experience points out problem areas that should be considered when establishing a reduced gravity maintainability requirements.

Below are data elements found in the Lovelace Compendium that should be given consideration for incorporation into MSFC-STD-267A.

- Capability of Astronauts in EVA, Sec 7

  On Pages 151 to 158 the experience of astronauts during Gemini flights with respect to EVA and man's capabilities are discussed. This data which includes flight plans, checklist, training, spacecraft control, medical factors and future EVA recommendations should be considered in the development of a space oriented standard.

- Tether Lines for Astronaut Retrieval, Sec 7

  The Lovelace Compendium narrative, Pages 158-166, on tether lines, their uses, advantages and disadvantages would be helpful if and when space environment data are added to MSFC-STD-267A.

- Restraints, Sec 7

  The Lovelace Compendium, Page 175, has twelve (12) direct reduced gravity restraint recommendations which should be added to the maintainability section of MSFC-STD-267A. They cover:

  (a) Restraint configuration and effectiveness

  (b) Foot strap, cage, waist restraints

  (c) Stability of work positioning

  (d) Free pivoting restraints

- Tools, Sec 7

  Page 175 contains nine specific space tool recommendations that would enhance MSFC-STD-267A in the following areas.

  (a) Wrenches

  (b) Screwdrivers

  (c) Tool performance versus subject position

  (d) Pliers and pincher type handles

  (e) Tool retention

  (f) Suit resistance

These should be added to 5.8.10 of MSFC-STD-267A.

- Fasteners, Sec 7

  The coverage of one-hand clamps, non-captive hardware, wrenches versus slotted bolts and bolt sizes provides recommendations not in MSFC-STD-267A and should be added to that document.

- Locomotion aids, Sec 7

  The Lovelace Compendium discusses the rigidity of space environment locomotion aids, the most desirable type and package carrying requirements not found in MSFC-STD-267A.

- Work, Sec 7

  Work during EVA is discussed in the Lovelace Compendium with specific recommendations given for:

  (a) Procedures and Training

  (b) Two-handed task

  (c) Arm extension

  (d) Visual requirements

  (e) Multi-tool usage

  (f) Accessibility requirements

- Access requirements, Sec 16

  The pressure suit access requirements on Page 26-33 of the Lovelace Compendium would be helpful if added to MSFC-STD-267A, Section 5.8.5.

<u>Human Capabilities and Responses</u>

Of all nine references reviewed the Lovelace Compendium provided the most complete discussion of the factors influencing man's performance in space and their impact on spacecraft design requirements. Much of the information was in a form not directly transferable to a standard. The sections and pages which contain human performance data constitute ninety percent of the document so they will not be listed here. However, when and if a standard is formulated for reduced gravity conditions the entire Lovelace Compendium should be review and considered for establishing human capabilities and responses.

Anthropometry and Work space

The Lovelace Compendium provides discussions of work-rest-cycles with respect to its relationship to future space missions. It also provides astronaut population data, habitability and confinement studies and work space allotments. More specifically:

- Work-Rest-Sleep Cycle, Sec 16

  The Section 16, Page 79 to 92 discussions on studies and experiments relative to man's efficiency and work-rest-sleep cycles provide data that would be useful in MSFC-STD-267A, after conversion to a standard type format, in the area of:

  (a) Diurnal or circadian rhythms

  (b) Sleep duration

  (c) Duration of work periods

  (d) The work-rest cycle

  (e) Efficiency during wakefulness

  (f) Non-temporal factors

- Astronaut Population, Sec 16

  Population data presented in the six page Table 16-4 covering all necessary dimensions of the astronauts would be a useful addition to MSFC-STD-267A, Sec. 5.5.1, which does not contain data relative to astronauts.

- Work space factors, Sec 16

  Based on data from discussions on habitability compartment studies and past space vehicle operations (P. 24, 36-37) recommendations are made concerning minimum volumes, hatch and air-lock locations, minimum hatch dimensions and minimum airlock envelopes. These recommendations should be added to MSFC-STD-267A, Section 5.5.2.

- Volume/Duration Factors, Sec 16

  The Compendium has a narrative and tables (P 69-76) which depict the effects of mission duration and confinement space vehicle volume requirements, thresholds necessary to prevent individual or group negative psychological effects. This type data is not in MSFC-STD-267A and would enhance that standard if added.

Illumination, Vibration and Noise

The Lovelace Compendium covered considerable data not found in MSFC-STD-267A on illumination, noise, and vibration as shown in the examples below.

- Vision in Rendezvous and Docking, Sec 2

  The Lovelace Compendium (Pages 96-99) contains a summary of visual problems in acquisition of spacecraft, the ability of an observer to detect a target satellite and the effects of flashing all of which are not found in MSFC-STD-267A. The summary information could be useful to MSFC-STD-267A if specific requirements were extracted and added to Section 5.6.

- Viewing Ports and Visors, Sec 2

  The Lovelace Compendium (Pages 78-80) provides recommended guidelines for the design of visors and viewing ports, including field restrictions, optical distortions, optical transmission and visual impairment due to fogging, not included in Section 5.6 of MSFC-STD-267A.

- Spacecraft Illumination, Sec 2

  The general recommendations concerning illumination factors to consider, color, light intensity, workspace reflectance and work surface reflectance factors for various finishes, on Pages 73 - 75 are currently not available and should be added to Section 5.6.

- Spacecraft Illumination Systems, Sec 2

  The 14 specific color, intensity, and types of lighting recommendations on spacecraft illumination found on pages 77 and 78 would be helpful if added to MSFC-STD-267A.

- Instrumentation and Displays, Sec 9

  The Summary, Pages 81-91, on visual factors effecting the design of instruments and displays concerning itself with viewing distances, graduation intervals, illumination reading conditions, relative efficiency of instrument reading and CRT criteria should be considered for addition to Section 5.6.1.7 Illumination and Visual Displays of MSFC-STD-267A.

- Microphone and Electronic Processing in Speech Intelligibility, Sec 9

  A discussion on microphones, their characteristics, noise shields, word intelligibility and electronic processing of speech could yield some specific requirements to add to MSFC-STD-267A, Section 5.6.3.9.5.

- Speech, Sec 9

  The entire section from Page 21 through Page 35 deals with speech, the speech spectra, intelligibility, and speech interference factors from the environment. The main body of information is provided by a narrative enforced by tables and graphs. This section could also yield specific criteria that would be useful in MSFC-STD-267A.

- Analysis of Sound and Noise Factors, Sec 9

  The sequential approach for analysis of sound and noise, the factors to consider, data needed for analysis and corrective measures for reducing noise levels (Pages 81 and 82) would help MSFC-STD-267A if it were converted to a standard format.

- Personnel Protective Equipment, Sec 9
  The discussion on personnel protective equipment for noise reduction would be useful information to extract and put in MSFC-STD-267A, Section 5.6.3.4.

- Noise Reduction, Damage Risk Factors, Sec 2
  The twelve curves on damage risk of human exposure to noise provide limitations and acceptable acoustic noise levels. The data should be a part of MSFC-STD-267A, Section 5.6.3.1.

- Effects of Noise on Performance, Sec 9
  A summary of past studies on the topic of noise effects on human performance is presented on Pages 49 through 51. The studies cover vigilance task, serial reaction tasks, and psychomotor performance. In addition, the possible use of noise as a positive psychological stimuli is considered. From these studies a number of specific requirements could be derived which could be helpful in Section 5.6.3.7 of MSFC-STD-267A.

- Human Response to Noise, Sec 9
  The human response to noise such as ear discomfort, ear damage, hearing loss and non-aural effects discussed in this section (Pages 41-48) provide data on the ear, hearing, sound frequency and intensity levels that could be useful in MSFC-STD-267A, Section 5.6.3.1.

- Performance During Vibration, Sec 8

  An entire subsection (Pages 67-90) is devoted to the effects on performance of vibrations, the narrative and tables cover such topics as visual tasks, vigilance reaction times, motor tasks and speech. Each is treated in such a manner they could not be directly used in MSFC-STD-267A, but after analysis some discrete criteria could be derived which would enhance Section 5.6.2.3 of MSFC-STD-267A.

- Human Tolerance to Vibration, Sec 8

  The limits and tolerances given in this subsection (Pages 51-66) should be helpful if added to MSFC-STD-267A.

Temperature and Clothing

The temperature and clothing data in the Lovelace Compendium contains little that would contribute to MSFC-STD-267A, however the few examples below would improve MSFC-STD-267A if incorporated in that document.

- Pain From Conductive Heating, Sec 6

  The table on Page 108, providing pain threshold data for various body locations should be added to MSFC-STD-267A, Section 5.7.1.

- Operative Temperature, Sec 6

  A discussion of six different areas which relate (con't)

- Operative Temperature (continued)

  environmental parameters to subjective impressions of comfort and measured values of selected physiological variables are reviewed. The data contained therein would be useful if researched and converted into standard type requirements.

- Performance Under Heat and Stress, Sec 6

  The effects of heat stress on performance is summarized in the Lovelace Compendium. The subject is well covered and standard requirements could be extracted from it for use in Section 5.7.1.2 of MSFC-STD-267A.

- Space Suits and Clothing, Sec 6

  The Lovelace Compendium goes into much detail (Pages 53-71) on the thermal physiology of clothing and space suits. MSFC-STD-267A does not contain this data so it would be beneficial to add it to 267A.

Safety

Most of (11) of the 16 sections of the Lovelace Compendium cover some aspects of safety intermixed with tolerances and environmental limits humans can withstand under given conditions. The effort to extract these data and convert them to a standard type presentation would be tedious, but the result would be a safety standard which would encompass more safety factors than MSFC-STD-267A now possesses. This is illustrated by the examples below.

- Skin and Body Contact Resistance, Sec 5
  The skin and body resistance criteria and the way it affects the shock hazards explained on Pages 3-8 will be useful in establishing safety requirements for Section 5.7.3.1 of MSFC-STD-267A.

- Amperage, Sec 5
  Pages 8-11 of the Lovelace Compendium provide the effects of different current levels on the human body and brain including estimates of physiological thresholds. This data would be helpful to MSFC-STD-267A, Section 5.7.3.1.

- Frequency Factors, Sec 5
  The greater injurious effects of alternating current over direct current levels shown in this section (Pages 11-12) should be considered in establishing criteria for MSFC-STD-267A.

- Organ Damage by Electric Current, Sec 5
  The effects of electric current on different organs, central nervous system, skin, voluntary muscles, bones, blood vessels, eye and heart defined on Pages 12-14 are of prime importance and would be helpful in establishing specific requirements for MSFC-STD-267A, Section 5.7.3.1.

- Limits of Tolerance to Electric Current, Sec 5
  The human tolerance limits for electric current on Pages 15-20, shock duration, lethal voltage, surge currents, let-go currents, are a necessity if MSFC-STD-267A, Section 5.7.3.1 is updated.

- Microwave Effects in Humans, Sec 1
  The narrative on Pages 9-14 which gives the basic effects of microwaves on man and human tolerance limits for microwaves would be helpful if added to Section 5.7.3.2 of MSFC-STD-267A, which does not cover this topic.

- Glare and Flash Blindness Phenomena, Sec 2
  The general and threshold data on Glare, irradiation, flash blindness, retinal burns, laser burns, and effects on the skin along with protective measures given on Pages 51-68 should be added to MSFC-STD-267A, Section 5.7.3.2

- Ultraviolet Radiation, Sec 2
  The effects of ultraviolet radiation on the skin and eye depicted along with protective measures, Pages 110-120 would be helpful if added to Section 5.7.3.2 of MSFC-STD-267A.

- Ionizing Radiation, Sec 3
  The complete Section 3 (Pages 1-90) deals with space radiations, its effects on humans and protective methods. Specific requirements should be extracted and added to the safety requirements of 267A.

- Thermal Environmental, Sec 6
  The Heat Stress and Tolerance data (Pages 71-73), skin pain and heat pulse (Page 107) and cold stress data (Pages 107-125) are not covered in the safety section of MSFC-STD-267A and should be added to it.

- Acceleration, Sec 7
  The data contained in Pages 1 through 35 are all related to safety, particularly the maximum acceleration tables of Figures 7-5 through 7-11 and 7-14 through 7-17. They contain maximum tolerance limits under different acceleration conditions that would be helpful if added to 267A.

- Vibration, Sec 8
  The data throughout this section is pertinent to man's safety and should be considered for use in section 5.6.2 of MSFC-STD-267A. Particular attention should be given to the human tolerance to vibration data, visual effects, vigilance, performance under vibration and protection against vibration.

- Sound and Noise, Sec 9
  The portions of Section 9 (Pages 40-81) which cover biological responses to noise exposure and tolerance, including the physiological effects of noise, ear discomfort and damage and noise control and protection should be placed in a standard format and incorporated into MSFC-STD-267A, Section 5.6.3.

- Oxygen-CO_2 Energy, Sec 10
  The safety data on oxygen and carbon dioxide in the lung, hypoxia, hyperoxia, fire hazards and CO_2 effects would enhance MSFC-STD-267A, Section 5.7.3.4.1.

- Contaminants, Sec 13
  The environmental toxicity data found throughout the entire Section 13 of the Lovelace Compendium would be useful in MSFC-STD-267A, Section 5.7.3.4 after conversion to a standard format.

- Water, Sec 15
  The water purity standards provide data not presently in MSFC-STD-267A and should be added to that standard.

5.2.5.4 SUMMARY

The Lovelace Compendium was intended to present a comprehensive description of human parameters in the aerospace environment. As such, the document does not provide data in a form appropriate for a standard. The manner of organization of the document is clear and thorough. The text of the report is lengthy, but not overly so, considering the comprehensive treatment of a large number of topics. The illustrations provided augment the text well, and are presented clearly.

The Lovelace Compendium presents threshold and basic capabilities data in a number of major chapters relevant to the aerospace environment.

MSFC-STD-267A is specifically lacking in data applicable to reduced gravity conditions. As a result, the Lovelace Compendium would represent a considerable contribution to MSFC-STD-267A.

If one were to use the reference to extract data for the enhancement of MSFC-STD-267A, the task would be tediuos due to the narrative form prevalent in the Lovelace Compendium. The return from such an effort would, however, provide reduced gravity data not now in MSFC-STD-267A. The Lovelace Compendium is, therefore, an excellent reference for engineers and scientists working in the aerospace field. It affords them a fine handbook and could greatly strengthen the worth of MSFC-STD-267A after conversion of the data into a standard configuration.

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5.2.6 DATA BOOK FOR HUMAN FACTORS ENGINEERS
KUBOKAWA, WOODSON

5.2.6.1 PURPOSE AND BACKGROUND

The purpose of the data book was to collect data most often used by practicing human factors specialists into one convenient reference. This was done with the hope that it would reduce the time human engineers normally spend searching through numerous references to obtain needed data. The material included in the data book was taken directly from other sources with a few exceptions.

The data book is divided into two volumes each containing somewhat different information. Volume one is concerned with human engineering data that may be used to obtain optimum equipment designs for human operation and maintenance. The second volume contains formulas, conversion tables, nomographs, definitions, abbreviations and other data which are helpful when applying the human factors principles.

For the purpose of this review, the first volume received a paragraph-by-paragraph comparison with MSFC-STD-267A. The second volume was considered more as handbook information rather than data applicable to a standard, and was not reviewed in as great a depth.

5.2.6.2 GENERAL COMPARISON

The Kubokawa-Data Book for Human Factors Engineers was found to be a collection of data from MSFC-STD-267A and other sources. The document was not organized below the major section level, which resulted in a cumbersome data retrieval problem. Since the document was not intended to be a design standard, no directive statements were made as to how equipment should be designed. Rather, data sheets were given on a variety of topics.

MSFC-STD-267A was found to contain more human factors design standard information than the Kubokawa-Data Book. One must keep in mind the stated intention of the data book was to provide "most used reference information" and as such would not be expected to cover as much overall information as a standard.

Conflicts were noted between the data book and MIL-STD-1472A which was previously reviewed. The one and two-handed access quantitative data do not agree. There is agreement, however, between MSFC-STD-267A and the data book.

Conflicts were also found between the Kubokawa-Data Book weight lifting charts (1-60) and the criteria of Section 5.8.7.3 in MSFC-STD-267A.

Still more conflicts were found in the control/display sections. For example:

- The Kubokowawa-Data Book and MSFC-STD-267A disagree in the maximum diameters for legend switches. Pages 1-87 of Kubokawa-Data Book specifies 1.5 in. while Section 5.1.3.7 of MSFC-STD-267A specifies 1.25 in.
- Some disagreement in letter style and size was identified between 267A, Section 5.2.4.5 and the Kubokawa-Data Book, Pages 1-113 to 1-116. The panel labelling illustration on Page 1-118 also disagrees with that provided in MSFC-STD-267A, Section 5.2.4.5.
- Several values in the detent position knobs, Section 5.1.3.11, of MSFC-STD-267A were found to disagree with the values stated on Pages 1-89 of the Kubokawa-Data Book.
- Considerable disagreement in rotary knob design values were found between Pages 1-90, 1-91 and Section 5.1.3.9 of MSFC-STD-267A. The Kubokawa-Data Book's minimum diameter for finger tip and palm grasp knobs disagree with those stated in MSFC-STD-267A. The data book also gives several design quantities on this page which are not discussed in MSFC-STD-267A.

One advantage of the Kubokawa-Data Book is its extensive use of figures, charts, tables, and graphs. A technique not used to its fullest potential in MSFC-STD-267A. It is recommended this technique of data display be adopted by MSFC-STD-267A to further complement that document.

5.2.6.3 PARAGRAPH-BY-PARAGRAPH COMPARISON

In the paragraph-by-paragraph review, most of the information in the Kubokawa-Data Book was found to be the same as that in MSFC-STD-267A. The data book, therefore, has little to contribute to MSFC-STD-267A. Some data were found in the control, display, maintainability, anthropometry and work space sections which should be added to MSFC-STD-267A.

<u>Controls and Displays</u>

- Typical Pushbutton Switch Component, Sec 1
  The Kubokawa-Data Book's detail drawings of various control types presented in Pages 1-97 to 1-110 could be integrated into the text of MSFC-STD-267A, Section 5.1.3. These illustrations could be a useful supplement to the data already provided. Kubokawa also provides some data on joysticks and Alpha-numeric keyboards. These could be included in M -STD-267A, Section 5.1.3 to alleviate deficiencies.

- Thumbwheel Control, Sec 1
  The Data Book section on thumbwheels (Page 1092) provides dimensions, resistance and separation values that are presently not given in MSFC-STD-267A, Section 5.1.3.4.

- Hand Pushbuttons, Sec 1

  Page 1-88 of the data book gives additional specification pushbuttons that could be useful in Section 5.1.3.6 of MSFC-STD-267A.

- Ganged Knobs, Sec 1

  As in other references, the Kubokawa Data Book gives values for ganged controls (Pages 1-92) that are not given in MSFC-STD-267A, Section 5.1.5.6.1.

- Pedal Selection Requirements, Sec 1

  Page 1-94 of the Kubokawa Data Book provides much more retrievable specifications on pedals than the data given in MSFC-STD-267A, Section 5.1.3.15.

- Visual Displays, Sec 1

  The Kubokawa Data Book provides descriptions, although incomplete, of several display types not given in MSFC-STD-267A (Pages 1-119 to 1-120). These are:

  - Mechanical Flags
  - Placard Indicators
  - Tape Displays
  - Solid State Meters
  - Flight Instruments

These data would be useful supplements to MSFC-STD-267A, Section 5.2.3.

- Auditor Warning Signals, Sec 1

  The Kubokawa Data Book discusses the desirable characteristics of auditory warning devices on Pages 1-11 and 1-112. The tabular format given would be a most appropriate addition to MSFC-STD-267A, Section 5.2.3.

- Color Coded Lights and Annunciator, Sec 1

  Page 1-129 of the Kubokawa Data Book provides data on coding scale indicators which includes color and graphic coding techniques. These data are not given in complete form in MSFC-STD-267A, Section 5.2.3.2.2.

- Cathode Ray Tubes, Sec 1

  As in other references, the Kubokawa Data Book supplies data that are needed in the cathode ray tube section of MSFC-STD-267A, Section 5.2.3.7. On Pages 1-142, the characteristics of various CRT phosphars are given.

- Color Coding, Sec 1

  Page 1-131 to 1-141 give color coding data that would be appropriate for ground support equipment. Colors are specified for electrical connectors, hydraulic connectors, etc. These data could be included in MSFC-STD-267A, Section 5.2.5.2 or moved to a more remote location in the document.

- Control-Display Ratios, Sec 1

  Pages 1-96 of the Kubokawa-Data Book specifies optimum control-display ratios for various types of controls. These data would be useful as supplements to MSFC-STD-267A, Section 5.3.4.

- Control Direction of Motion, Sec 1

  Pages 1-95 provide data on direction of motion conventions for control/display interaction. These data would be useful for integration into MSFC-STD-267A, Section 5.3.4.4.2.4.

Maintainability

- Internal cabinet Access, Sec 1

  The dimensional considerations for internal cabinet access and depth of reach on Pages 1-56 are not in MSFC-STD-267A and should be added to Section 5.8.6.2.4.

- Weight Limits for Packing Design, Sec 1

  Recommended weight limits for various package configurations are given in the Kubokawa Data Book, while MSFC-STD-267A, Section 5.8.7 limits the criteria to weight alone.

- Chassis Weight Distribution, Sec 1

  The charts used in the Kubokawa Data Book, 1-60, to present the weight lifting data differs from those in MSFC-STD-267A and should be considered for use in Section 5.8.7.3.

- Spring-Loaded Panel Fastener, Sec 1

  The spring loaded panel fastener pictures are more definitive than those in MSFC-STD-267A, Sections 5.8.9.5.2 and 5.8.9.2

- Latch Locks and Handles, Sec 1

  The Kubokawa Data Book pictures are in greater detail than MSFC-STD-267A and should be used in Sections 5.8.9.3.7, 5.8.9.3.8, and 5.8.9.5.4 of that document.

- Handles, Sec 1

  The combination handle assemblies on Pages 1-63 are not presently in MSFC-STD-267A, Section 5.8.11 and should be added to MSFC-STD-267A.

Human Capabilities and Responses

The Kubokawa Data Book does not contain human capability and response information comparable to MSFC-STD-267A.

Anthropometry and Work Space

- Standing Operator, Sec 1

  The general dimensions for a mock-up of a standing operator station in the Kubokawa Data Book are not in MSFC-STD-267A. These data would be useful in MSFC-STD-267A, Section 5.5.2.3.

- Rack Interface, Sec 1

  The anthropometric data on the operator and equipment rack interface, P 1-52, of the Kubokawa Data Book would be a useful addition of MSFC-STD-267A, Section 5.2.2.4.

Illumination, Vibration and Noise
Temperature and Clothing Safety

The Kubokawa Data Book contains information on environmental conditions of illumination, temperature, noise atmosphere and safety hazards, but none that is not adequately covered in MSFC-STD-267A or the other references.

5.2.6.4 SUMMARY

In summary, it can be concluded that the Kubokawa Data Book for Human Factors Engineers was not intended to and does not contain as much appropriate data for a complete human factors standard as MSFC-STD-267A. It does, however, contain data which agrees with, conflicts with and complements MSFC-STD-267A. The complementary data should be added to MSFC-STD-267A and the areas of conflict explored in greater detail to determine the correct data. The illustration methods used in the Kubokawa Data Book should be considered for use in MSFC-STD-267A.

5.2.7 HANDBOOK OF HUMAN ENGINEERING DESIGN DATA FOR REDUCED GRAVITY CONDITIONS - GENERAL ELECTRIC COMPANY

5.2.7.1 PURPOSE AND BACKGROUND

The G.E. Handbook, prepared for NASA by the General Electric Company was to "provide a Handbook of Human Engineering Design Data for Reduced Gravity Conditions for the use of engineers, designers, and human factors specialists during developmental and detail design phases of manned spacecraft programs."(Page i) The basic approach for accomplishment of this purpose was a literature search of the NASA Scientific and Technical Information Division, the Defense Documentation Center and the Tufts University Human Engineering Information and Analysis Service for data reflecting human performance in a reduced gravity environment.

The appropriate literature, available up to June 1969, was then reviewed and compiled to determine which data would be most beneficial to a handbook of this type. As stated in the handbook forward, the "Level of Effort" nature of the work necessitated by modified funding prompted modifications to the overall effort and the final product was short of its original goals. The end result was a collection of reduced gravity data from many sources, organized into three major sections, human characteristics, characteristics of space environment and vehicular characteristics.

Each of these individual sections present the data with maximum use of pictures, tables, graphs and charts with little or no narrative or interpretation.

MSFC-STD-267A on the other hand makes considerable use of the narrative form to present its data which are oriented toward design standardization of large earth-launch booster systems.

5.2.7.2 GENERAL COMPARISON

MSFC-STD-267A is directed toward earth launch booster systems while the G.E. Handbook is directed toward reduced gravity situations and their associated tasks.

The two documents (i.e. MSFC-STD-267A and the G.E. Handbook) have similar objectives in the area of related human tasks that are equally appropriate under one "g" or reduced gravity conditions and have some common base for comparison.

In general, the G.E. Handbook was found to contain little data not in MSFC-STD-267A or other references thus far reviewed. This is easily understandable in light of the handbook's stated purpose of collecting existing reduced gravity reference material into one document.

The G.E. Handbook contains some data elements which are not presently in MSFC-STD-267A sections on displays, controls, maintainability and Human Capabilities. These data elements are described in more detail under the paragraph-by-paragraph comparison section.

The one and two-handed access data in the G.E. Handbook were exactly the same as MSFC-STD-267A; however, both conflict with MIL-STD-1472A. As mentioned earlier, further research will be needed to resolve this problem.

5.2.7.3 PARAGRAPH-BY-PARAGRAPH COMPARISON

The following data elements were found that should be considered for incorporation into MSFC-STD-267A:

<u>Controls and Displays</u>

- Control coding, Sec. 3

  The chart on p. 3-11 of the G.E. Handbook covers the advantages and disadvantages of various types of control coding, location, shape, size, mode of operation, labeling and color, which would enhance MSFC-STD-267A, Sec. 5.1.6.

- Switch Performance Time, Sec. 3

  MSFC-STD-267A, Sec. 5.1.2 does not contain the performance time data on pushbutton, toggle and rotary switches under zero g conditions.

- Knobs, Sec. 3

  Handbook data with respect to maximum torque by knob size would be a useful addition to MSFC-STD-267A, Sec. 5.1.3.8.

- Dial and Scale Design, Sec. 3

  The nomograph, p. 3-7, used to depict the number of scale divisions and scale intervals is a useful tool that could be used in MSFC-STD-267A, Sec. 5.2.4.

- Letter Heights

  The table and computation formulas for letter height in dial and scale design, p. 3-9, 3-10, should be added to MSFC-STD-267A, Sec. 5.2.4.

Maintainability

- One-Arm Reach, Sec. 3

  The G.E. Handbook covers quantitative access requirements for:

  - o standing forward reach
  - o standing lateral reach
  - o aperture size, shapes and depths of reach
  - o for shirt-sleeved technicians
  - o aperture size, shape and depths of reach for technicians wearing pressure suits

All of which are not in MSFC-STD-267A but would be useful in sections 5.8.6.2.5 and 5.8.6.2.4.

- Fastener, Sec. 3

  The G.E. Handbook provides considerable information related to fasteners, p. 3-12 to 3-20, not covered in MSFC-STD-267A along with some similar data which are presented in a more concise and definitive form. This data, including a table which compares the various fasteners giving advantages and disadvantages, should be used to complement Sec. 5.8.9 of MSFC-STD-267A.

- Two-Arm Reach, Sec. 3

  The two-arm reach data on p. 3-21 to 3-39 provides information important to designers but not presently in MSFC-STD-267A, Sec. 5.8.6.2.7 and 5.8.6.2.6 covering:

  - o standing forward reach
  - o seated forward reach
  - o recommended aperture, size and depths of
  - o reach for shirt-sleeved technicians
  - o aperture sizes and depths of reach for pressure suits

Human Capabilities and Responses

- Force Emission, Sec. 1

  The reference tables, 1-72 to 1-84 for human capabilities of force emission during simulated zero-gravity conditions for sustained and impulse force would be useful in MSFC-STD-267A.

Anthropometry and Workspace

Illumination, Vibration, and Noise

Temperature and Clothing

Safety

The G.E. Handbook does not contain any data in these areas which are not in MSFC-STD-267A or previously considered references.

5.2.7.4 SUMMARY

As the title of the reference points out, it contains data for reduced gravity conditions. Much of the data was the same as that found in MSFC-STD-267A due to its applicability to both one "g" and reduced "g" conditions. The G.E. Handbook did have some information which was not in MSFC-STD-267A in the areas of controls, displays maintainability and human capabilities.

5.2.8 BIOASTRONAUTICS DATA BOOK/MSFC-STD-267A- WEBB ASSOCIATES

5.2.8.1 PURPOSE AND BACKGROUND

The Bioastronautics Data Book, prepared by Webb Associates for NASA, was the second phase of a planned effort to fulfill the need for quantitative and qualitative human data upon which the engineer could develop design criteria for aerospace vehicles and equipment.

The first phase was the development of the NASA Life Sciences Data Book published in limited number in 1962. The Life Sciences Data Book was evaluated by research workers and engineers throughout the aerospace industry. Their comments were integrated into the Bioastronautics Data Book issued in 1964.

The Bioastronautics Data Book is divided into twenty sections of data, mostly in graphic form, covering the state-of-the-art, at that time, in applied physiology and space medicine. The Bioastronautics Data Book "...is meant to be useful, but in no sense is it intended to e a text, a set of rules, or a detailed design manual." (Page V)

The Bioastronautics Data Book was chosen for this review by virtue of its past reputation as a useful document even though it was not intended to be a standard.

5.2.8.2 GENERAL COMPARISON

The Bioastronautics Data Book contains similar type information, using a similar format to the Serendipity Report, (Ref. #2), 3 OF 3

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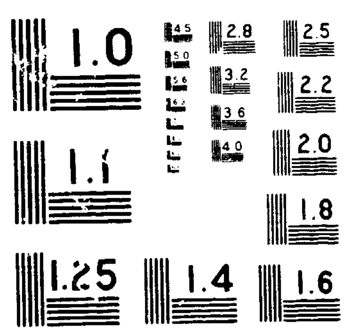


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963

the Lovelace Compendium (Ref. #4), and the G.E. Reduced Gravity Handbook (Ref. #6). Those documents were published at a later date and therefore had the advantage of further research into many of the subjects. The majority of the data in the Bioastronautics Data Book has therefore been included in or replaced by data in the other documents. Where this was the case, the other reference discussions cover the germane points and are not repeated here. The main difference between the Bioastronautics Data Book and MSFC-STD-267A is the type of material presented and the format used. The Bioastronautics Data Book presents its information in a form which provides general and expanded coverage of each topic. The data contained in the Bioastronautics Data Book recommended for incorporation into MSFC-STD-267A must therefore be converted into more specific criteria of a standard format.

In general, the Bioastronautics Data Book does not contain a large amount of data that are not already in MSFC-STD-267A or the other references. More specifically, the control, display, anthropometry, and human capabilities and response sections of MSFC-STD-267A would benefit from the few data items listed in the paragraph-by-paragraph comparison. However, the Bioastronautics Data Book has nothing to contribute to the maintainability, safety, workspace, illumination, vibration, noise, temperature, and clothing.

5.2.8.3 PARAGRAPH-BY-PARAGRAPH COMPARISON

The following information from the Bioastronautics Data Book is considered to be helpful if added to MSFC-STD-267A:

Controls and Displays

The Bioastronautics Data Book was not intended to be a control/display design reference so it contains only three data elements that could be applied to the MSFC-STD-267A control and display section.

- Tracking Performance, Sec. 18

  A new section could be added to include the tracking performance data from pages 352, 353. These data could provide a basis for tracing system design with various time delays, dead-space, and backlash. MSFC-STD-267A currently provides no data on these parameters.

- Quickening and Predictor Displays, Sec. 18

  MSFC-STD-267A section 5.2.2.4 on Feedback Information could be supplemented with the data from pages 358 and 359 on quickened and predictive displays. MSFC-STD-267A does not discuss these design alternatives at present.

- Display Divisions, Sec. 18

  Section 5.2.2.6 on Minimum lag in status change feedback could make use of tracking error data provided on p. 354 to 355. These sheets present graphs of tracking error under various display divisions and frequency of presentation.

Maintainability

The type of information contained in the Bioastronautics Data Book is not directly related to the maintainability section of MSFC-STD-267A. The Bioastronautics Data Book could be used as a general reference to assure any maintainability criteria added to MSFC-STD-267A are comparable to human performance. The review did not find any information in the Bioastronautics Data Book which could be recommended for use in MSFC-STD-267A.

Human Capabilities and Responses

The following four data elements of the Bioastronautics Data Book would be helpful if added to MSFC-STD-267A:

- Monocular & Binocular Visual Field, Sec. 17
  Monocular and Binocular visual fields are depicted using parametric charts for the average monocular visual field for the right eye, average monocular vision for achromatic and chromatic targets, normal field of view for a pair of human eyes. This information is supplemented with a table covering binocular visual fields with head and movement. The data could be added to Sec. 5.4 of MSFC-STD-267A.

- Discrimination, Sec. 17

  The human capability for discrimination of movement in depth, the effects of luminance and rate of movement data on p. 326 omplements Sec. 5.4 of MSFC-STD-267A.

- Side-arm Controller Forces, Sec. 14

  The references (p. 263) provide specific data on the levels of exertion and human capability to apply forces to side-arm controllers that should be in MSFC-STD-267A, Sec. 5.4.1.1.

- Side-arm Controller Forces, Sec. 14

  Page 262 of the Bioastronautics Data Book provides a table of maximum controller deflection angle requirements in yaw, pitch, any roll deflections. This data is not in Sec. 5.4.3 of MSFC-STD-267A.

Anthropometry and Work Space

The reference data on anthropometry were already adequately covered by MSFC-STD-267A, but one data element was found that could be added to the workspace section of the reference:

- Workspace, Sec. 14

  The Bioastronautics Data Book provides a table of standard values for critical dimensions used in the design of instrument consoles not in MSFC-STD-267A.

Illumination, Vibration and Noise

Temperature and Clothing

Safety

The Bioastronautics Data Book does not contain any information that would enhance MSFC-STD-267A.

5.2.8.4 SUMMARY

The Bioastronautics Data Book information is much like the data in the Serendipity Report, the Lovelace Compendium, and the G.E. Reduced Gravity Handbook. All these documents, reviewed earlier, are more recent documents and therefore contain more up-to-date data. Under this condition, the Bioastronautics Data Book has a few data elements covering controls, displays, human capability and responses and work space that would improve MSFC-STD-267A but in general would have little impact on MSFC-STD-267A.

5.2.9 ENGINEERING DESIGN HANDBOOK

MAINTAINABILITY GUIDE FOR DESIGN - U.S. ARMY MATERIEL COMMAND

5.2.9.1 PURPOSE AND BACKGROUND

The U.S. Army Material Command sponsors a series of Engineering Design Handbooks to provide fundamental data useful in design and development of systems to meet the needs of the Armed Forces.

The Army Design Guide, August 1967, is one boo of the series directed toward the overall field of maintainability. The purpose was to influence design of equipment so the equipment will, if possible, not require servicing during its intended life or when it does require servicing and repair, the task can be accomplished effectively and efficiently. To this end, the Army Design Guide gives comprehensive coverage of all aspects of maintainability.

The first major section, Part one, deals with the maintenance problem, its impact on the expenditure of money, men and material, the Army's approach to reducing the effects of the problem, interaction between Reliability and Maintainability and System Effectiveness.

Part two is concerned with the maintenance process, its objectives, procedures and techniques. Covered in this section are such things as maintainability decision points and requirements, overall program controls and plans, design and maintainability reviews, trade-off considerations and general coverage of maintenance manuals.

Part three covers the main factors affecting maintainability logistical support, personnel skills, basic Human Factors, environmental conditions, facilities and equipment.

The fourth section continues this trend by providing general design application considerations and specific requirements. The data in this section leans toward the type of data found in a standard including human factors constraints along with other design requirements.

Part five completes the Army Design Guide with a number of chapters on specific types of equipment, their particular maintainability, design situations, and requirements.

Parts three, four and five are the sections which are most applicable to the type of data found in MSFC-STD-267A.

5.2.9.2 SIMILARITIES

Both the Army Design Guide and MSFC-STD-267A contain data on basic human factors, anthropometry, human capabilities, controls, displays, environmental conditions, maintainability and safety. In many cases the data are similar. It would appear one was used as the base for development of the other or they both used a mutually common source, possibly MIL-STD-1248, Missile Systems Human Factors Engineering Criteria, Jan. 1964. For example:

Army Design Guide

> Whenever lost screws, bolts or nuts might cause excessive maintenance time or could cause damage as a foreign object, captive fasteners should be utilized.

MSFC-STD-267A

> Captive bolts and nuts shall be used in situations where the dropping of this small item into the equipment will cause damage or create a difficult removal problem.

In this case the same intent is portrayed while the words are slightly different.

Army Design Guide

> Design, locate and mount covers, cases and shields so they can be lifted off of units rather than the units lifted out of them.

MSFC-STD-267A

> Cases shall be designed to lift off units rather than units be lifted out of cases.

These are but two of the numerous similarities found between the two documents.

Not only are the two documents similar in narrative but also in content. In many cases they use the same charts, pictures and illustrations.

These similarities are easy to understand since both documents have, as at least one of their objectives, the presentation of data which will aid in the design of equipment to be effectively and efficiently maintained by man.

5.2.9.3 DIFFERENCES

The main difference between MSFC STD-267A and the Army Design Guide is the level and type of information covered. MSFC-STD-267A attempts to consider all human factors criteria which affect systems and equipment design and emphasizes the overall aspects of design with one limited section on maintainability. Conversely, the Army Design Guide considers all aspects of maintainability including overall planning, logistics, reliability, personnel skills and training and trade-off techniques. It briefly covers the general human factors criteria and emphasizes, in more detail, the criteria directly applicable to maintainability.

Due to this difference, MSFC-STD-267A has much more detailed coverage of human factors concepts in the sections on controls, displays, human responses and capabilities, anthropometry, workspace, illumination, vibration, noise, temperature and clothing. The Army Design Guide, in turn, has a more detailed coverage of direct maintainability requirements. For instance, the topic of unitization and modularization is covered in five short paragraphs in MSFC-STD-267A while the Army Design Guide provides four pages of data. In the establishment of these requirements, it draws from the vast amount of general human factors criteria and converts it to specific maintainability c eria.

Another major difference between the two documents is the method of data presentation. The Army Design Guide makes more use of illustrations, graphs and charts to reinforce the written requirements. More specifically, the Army Design Guide's illustrations concerning tools, covers and cases, fasteners, component location, unit mounting, guide pins, limit stops, handle location, connectors, connector alignment and orientation are more explicit than those in MSFC-STD-267A. In most cases, MSFC-STD-267A does not have illustrations in conjunction with narrative. One example of how illustrations can be of benefit is the unit removal requirement of MSFC-STD-267A and the Army Design Guide. Both say, "Units shall be removable along a straight or slightly curved line rather than through an angle." The Army Design Guide uses an example to show the reader what the requirement means while MSFC-STD-267A leaves it up to the reader's interpretation. Another example can be found in the section on connector alignment and orientation. MSFC-STD-267A talks about how connectors should be aligned, oriented and keyed. The Army Design Guide has the same basic words then gives two pages of examples to show what is desired.

Not only does the Army Design Guide have illustrations to complement the requirements but it also uses a type of illustration which shows both the desirable technique and the undesirable technique. This provides the user with examples of things to avoid as well as those to use.

Another method of data presentation used in the Army Design Guide which would enhance MSFC-STD-267A is the use of comparison or trade-off tables. Similar techniques for accomplishing the same tasks are shown in one table which gives the advantages and disadvantages of each technique in a form that is easy to use.

MSFC-STD-267A does have an advantage over the Army Design Guide in that it contains more detailed data on environment operating conditions, unit mounting, component location, and one and two handed data, one-handed access and the size and weight of removable units.

5.2.9.4 CONFLICTS

The two documents are in general agreement where they contain similar data. In a few cases the sentence structure of the requirement could lead to different interpretations but not necessarily a conflict between the data. One point of direct conflict was found not between the Army Design Guide and MSFC-STD-267A but between both documents and other references. The handle dimensional data in the Army Design Guide and MSFC-STD-267A conflict with the same data in MIL-STD-1472A and the Data Book for Human Engineers. Further research will be necessary to alleviate this conflict.

5.2.9.5 PARAGRAPH-BY-PARAGRAPH COMPARISON

MSFC-STD-267A was found to contain considerably more data relative to controls, displays, human responses and capabilities, anthropometry, workspace, illumination, vibration, noise, temperature and clothing. The material in the Army Design Guide on those specific areas was already covered in MSFC-STD-267A or the other references reviewed. Therefore, it is concluded that the Army Design Guide has no informational contribution to make to MSFC-STD-267A in those areas.

The maintainability criteria and safety sections of the Army Design Guide were found to contain much more information than MSFC-STD-267A both in volume and content. Listed below are the contributions that the Army Design Guide has to offer MSFC-STD-267A in those two areas.

Maintainability

- Adjustment and Aligning, Sec. 16-5

  MSFC-STD-267A, Sec. 5.8.4, does not address the subject of adjustments in the detail of the Army Design Guide which covers in narrative form:

  - o Quantity of adjustments
  - o Maintenance level
  - o Adjustment characteristics and feedback
  - o Range of control
  - o Pivots and locking devices
  - o Alignment procedure
  - o Adjustment display association
  - o Mechanical adjustments

  These data if converted into standard statements would enhance MSFC-STD-267A.

- Unitization and Modularization, Sec. 19

  Unitization data briefly covered in Sec. 5.8.4.1 of MSFC-STD-267A would be considerably improved by the addition of the data of the Army Design Guide, chapter 20 covering:

  - o Disposable/Repairable Module
  - o Trade-off considerations
  - o Disposable module design requirements
  - o General modularization recommendations for:

    equipment division

    integrated approaches

    size, shape and weight

    operational and bench testing

    function design and layout

    adjustments

    maintenance and reliability levels

- Layout, Component location, Sec. 23-1,4,5

  The various methods of component layout described in 23-1 are not covered in MSFC-STD-267A. This and the detailed component location data of 23-4 and 23-5 would be helpful if added to MSFC-STD-267A, Sec. 5.8.4.2.

- Mounting of units, Sec. 23-1 to 23-5

  The more detailed and enforceable requirements of the Army Design Guide on the subject of how units are mounted should be added to MSFC-STD-267A, Sec. 5.8.4.3.

- Drawers and racks

  MSFC-STD-267A, Sec. 5.8.4.3.3 covers rollout racks and slides in one single short statement. The Army Design Guide has two pages of criteria.

- Replaceable units, Sec. 23-3

  The guide pin data in 23-3 would supplement the MSFC-STD-267A, Sec. 5.8.4.3.4 data.

- Hinged braces, Sec. 23-4

  The Army Design Guide's illustrations of hinged type braces are not shown in MSFC-STD-267A, Sec. 5.8.4.3.5.

- Unit removal, Sec. 23-3

  The unit removal criteria of MSFC-STD-267A, Sec. 5.8.4.3.6 is difficult to understand. The Army Design Guide uses an illustration to avoid confusion.

- Shape of Accesses, Sec. 12-6

  MSFC-STD-267A, Sec. 5.8.5 access requirements does not consider access shapes such as that found in 12-6 of the Army Design Guide.

- Accessibility, General, Sec. 12-1

  The Army Design Guide treats the subject in more detail than MSFC-STD-267A, Sec. 5.8.5.1, 5.8.5.2.

- Maintenance Accesses, Sec. 12-3
- Split Line Design, Sec. 12-11

  The split line design is called out in MSFC-STD-267A but not defined as in the Army Design Guide. Table 12-1 showing the most to least desirable equipment accesses should be integrated into MSFC-STD-267A, Sec. 5.8.5.4.1.
- Other Design Recommendations, Sec. 12-7

  The interlock fuses, door locking, visual access, edge protection and internal lighting are not in MSFC-STD-267A, Sec. 5.8.5.4.8 and should be added to that document.
- Location of Accesses, Sec. 12-4

  The floor and work stand dimensional data of the Army Design Guide would augment MSFC-STD-267A, Sec. 5.8.6.1.
- Size of Access, Sec. 12-31, 12-5

  MSFC-STD-267A, Sec. 5.8.6.2.1 does not establish the criteria on hinged doors, cover plates, sliding access doors, spring loaded covers and stress requirements that are in the Army Design Guide.
- Size of Access, Sec. 12-5

  The table used to display one-handed access requirements in the Army Design Guide would be a useful addition to MSFC-STD-267A, Sec. 5.8.6.2.4b.

- Lubrication, Sec. 16-2, 16-3

  The lubrication requirements such as point of application, blind fittings, seal access, dipsticks, standardization, schedules and charts and filling and draining requirements are not discussed in MSFC-STD-267A, Sec. 5.8.8.

- Fasteners, Sec. 21-1 through 21-4

  The Army Design Guide covers fasteners with thirteen pages as opposed to the 3.5 pages in MSFC-STD-267A, Sec. 5.8.9. The additional coverage includes:

  - o Self-locking nut requirements
  - o Floating nuts
  - o Clinch nuts
  - o Self-sealing nuts
  - o Wing/knurled nuts
  - o Wrenching space
  - o Rivets
  - o Gang Channeling
  - o Cotter keys
  - o Safety wire
  - o Retaining rings

o Retaining chains

o Clamps

The Army Design Guide's additional information would enhance MSFC-STD-267A.

- Hand tools, Sec. 11-3

  The hand tool data of MSFC-STD-267A is very limited while the Army Design Guide has 5 pages on the subject covering types of tools and their optimum use. This data would greatly improve MSFC-STD-267A.

- Handle design, Sec. 23-6.2

  The general and specific handle usage requirements including printed circuit board handles, is not covered in MSFC-STD-267A and would be a helpful addition to Sec. 5.8.11.

- Handles for Equipment units, Sec. 23.6

  The handle usage requirement and center of gravity criteria of the Army Design Guide would supplement the data in MSFC-STD-267A, Sec. 5.8.11.1.

- Handle location, Sec. 23-6.2

  The illustrations on page 23-9 should be considered for use in MSFC-STD-267A, Sec. 5.8.11.5.

- Covers, cases, shields, Sec. 23-8

  Comparison of the Army Design Guide's data with MSFC-STD-267A shows the Army Design Guide's coverage of covers, cases and shields more detailed and extensive.

It contains data not in MSFC-STD-267A on:

- o structural load
- o extensions/accessories
- o equipment balance and interference
- o stops, locking devices
- o one-man handling
- o lift eyes & handles

In addition the use of illustrations increases the clarity of the presentation.

- Case size, Sec. 23-8

The Army Design Guide's data on case size positioning and handling would be a useful addition to MSFC-STD-267A, Sec. 5.8.12.3.

- Hinged doors, hoods and caps, Sec. 23-8.2

MSFC-STD-267A does not treat the subject in the detail provided in the Army Design Guide particularly in the areas of:

- o double & split doors
- o cover, bolt considerations
- o hinge locations
- o interference
- o stops & retainers
- o removability

- Cable routing, Sec. 23-10, 23-11.2

  Wire connections and termination are not considered in MSFC-STD-267A, Sec. 5.8.13. The Army Design Guide's data on plug-in contacts, wire removal, lug types and spacing would be useful if added to MSFC-STD-267A.

- Cable routing 23-11.2

  The Army Design Guide treats the subject in greater detail than MSFC-STD-267A in the areas of:

  - o cable length standardization
  - o factory construction
  - o junction box configuration
  - o preformed cables
  - o clear coverings
  - o wire/insulation requirements
  - o recoil/extender arms
  - o storage
  - o environmental conditions
  - o coding

- Replaceable units, Sec. 23-3

  The Army Design Guide supports its requirements with illustrations not found in MSFC-STD-267A.

- Connectors, Sec. 23-12

  The two pages of illustrations in the Army Design Guide on alignment and orientation would greatly supplement the two statements on the subject in MSFC-STD-267A, Sec. 5.8.14.

- Interchange of connectors, Sec. 23-12.1

  The requirements relative to connector interchangeability found in the Army Design Guide should be integrated into MSFC-STD-267A, Sec. 5.8.14.6.

- Protection, Sec. 23-3

  The captive cap data in the Army Design Guide would complement the data in Sec. 5.8.14.7 of MSFC-STD-267A.

- Test points, Sec. 23-14 to 23-26

  MSFC-STD-267A provides only superficial coverage of test point requirements while the Army Design Guide goes into much detail on:

  o test point classification

  o functional location of test points

  o physical location of test points

  o test point grouping

  o test point labeling

  The Army Design Guide also deals with trade-off considerations for built-in test equipment vs. partial or external test equipment. Automatic, handheld, portable and console type testers are covered in much detail.

All the above data would be a useful addition inSec. 5.8.15 of MSFC-STD-267A.

- Identification, Sec. 13-1 to 13-5

  The ten pages of identification criteria in the Army Design Guide contain considerable data not covered in the eight statement treatment of the subject in MSFC-STD-267A. The Army Design Guide data should be considered for use in MSFC-STD-267A, Sec. 5.8.16.

Safety

Both the Army Design Guide and MSFC-STD-267A contain data not found in the other. The Army Design Guide contains the following items that would enhance MSFC-STD-267A if added to it:

- Electrical shock, Sec. 15-2

  The Army Design Guide deals with the effects of current, short duration shock, safety marking and colors and capacitive discharge requirements and devices not found in Sec. 5.7.3.2.4 of MSFC-STD-267A.

- Fire, Sec. 15-3.1

  MSFC-STD-267A does not consider the safety precautions for fire that are given in the Army Design Guide.

- Toxic agents, Sec. 15-3.2

  Table 15-2 on various sources of toxic agents and the maximum allowable concentrations should be a helpful addition to MSFC-STD-267A.

- Implosions and explosions, Sec. 15-3.2

  MSFC-STD-267A does not treat the topic of implosions and explosions and should have the Army Design Guide's data incorporated into section 5.7.3.

- Stability, Sec. 15-3.4

  The equipment stability requirement of the Army Design Guide should be considered for use in MSFC-STD-267A.

5.2.9.6 SUMMARY

In summary, it was found that the Army Design Guide covered most of the material in MSFC-STD-267A in more detail and then covered additional data as well. MSFC-STD-267A contained data not in the Army Design Guide in only a few limited areas.

5.2.10 MAINTAINABILITY DESIGN CRITERIA HANDBOOK - U.S. NAVY

5.2.10.1 PURPOSE AND SCOPE

The Maintainability Design Criteria Handbook for Designers of Shipboard Electronics Equipment was first published for the U.S. Navy, April 1962, by the Federal Electric Corporation. It has since undergone two revisions, the latest in March,1965.

The purpose of the Navy Design Criteria is to insure optimum maintainability of shipboard electronic equipment. The approach to accomplishment of this purpose was to provide the designer with information on established shipboard maintenance methods, shipboard working conditions, technician qualifications and skill levels and desirable maintainability techniques and criteria.

The first part of the Navy Design Criteria is concerned with overall maintenance concepts, the design development stage, maintainability predictions, shipboard environments and Navy personnel skills and qualifications.

The second part is more concerned with actual maintainability criteria of the nature found in MSFC-STD-267A. It is data from this second half that would have the largest impact on MSFC-STD-267A.

5.2.10.2 SIMILARITIES

The two documents are similar in the type of data presented in the control, display, safety and maintainability sections. The maintainability section in particular is very similar in the coverage of accessibility, hardware mounting, modularization and cables and connectors. In many cases, the data found in each of the documents is identical or near-identical.

5.2.10.3 DIFFERENCES

The differences between the two documents are far greater than the similarities. First of all, they differ in their intent. MSFC-STD-267A is intended to be used as a Human Factors Standard for large earth-launch vehicle systems and associated equipment while the Navy Design Criteria is directed toward the overall task of shipboard maintenance of electronic equipment.

Although many of the human factors requirements are common to both types of hardware, each has its unique requirements which are not valid for the other. For instance, the Navy living and working areas are more limited than the ground facilities of a space vehicle launch facility but generally larger than the internal work areas of space vehicles.

Another major difference is the type of data covered. The first part of the Navy Design Criteria is concerned with shipboard maintenance concepts, Navy maintainability program development, predictions, shipboard environments and personnel qualifications. This same type of information is not available in MSFC-STD-267A. This is actually one advantage the Navy Design Criteria has over MSFC-STD-267A. When designing any type of equipment for human operation or maintenance, one must consider the skill levels and

FOLDOUT FRAME 1

SUMMARY OF MANS

	PARAMETER / PROGRAM	MERCURY	GEMINI	APOLLO CSM	APOLLO LM	APOLLO LRV	SKYL
MISSION	MISSION OBJECTIVES	ESTABLISH FEASIBILITY OF MANNED ORBITAL FLIGHT	DEVELOP TECHNIQUES FOR RENDEZVOUS/DOCKING, AND EVA. EXTEND FLIGHT DURATION	TRANSPORT THREE MEN TO LUNAR ORBIT AND RETURN	LAND TWO MEN ON THE LUNAR SURFACE	TRANSPORT TWO MEN ON LUNAR SURFACE	ESTABLISH LO FLIGHT CAPAB PERFORM SCIE RESEARCH
	MISSION DURATION	34 HRS. 20 MIN	14 DAYS	12-1/2 DAYS	2 1/2 DAYS	6 HRS.	1 - 28 DAY 2 - 56 DAY
	LEVEL OF AUTONOMY	LOW	LOW	LOW	MEDIUM	HIGH	MEDIUM
	SPECIALIZED HARDWARE	ENTIRELY	ENTIRELY	ENTIRELY	ENTIRELY	ENTIRELY	UTILIZES APO
	ON-ORBIT MAINTENANCE	CONTINGENCY ONLY	CONTINGENCY ONLY	CONTINGENCY ONLY	CONTINGENCY ONLY	CONTINGENCY ONLY	LIMITED (FI BULBS, ETC.
CREW	CREW SIZE	1	2	3	2	2	
	CREW SKILLS	TEST PILOT	TEST PILOT	TEST PILOT + SCIENTIST/ ASTRONAUT	TEST PILOT + SCIENTIST/ASTRONAUT	TEST PILOT + SCIENTIST/ASTRONAUT	TEST PILOT ASTRONAUT
	SELECTION CRITERIA	PILOT TRAINING PHYSICAL CONDITION	PILOT TRAINING PHYSICAL CONDITION	PILOT TRAINING PHYSICAL CONDITION FLIGHT EXPERIENCE	SAME AS CSM + SCIENTIFIC BACKGROUND	SAME AS LM	SAME AS CS EMPHASIS O BACKGROUND
	WORK REST CYCLE	CONTINUOUS WORK (SHORT DURATION)	12-16 HR/DAY (SHORT DURATION)	12-16 HRS/DAY (SHORT DURATION)	12-16 HRS/DAY (SHORT DURATION)	CONTINUOUS WORK (SHORT DURATION)	12-14 UP TO
	TRAINING	LONG DURATION TRAINING	SAME AS MERCURY	SAME AS MERCURY	SAME AS MERCURY	SAME AS MERCURY	SAME AS
	ON-ORBIT ACTIVITIES	- MONITORING - OBSERVATION - LIMITED COMMAND INPUTS - LIMITED MOVEMENTS WITHIN CABIN	FORMER + - RENDEZVOUS - DOCKING - EVA - PILOTING - NAVIGATION - RETRIEVAL OF EXPERIMENTAL SAMPLES - PHOTOGRAPHY - LIMITED HYGIENE - FOOD PREPARATION	FORMER + - CONDUCT SCIENTIFIC SUITCASE) EXPERIMENTS - SATELLITE DEPLOY - LIMITED MAINTENANCE	- LUNAR DESCENT/HOVERING - LUNAR LANDING - LUNAR EVA - LUNAR LIFT-OFF - DEPLOY/ACTIVATE LUNAR EXPERIMENTS - SCIENTIFIC OBSERVATION AND ON-SITE ANALYSIS FOR LUNAR SAMPLES COLLECTION - ON-ORBIT CHECKOUT AND ACTIVATION	- LAND MARK IDENTIFICATION - LRV DEPLOYMENT - LUNAR SURFACE NAVIGATION	- CONDUCT EXPERIME - SOLAR - EARTH - BIOME - TECHN - DEFEN - INCLUDIN SUCH AS - EXPER ACTIV CHECK - FEATU IDENT - LIMIT DECIS - DATA - OBSER - COMPLET - UNLIMIT - ON ORBI ACTIVAT - INCREAS OPERATI - LIMITED

5-170.1

FOLDOUT FRAME

SUMMARY OF MANS ROLE IN SPACE

LRV	SKYL	SHUTTLE	SPACE STATION	EXPERIMENTS SHUTTLE-BASED	EXPERIMENTS STATION-BASED	SUMMARY OF TRENDS
TWO MEN OVER ...ACE	ESTABLISH LONG DURATION FLIGHT CAPABILITY, PERFORM SCIENTIFIC RESEARCH	PROVIDE LOW COST EARTH TO ORBIT TRANSPORTATION	SUPPORT SIX MAN CREW FOR EXTENDED DURATION ON ORBIT	PROVIDE SHORT [illegible] ORBITAL RESEARCH CAPABILITY	[illegible] LONG DURATION EARTH ORBITAL RESEARCH CAPABILITY	FEASIBILITY OF MANNED FLIGHT → LONG DURATION EARTH ORBITAL RESEARCH
...RS.	1 - 28 DAY MISSION 2 - 56 DAY MISSIONS	7 DAYS	90 DAYS/CREWMAN	5 DAYS	UP TO 10 YEARS	DAYS → UP TO 10 YEARS
...CH	MEDIUM-HIGH	HIGH	HIGH	HIGH	HIGH	LOW → HIGH
...RELY	UTILIZES APOLLO HARDWARE	COMMERCIAL AVIONICS	LARGELY	COMMERCIAL EQUIPMENT	COMMERCIAL EQUIPMENT	SPECIALIZED HARDWARE → COMMERCIAL EQUIPMENT
...NCY ONLY	LIMITED (FILTER CHANGE, BULBS, ETC.)	CONTINGENCY ONLY	PLANNED (CMG's, THRUSTERS, BATTERIES, ECT.)	PLANNED (FREE FLYING MODULE SERVICING)	PLANNED	CONTINGENCY ONLY → PLANNED
?	[illegible]	2 (+ 2 PASSENGERS)	6	2	6	1 → 6
...OT + ...I/ASTRONAUT	TEST PILOT + SCIENTIST/ ASTRONAUT	PILOT	SCIENTIST	SCIENTIST	SCIENTIST	TEST PILOT → SCIENTIST
...AS LM	SAME AS CSM + INCREASED EMPHASIS ON SCIENTIFIC BACKGROUND	PILOT TRAINING PHYSICAL CONDITION	SCIENTIFIC BACKGROUND PHYSICAL CONDITION	SCIENTIFIC BACKGROUND PHYSICAL CONDITION	SCIENTIFIC BACKGROUND PHYSICAL CONDITION	PILOT TRAINING PHYSICAL CONDITION → SCIENTIFIC BACKGROUND PHYSICAL CONDITION
...'S WORK ...RATION)	12- HRS/DAY (UP TO [illegible] DAYS)	12 HRS. ON/12 HRS. OFF SIMULTANEOUSLY	SINGLE SHIFT - 12 HR/DAY 60 HR/WK (DUAL SHIFTS ARE LIKELY)	5 DAYS ON ORBIT 12-14 HRS/DAY	SAME AS SPACE STATION	CONTINUOUS WORK (SHORT DURATION) → 60 HR/WK (LONG DURATION)
...MERCURY	SAME AS MERCURY	HIGHLY TRAINED SPECIALIZED SIMULATORS	LESS HIGHLY TRAINED SPECIALIZED SIMULATORS UNLIKELY	LESS HIGHLY TRAINED SPECIALIZED SIMULATORS [illegible]	LESS HIGHLY TRAINED SPECIALIZED SIMULATORS UNLIKELY	LONG DURATION TRAINING → SHORT DURATION TRAINING
...RK ...FICATION ...PLOYMENT ...URFACE ...ION	- CONDUCT SCIENTIFIC EXPERIMENTS IN - SOLAR ASTRONOMY EARTH OBSERVATION - BIOMEDICINE - TECHNOLOGY - DEFENSE - INCLUDING OPERATIONS SUCH AS - EXPERIMENT DEPLOY/ ACTIVATION CHECKOUT OPERATIONS - FEATURE IDENTIFICATION - LIMITED SCIENTIFIC DECISION MAKING - DATA COLLECTION - OBSERVATION - COMPLETE HYGIENE - UNLIMITED MOVEMENTS - ON ORBIT CHECKOUT/ ACTIVATION - INCREASED EVA OPERATIONS - LIMITED MAINTENANCE	-PILOTING/NAVIGATION -ON ORBIT MANEUVERS -APPROACH AND LANDING	SKYLAB + - ORBITAL ASSEMBLY - EQUIPMENT INSTALLATION - INCREASED MAINTENANCE	- CONDUCT SCIENTIFIC EXPERIMENTS IN - ASTRONOMY - PHYSICS - EARTH OBSERVATION - TECHNOLOGY - LIFE SCIENCES - MATERIAL SCIENCES - COMMUNICATION/ NAVIGATION - CALIBRATION/ ALIGNMENT - OBSERVATION - MONITORING - DATA COLLECTION - LIMITED SCIENTIFIC DECISION MAKING - FEATURE IDENTIFICATION - EXPERIMENT CONFIGURING - MAINTENANCE	SAME AS SHUTTLE BASED + ADDITIONAL OPERATIONS SUCH AS - EXPERIMENT PLANNING - SCIENTIFIC DECISION MAKING - CONFIGURING EQUIPMENT - DATA ANALYSIS AND EVALUATION	LIMITED ACTIVITIES SUCH AS: - OBSERVATION - MONITORING - LIMITED COMMAND INPUTS - LIMITED MOVEMENTS → ESSENTIALLY UNLIMITED ACTIVITIES TO INCLUDE: - EXPERIMENT PLANNING - SCIENTIFIC DECISION MAKING - DATA ANALYSIS AND EVALUATION - CONFIGURING EQUIPMENT - MAINTENANCE OPERATIONS - EXPERIMENT DEPLOY ACTIVATION, CHECKOUT - ETC.

5-170.2

TABLE 3-4

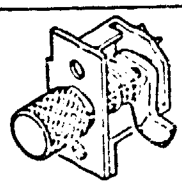
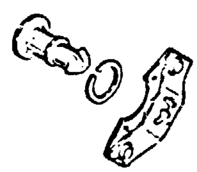
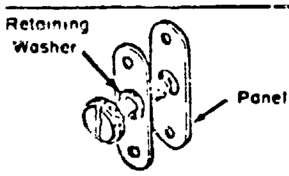
qualifications of the personnel involved in its use. The personnel data in the Navy Design Criteria would not be directly transferable to MSFC-STD-267A but it is recommended it be used as a guide for development of a similar section in MSFC-STD-267A.

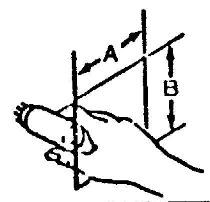
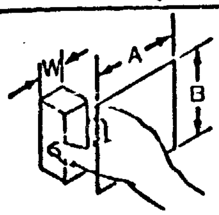
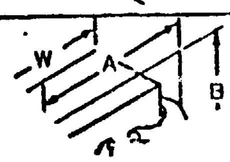
The second part of the Navy Design Criteria covers considerable maintainability aspects of shipboard hardware and touches on workspace, safety, controls and display requirements. It does not include data on Human Responses and Capabilities, anthropometry, illumination (other than for maintainability), noise, temperature and clothing

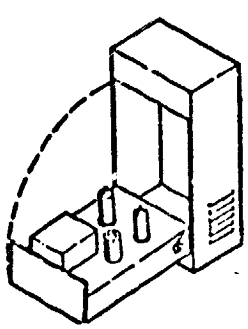
Within the maintainability sections, the Navy Design Criteria understandably provides broader coverage of the subject. The Navy Design Criteria treatment of test points and test techniques is detailed and complete while MSFC-STD 267A barely touches this topic. Unitization and modular data occupies a major section of the Navy Design Criteria and even goes into the details of how to construct various types of modules. MSFC-STD-267A touches on this topic but only in general terms. Much of this handbook data would enhance MSFC-STD-267A.

The third major difference between the two documents is the data presentation methods. To begin with, the Navy Design Criteria makes more use of figures, charts, tables and graphs than MSFC-STD-267A.

The format of illustrations used in the Navy Design Criteria often consist of one or more of the following items: a picture of the hardware of task involved, a description or requirements, the advantages and disadvantages of the given technique and maintainability considerations. The three examples below taken from the Navy Design Criteria show this technique.

Type	Description	Maintainability Considerations
	Adjustable pawl fastener As knob is tightened the pawl moves along its shaft to pull back against the frame. 90° rotation locks, unlocks fastener.	1. No tools required.
	"Dzus" type fastener with screwdriver slot Three-piece 1/4 turn fastener. Spring protects against vibration. 90° rotation locks, unlocks fastener.	1. Tools may be required. 2. Should not be used for front panel fasteners or in structural applications. Preferred type for light weight panels other than front panels.
	Wing head, "Dzus" type 90° rotation locks, unlocks fastener.	1. No tools required. 2. Should not be used for front panel fasteners or in structural applications. Preferred type for light weight panels other than front panels.
	Captive fastener with knurled, slotted head The threaded screw is made captive by a retaining washer.	1. Tools may be required. 2. Operating time depends on number of turns required.

Opening Dimensions	Dimension* (In Inches)		Maintenance Task
	A	B	
	4.8	5.0	Grasping small objects (less than 2 1/2" diameter).
	W+1.75	5.0**	Grasping large objects (more than 2 1/2" wide).
	W+ 3.0	5.0**	Grasping large objects with two hands, with hands extended through openings up to fingers.

Example	Description	Advantages	Disadvantages
	Hinged chassis. Can be hinged on side, top, or bottom.	1. Easy access from top or bottom of chassis.	1. Dust plate must usually be removed for access to front of chassis. 2. Open equipment requires excessive space. 3. Difficult access to both top and bottom of chassis at same time. 4. Chassis and parts can be damaged by dropping panel heavily.
	"Book" type opening. Parts on either side	1. Easily accessible from [illegible]	

MSFC-STD-267A in contrast uses this technique to a limited extent but is inconsistent in the location of the words which accompany a given figure. The words can be found below, above, beside the figure or on a separate page. In some cases the figures are four pages away from the text material.

5.2.10.4 CONFLICTS

The tube insertation data in fugure III-1-2 of the handbook gives the dimensions of 4.8" x 5.0" for a rectangular opening and MSFC-STD-267A figure 99 gives a clearance of 2" around miniature tubes and 4" around large tubes. The two are not compatible and need resolution as to which is correct.

The Navy Design Criteria data on envelopes for grasping and turning tools (figures III-1-2, III-1-3, III-1-15 and III-1-16) differ from the data of table XXXIII through XXXVII of MSFC-STD-267A. Further investigation must be conducted to resolve the conflict.

5.2.10.5 PARAGRAPH BY PARAGRAPH COMPARISON

Although both MSFC-STD-267A and the Navy Design Criteria contain data that would be helpful to the other, the intent of this review was to find areas where the Navy Design Criteria could supplement MSFC-STD-267A.

The review found that MSFC-STD-267A contained more relevant data on human capabilities and responses, anthropometry, illumination, noise, temperature, and clothing than the Navy Design Criteria. The Navy Design Criteria has no contribution to make to MSFC-STD-267A in those sections. The Navy Design Criteria does, however, contain data that pertains to maintainability and safety that are not in MSFC-STD-267A. These are described below.

Maintainability

- Unitization, Sec. IV

  The Navy Design Criteria goes into much detail on modular and plug in units, including insertion and removal force limits for various distances from man's shoulder height, preferred and acceptable modular unit dimensions, the effects on maintainability related to the quantity of modular units and fault isolation times and test points all of which would enhance MSFC-STD-267A if added to section 5.8.4.1.

- Mounting of units, Sec. IV

  The Navy Design Criteria considers channel type guides for module boards and color coding to prevent improper insertion not found in MSFC-STD-267A, section 5.8.4.3.

- Equipment Packages, Sec. III

  The Navy Design Criteria gives examples of various basic types of equipment packaging along with descriptions, advantages and disadvantages of each. These data should be considered for use in section 5.8.5.4.1 of MSFC-STD-267A.

- Access Openings, Sec. III

  Tables in the Navy Design Criteria (III-1-1, III-1-4, III-1-5 & III-1-6) provide criteria with respect to equipment mounting preferences, removable covers, hinged panels and sliding chassis which are not covered in MSFC-STD-267A. These data would be helpful in section 5.8.6.1 of MSFC-STD-267A.

- Two handed Access, Sec. III

  The two handed data of MSFC-STD-267A, section 5.8.6.2.7 and 5.8.6.2.6 could be improved by adding the Navy Design Criteria (Figure III-1-2) examples which show grasping of large objects and inserting them into openings.

- Fasteners, Sec. III

  Pages 1-13 to 1-17 and 2-1 to 2-8 of the handbook contain data on:

  - o Adjustable panels
  - o Dzus fasteners
  - o Screwdriver and wing head fasteners
  - o Captive fasteners
  - o Knurled and slotted head fasteners
  - o Draw hook latches
  - o Trigger action latches
  - o Snapslide latches
  - o Bolt and screw head configurations
  - o Captive screw retainers

  These data along with the various chassis mounting techniques are covered in detail in the Navy Design Criteria but touched lightly in MSFC-STD-267A. The handbook data should be added to MSFC-STD-267A, section 5.8.9.

- Handles, Sec. LV

  MSFC-STD-267A does not consider collapsible handles.

The specific handbook data on this type handle would complement MSFC-STD-267A, section 5.8.11.

- Cables and Terminations, Sec. III and VII

  The Navy Design Criteria provides considerable narrative data on conductor terminations, terminal mounting positions, lead wrapping, cable maintenance and repair techniques which could be converted to a standard format and be used in section 5.8.13 of MSFC-STD-267A.

- Cable Harnesses, Sec. VII

  Pages 1-1 through 1-10 of the Navy Design Criteria cover design requirements for cable harnesses, clamps and bindings in a narrative form. These data could be converted to a standard format and used in section 5.8.13.1 of MSFC-STD-267A.

- Cable Clamps, Sec. VII

  Figures VII-1-15 and VII-1-29 give examples of cable clamps and wiring ducts not shown in MSFC-STD-267A, section 5.8.13.2.

- Color Coding, Sec. VII

  The Navy Design Criteria, VII-1-35 to VII-1-39 provides examples of color coding techniques for cables and wires. Coding is required by MSFC-STD-267A, section 5.8.13.7 but is not described in that section.

- Connector Selection, Sec. VII

  The Navy Design Criteria gives a number of selection criteria for connector coupling methods. These data are not covered in MSFC-STD-267A, section 5.8.14 and would supplement that section if added.

- Alignment, Sec. VII

  The examples of connector alignment techniques in the handbook would help reinforce the requirements of MSFC-STD-267A, section 5.8.14.5 and 5.8.14.4.

- Covers, Sec. VII

  The connector protective covers shown on 2-24 of the Navy Design Cirteria are not covered in MSFC-STD-267A, section 5.8.14.7.

- Test Points, Sec. V

  The Navy Design Criteria devotes around one hundred and twenty pages to test point, test point criteria. MSFC-STD-267A does not treat the subject in such detail. The handbook data includes:

  - Test Point types

- Safety recommendations
- Functional location of test points
- Isolation techniques
- Dynamic measuring methods
- Symbolic methods for function identification
- Reference designations
- Test point identification and labeling
- Dyanmic test point locations
- Fifty-three pages of schematics showing test point locations in common electronic circuits
- Remote test points
- Test point grouping

These data and requirements should be integrated into MSFC-STD-267A.

- Test Equipment, Sec. V

Sections V-2 and V-3 cover in 54 pages the various types of test equipment, automatic, manual and semi-automatic. Each type is compared with the other with respect to maintainability, application, logistics, and human factors. This data would complement section 5.8.5 of MSFC-STD-267A.

Safety

The Safety requirements in MSFC-STD-267A provide more coverage than the Nave Design Criteria but the handbook did contain data which should be helpful in MSFC-STD-267A.

- Hazard classification, Sec. VIII-4

  The Navy Design Criteria contains a table of voltage hazard classifications relative to the contact area between man and equipment.

- Spark gap breakdown, Sec. VIII-4

  Breakdown voltages are given at various air gap distances to aid in determining the minimum distance personnel may come to different voltage points.

- Test points, VIII-4

  The Navy Design Cirteria provides test point safety recommendations not found in MSFC-STD-267A.

5.2.10.6 SUMMARY

The Navy Maintainability Design Criteria Handbook was intended to provide the designer all the data required for optimum maintainability. As such, it contains information applicable to disciplines other than human factors. About 40 per cent of the handbook is oriented toward human factors. The human factors data touches lightly on controls, displays but to a lesser degree than MSFC-STD-267A. The Safety section has only three data elements not in MSFC-STD-267A. The rest of the human factors data is naturally directed toward maintainability.

The Maintainability data of the handbook exceeds that in MSFC-STD-267A and covers the major topics of test points (12 pages) and test equipment (54 pages) which are barely considred in MSFC-STD-267A. That data along with the other items listed in the paragraph by paragraph review section would be a useful addition to MSFC-STD-267A. In addition, MSFC-STD-267A would be enhanced if the data presentation methods of the handbook were adopted.

The conclusion reached by this review is MSFC-STD-267A provides broader coverage of human factors in general and the Navy Criteria Design provides broader coverage of human factors related to maintainability.

5.3 QUESTIONNAIRE ON HUMAN ENGINEERING DESIGN STANDARDS

5.3.1 INTRODUCTION

The analytical review of MSFC-STD-267A as reported in section 5.1 of this report identified several problems which would tend to make the standard difficult to use and to enforce. In addition, a review of current NASA design practices has indicated that the standard has been relatively ineffective in standardizing human engineering design, (Section 3.0 and Appendix D) It appear that the standard has little impact on spacecraft design and is in general held in low esteem by designers.

In order to further investigate these hypotheses and to identify possible causes for the apparent ineffectiveness of the standard, a questionnaire on human engineering design standards was prepared and distributed to the users of the standard throughout the country. The results of this questionnaire are presented in this section.

5.3.2 DEVELOPMENT OF THE QUESTIONNAIRE

The following five primary hypotheses were formulated:

1. MSFC-STD-267A is not widely used and has little impact on spacecraft design.

2. MSFC-STD-267A is primarily used as a general reference and not as a standard.

3. MSFC-STD-267A has specific problems which tend to make designers ignore it.

4. Lack of standardization in human engineering design of spacecraft is the result of managerial problems in addition to inadequate human engineering standards.

5. The entire approach to a human engineering standard should be changed.

For each of these hypotheses, a list of questions was generated to test that hypothesis. The entire list of questions for all five hypotheses was refined and was then synthesized into a thirty-five item questionnaire which is included in Appendix E of this report.

The recipients for the questionnaire were selected using the NASA (MSFC) Bidder's List, and National and Local Human Factors Society Directories.

The questionnaires were distributed under both an official NASA letterhead and a personal letter from Dr. Rogers of the University of Alabama in Huntsville. Two channels of distribution were selected in order to assure that an individual response was received and not a company response. Seventy-five questionnaires were mailed through each channel, making a total of one hundred and fifty questionnaires distributed. A total of seventy-six questionnaires were returned of which eleven were blank, making a total of sixty-five usable responses to the questionnaire.

The response to the fixed choice items is depicted in Table I. Questionnaires one through nineteen are those that were distributed with an official NASA letterhead. Questionnaires twenty through sixty-five were distributed under the informal letterhead. A complete listing of the responses to the open-ended items and general comments made by the respondents is provided in Appendix E of this report.

5.3.3 RESPONDENTS

As can be seen in Figure 1, the majority of respondents were behavioral scientists who hold degrees at the masters or doctorate level. Nearly all respondents were employed by either large or small industries (see Figure 2). The majority of time was spent in systems design and management followed by research, test, and evaluation in that order (see Figure 3). Nearly all respondents had used MIL-STD-1472A in the last five years, whereas approximately half of the respondents had used MSFC-STD-267A. Forty-four percent

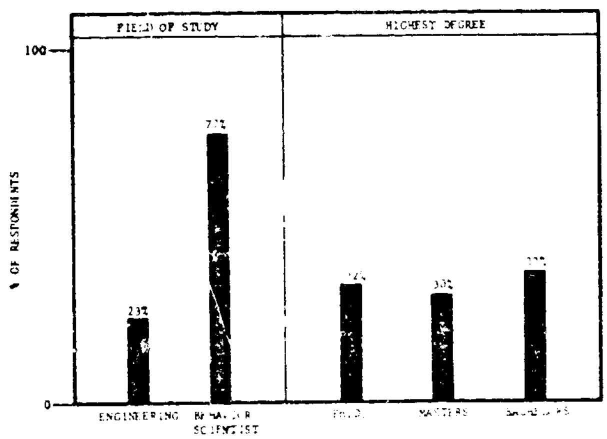


FIGURE 1

N = 65

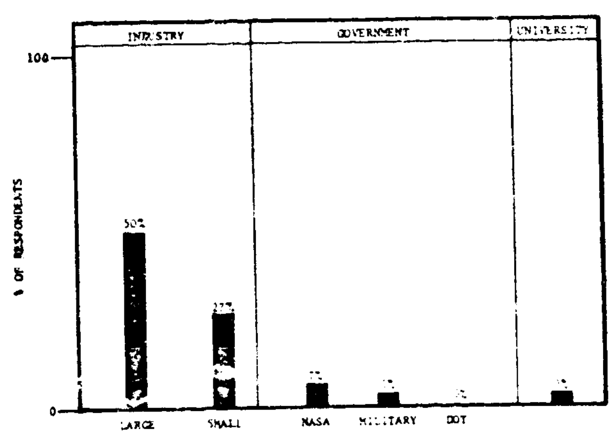


FIGURE 2

N = 65

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of the respondents considered their familiarity with MSFC-STD-267A to be moderate or above and twenty-one percent of the respondents considered their familiarity to be high or very high (see Figures 4 and 5). Forty-six of the sixty-five respondents had received the questionnaire under the unofficial letterhead.

All who received the questionnaire either are presently involved or previously were involved in space vehicle design at the company level. This implies that at some point in time they have been contractually obligated to comply with MSFC-STD-267A.

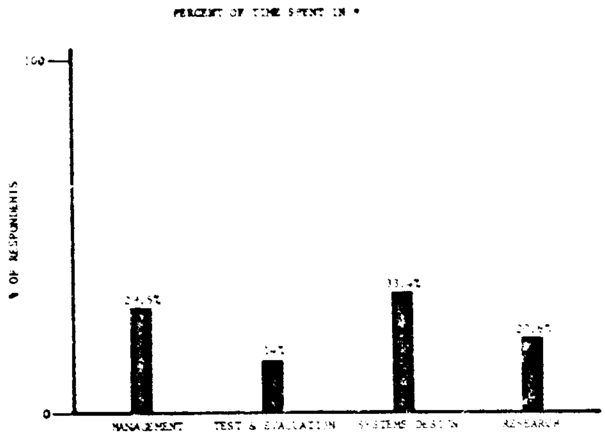


FIGURE 3

* N = 65

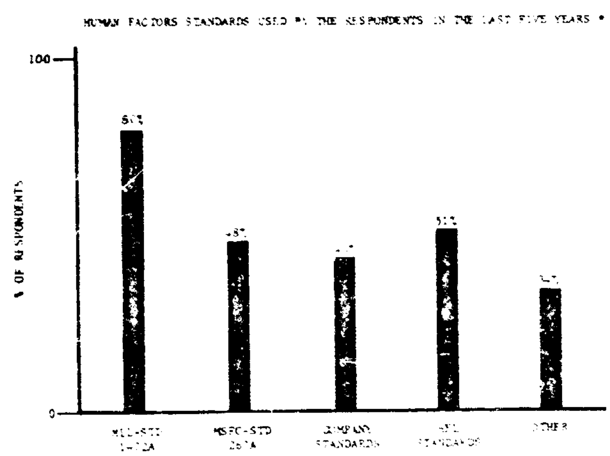


FIGURE 4

* N = 65

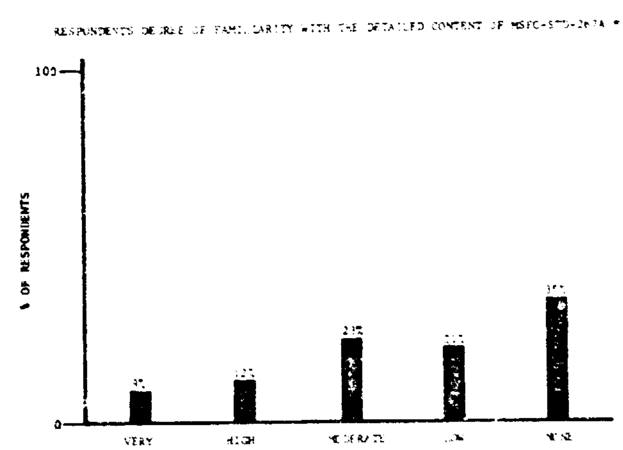
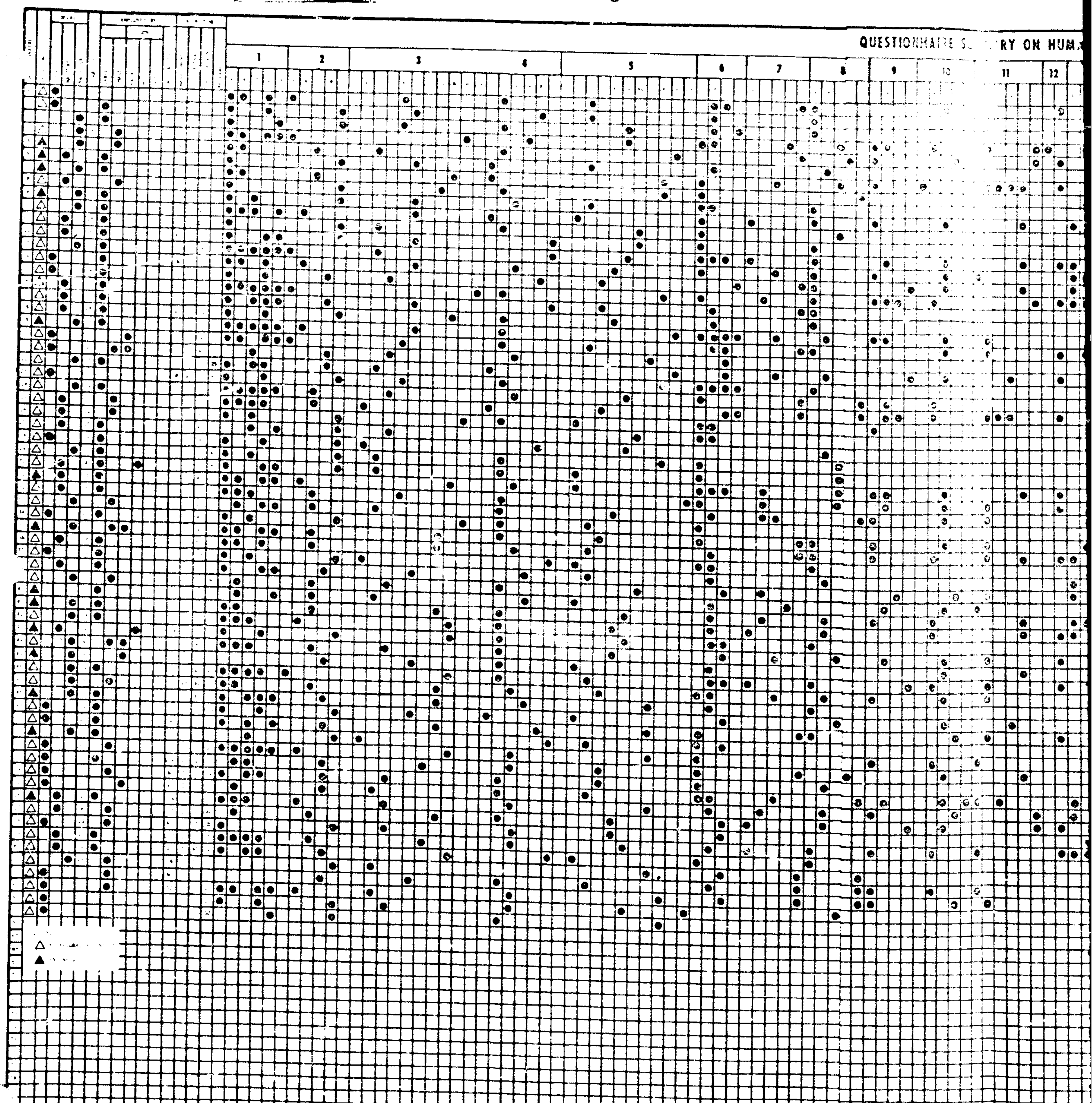


FIGURE 5

* N = 65

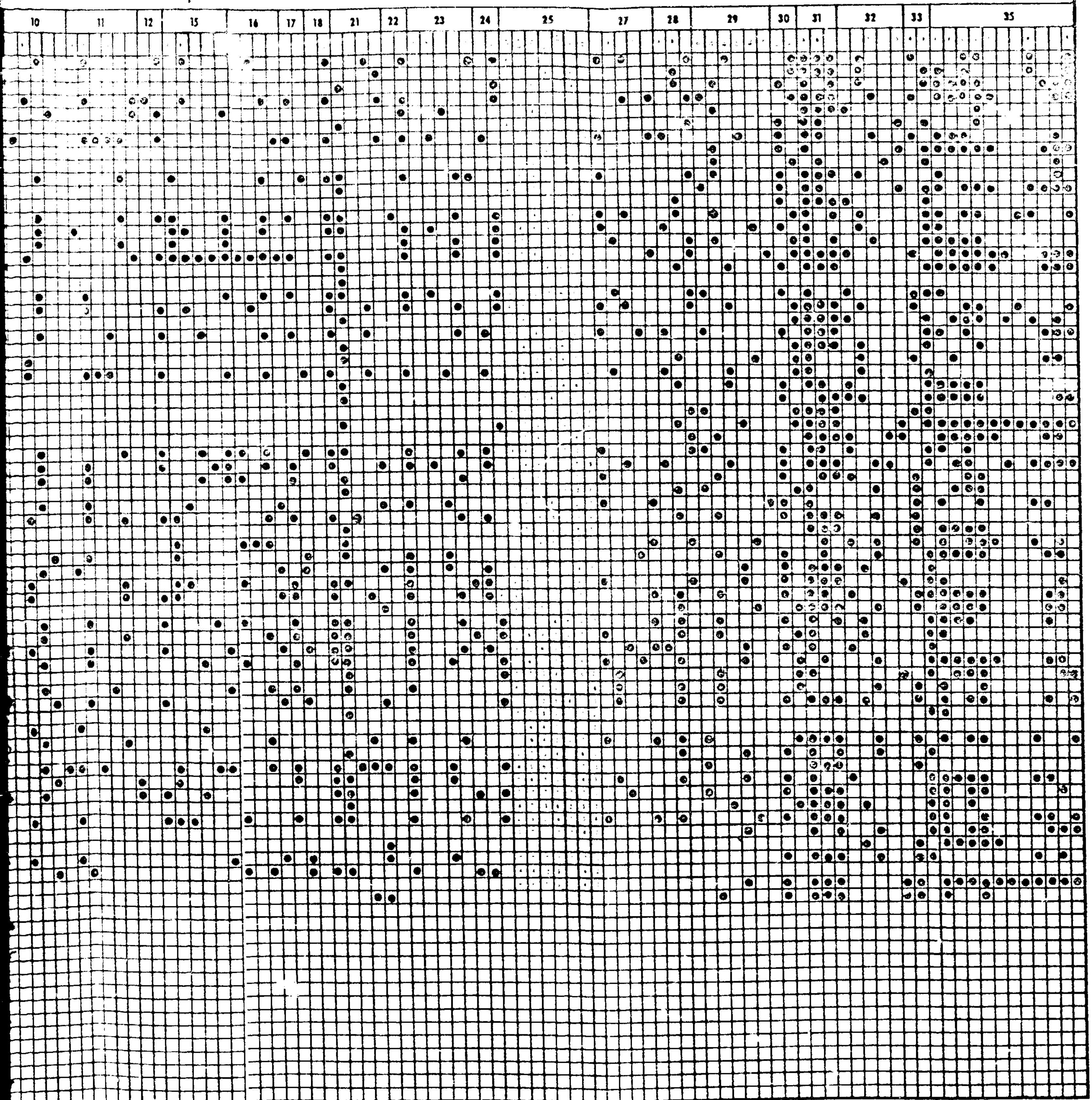
FOLDOUT FRAME

5-188



FOLDOUT FRAME 5

NAIRE SUMMARY ON HUMAN ENGINEERING DESIGN STANDARDS

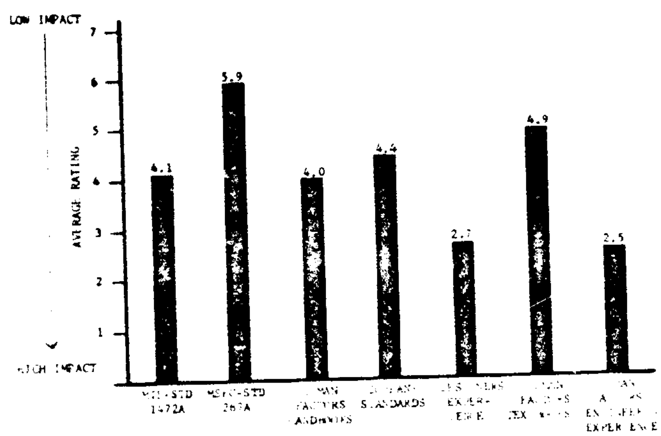


Question 25

Please rank the following data sources reflecting the amount of impact you feel they have on a designer's job.

- MIL-STD-1472A
- MSFC-STD-267A
- Human Factors Handbooks
- Company standards
- Designer's experience
- Human factors textbooks
- Human factors engineer's experience

The respondents were asked to rank order seven data sources reflecting the amount of impact that each had on the designer's job. A high average rating indicates a low impact and a low average rating indicates a high impact. The results are depicted in the figure. As shown, the primary data sources were considered to be the human factors engineer's/designer's experience, followed by human factors handbooks/MIL-STD-1472A followed by Company Standards/Human Factors textbooks, and lastly MSFC-STD-267A.



RANKING OF DATA SOURCES REFLECTING THE AMOUNT OF IMPACT ON A DESIGNERS JOB*

* N = 61

Question 26

Please list the most valuable human factors data sources used in your work.

When asked to list the most valuable human factors data sources used in their work, MSFC-STD-267A warranted listing by only eight percent of the respondents (see Table 1). The following were the most frequently listed data sources.

Title, authors

1. Woodson Conover
2. Human Engineering Guide to Equipment Design, Morgan et al.
3. MIL-STD-1472A
4. Human Factors Engineering, McCormick
5. Bioastronautics Data Book
6. Data Book for Human Factors Engineers, Kubokawa

TABLE 2

Responses to Question No. 26

1. MIL-STD-1472
2. MIL-STD-1472
   H. F. Design Guide HE Reference Books, WADC, WADC, ARMRL, TECH Reports, PhD references and literature Physiological References, Medical References, Safety Stds. Specs and Design Guides, Maintainability References and Design Guides.
3. MIL-STDS-1472 - System specs-Human Engineering texts, Air Force Design Handbooks series.
4. HE for equipment design - Woodson & Conover, The Human Body in Equipment Design - Dorman, et al.
6. MIL-STD-1472A, AFSC Design Handbook 1-3
7. MSFC-STD-267A, MIL-STD-1472A
9. Woodson, Chapanis, McCormick, Stevens, Hillborn
10. Contractual Oblications MSFC-STD-267A, textbook Morgan, Cook, Chapanis, Lund, personal file.
11. Texts by Woodson and McCormick
12. MIL-STD-1472, AFSC DH 1-3, E. J. McCormick, Human Factors Engineering, Morgan, Cook Chapanis, Andlund, Human Engineering Guide to Equipment Design, S. S. Stevens, Handbook of Experimental Psychology, Osgood, Method of Theory in Experimental Psychology.
13. Human factors reports file (personal library including texts and previous studies. Specialty texts and reports oriented to specific problems). AFSC design handbooks/MIL-STD-1472, MIL-STD-267/ H. E. Guide Etc.
14. Human Engineering, McCormick; IED Lighting Handbook; The Measure of Man, Dreyfuss; Handbook of Experimental Psychology, Stevens, Human Factors in Air Transport, McFarland, Bioastronautics Data Book, NASA; Handbook of Biological Data, Handbook of Human Engineering Design Data for Reduced Gravity Conditions, NASA.
15. 1. Morgan, et al, Human Engineering Guide to Equipment Design.
    2. Damon, Stoudtetal, Human Body in Equipment Design.
    3. MIL-STD-1472A
    4. DH 1-3, Personnel Sub-systems
    5. McCormick, Human Factors Engineering
16. MDAC Human Factors Engineering Manual 1, MSFC-STD-1472A, AFSC Design Handbook Series
17. Human Engineering Guide for Equipment Designers, Woodson/Conover Human Factors Engineering/ McCormick, The Human Body in Equipment Design/Damon AFSC-DH 1-2 through 1-4 and 2-1 through 2-3. Measure of Man/Dreyfuss, Pocket Data/Cornell Aero Lab, MIL-STD-1472A; NASA Bioastronautics Data Book SP-3006.
19. Compendium of Human Responses to the Aerospace Environemtn/Roth, et al; Various documents on Anthropometry.
21. McCormick - Human Factors Engineering; Welford - Fundamentals of Skill; Howell & Goldstein - Engineering - Current, Perspectives in Research.
22. Bioastronautics Data Book; Chapanis, et al, McCormick; Tuft's
23. Experience, Woodson & Conover, Morgan, et al; Various journals, private communication, MIL-STD-1472A.
24. HEL standards, MIL-STD-1472A, Related MIL-STDs.
25. Articles in journals, existing HF standards, summary texts and reports
26. AFSC Design Handbook DH 1-3
27. Past experience, close assoication with mechanical engineers, electrical engineers, trade magazines (Datanation, Modern Data, Machine Design, Design News, Product Engineering) Woodson & Conover, Morgan-Cook et al, McCormick
28. The standard handbooks and personal experience, with emphases on the latter.
29. Human Engineering Guide - Woodson & Conover, Human Factors Engineering - McCormick, Human Engineering Guide to Equipment Design - Morgan et al; Human Engineering Evaluation Manual - General Dynamics.
30. HE Guide to Equipment Design-Morgan, Cook, Chapanis, Lund; HE Theory and Practice - Meister Bioastronautics Data Book, HF Engineering - McCormick, HF Design Data [illegible] est. Research Techniques in HF-Chapanis, MSFC-STD-1472
31. WADC - Documents, HEL-Documents, HE-Text Books.
32. Human Factors Handbooks, MSFC-STD-267A, "Joe" and "Josephine" as designed by Henry Dreyfuss
33. McCormick, Woodson and Soltesberg, Cornell Aero Labs Handbook, Morgan-Cook-Chapanis-Psychology and Human Engineering texts.
34. MIL-STD-1472A, Books on Perception and Experimental Psychology, Human Body in Equipment Design by Damon et al, Journal of the Human Factors Society.
35. Human Factors Textbooks [illegible], McCormick, Christ[illegible] Compan, standards and Handbooks [illegible], systems & OSE, LMSC, MIL-STD 1472A, MSFC-STD-267A.
36. HEL-STD-S-heno, MIL-STD-1472A, Damon, et al, Human Body in Equipment Design, Morgan, et al, HE Guide to Equipment Design, Individual NASA, USAF, ARMY or contractor technical reports, AFSC DH 1-3 and 2-2 as applicable.
37. 1. 20 years of experience, university training, MIL-STD-1472A, HF text books
38. MIL-STD-1472A, McCormick-Human Engineering, Morgan, et al - H. F. Guide to Eq. Design, NASA Biotechnology manual, Stevens, S. S. Handbook of experimental psychology, military and NASA reports, Colleagues
40. Bioastronautics Data Book, Human Factors Text and Journals, Engineering Psychology publications.
43. Experience, Handbooks, MIL-STD-1472A, Textbooks, Society affiliation.
46. MSFC-STD-267A and MIL-STD-1472A, Lockheed Human Eng Criteria, Space Applications, Bioastronautics Data Book, IOM 32158 (NASA) Man Sys Design Requirements for OWS., IOM 32-47 Human Engineering Design Criteria, AAAP Exp., NHB [illegible], Safety.
47. Woodson & Conover, NASA-Humans, NASA ames handbook Kubokawa, et al.
48. MIL-STD-1472, AFSC, DH 1-3, Personnel Subsystems, Conover, Woodson, Human Engineering Guide for Equipment Designers, Morgan, C. T. et al. Human Engineering Guide to Equipment Design, Lockheed, Human Factors Reference Handbooks.
49. Question is ambiguous; do you mean original studies or data compilations? In the past I have used MIL-STD-1472, the Joint Services Guide (McGraw-Hill edition) and Woodson and Conover. occasionally a textbook like McCormick's.
50. Standards MIL-STD-1472A, Handbooks - DH-1, Human Eng Guide to Eq. Design., Technical Reports, Emperial Lab data or test data derived for specific program, i.e. touch, temperature, hatch size, zero-gravity requirements for an isometric controller, etc.
53. DH 1-3 Woodson & Conover, MIL-STD-1472A, MIL-STD-803A, McCormick, Ames Design Guide Kubokawa)
54. MIL-STD-1472A, Handbook of Experimental Psych - Stevens, Joint Services Handbook, Libraries and D.D.C., Other Human Factors Specialists, HEL STDS.
   Compendium-CR 1205, Astronautics Data Book.
55. Morgan, Cook, Chapanis, Lund, Woodson and Conover, Compendium-CR 1205, Astronautics Data Book.
58. Experience, original research reports, Human Factors Handbooks, MIL-STANDARDS
59. MIL-STD-1472A, AFSC DH 1-3 "Personnel Subsystems" C. T. Morgan, et al, "Human Engineering Guide to Equipment Design," S. S. Stevens, "Handbook of Experimental Psychology," [illegible] "Compendium of Human Response to the Aerospace Environment," NASA SP-3006 - Bioastronautics Data Book," E. J. McCormick, "Human Engineering."
60. MIL-STD-1472A, AFSC Design Handbooks, Human Engineering Guide to Equipment Design, Human Factors Journal.
62. Human Engineering Guide to Equipment Design.
63. Human Factors and Psychological Journals, textbooks, military research reports.
64. Various texts and research from field of experimental.
65. Human Engineering Guide to Equipment Design, Morgan, C. T. Cook, J. S. Chapanis, and Lund, M. W. (Eds.) McGraw-Hill, 1963), The Journal Human Factors, The Journal Ergonomics.

Conclusiors

The following conclusions can be drawn from the above results.

1. MSFC-STD-267A is not widely used.
2. MIL-STD-1472A is considered to be a more valuable human factors data source than MSFC-STD-267A.
3. MSFC-STD-267A appears to have little impact on spacecraft design by virtue that it is not used.

Hypothesis No. 2: MSFC-STD-267A is primarily used as a general reference and not as a standard.

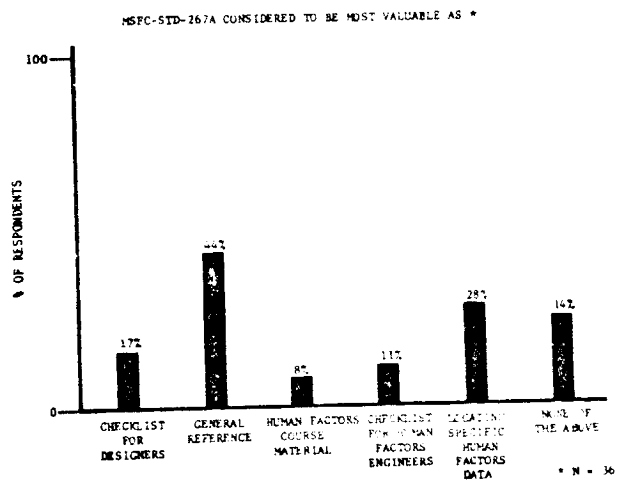
Summary Statement: This hypothesis was supported by the research findings.

Discussion of Applicable Questions:

Question 11

MSFC-STD-267A is most valuable as

A. Checklist for designers
B. General reference
C. Human factors course material
D. Checklist for human factors engineers
E. Locating specific human factors data
F. None of the above

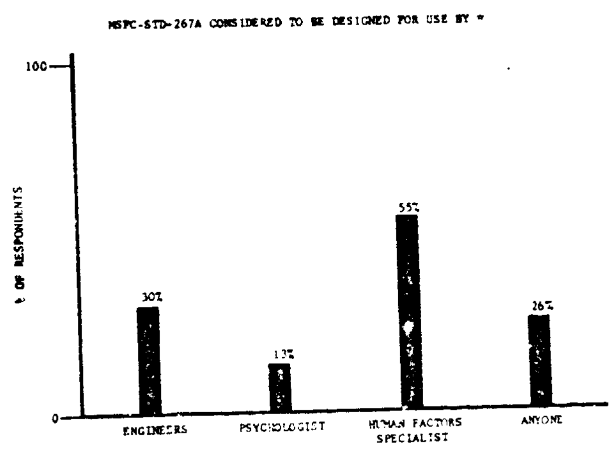


As shown in the figure, forty-four percent of the respondents considered MSFC-STD-267A most valuable as a general reference, while only twenty-eight percent of the respondents considered it most valuable for locating specific human factors data.

Question 16

MSFC-STD-267A is designed for use by:

A. Engineers
B. Psychologists
C. Human Factors specialists
D. Anyone



As shown in the figure, the respondents felt that MSFC-STD-267A was largely designed for use by human factors specialists.

Conclusion

The above results indicate the MSFC-STD-267A is largely considered as a general human factors reference for use by human factors specialists.

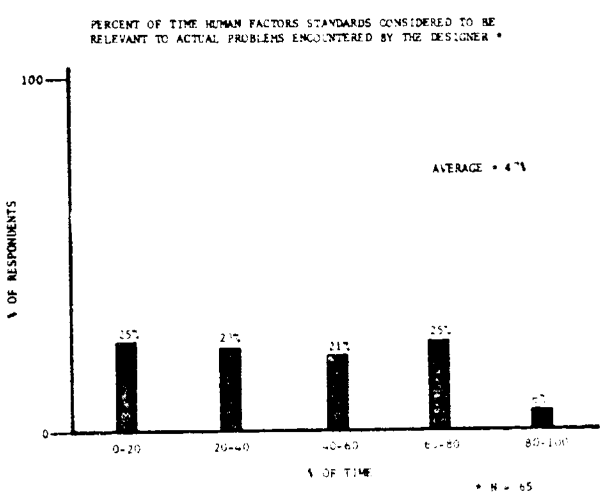
Hypothesis No. 3 - MSFC-STD-267A has specific problems which tend to make the designer ignore it.

Summary Statement: This hypothesis was supported by the research results.

Discussion of Applicable Questions:

Question 3

I feel that human factors standards have data relevant to the problems actually encountered by the designers ______% of the time. (0, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100)

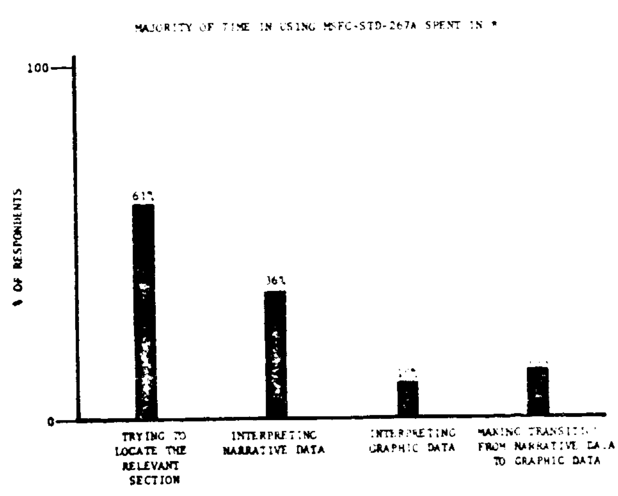


As shown in the figure, the responses to this question were nearly evenly distributed among the ranges. On the average, the respondents considered that human factors standards were relevant to actual problems encountered by the designer forty-seven percent of the time.

Question 9

In using MSFC-STD-267A, I find most of my time is spent

A. Trying to locate the relevant section
B. Interpreting narrative
C. Interpreting graphic data
D. Making transitions from narrative to graphic data

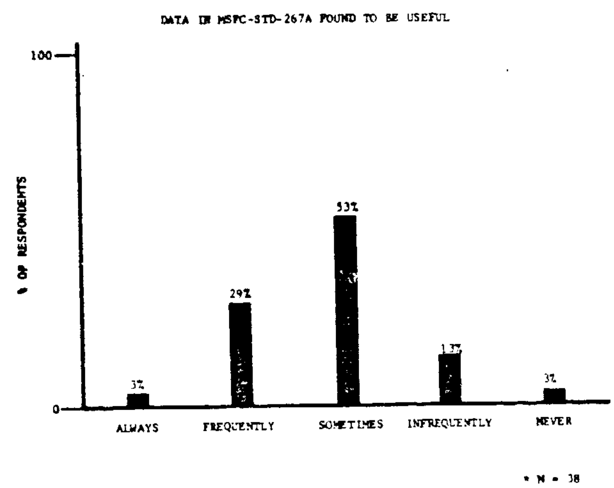


The respondents felt that most of their time in using MSFC-STD-267A is spent in trying to locate the relevant section and interpreting narrative data.

Question 10

On the occasions when I have consulted MSFC-STD-267A, I have found the data useful.

A. Always
B. Frequently
C. Sometimes
D. Infrequently
E. Never



As shown in the figure, the majority of respondents felt that the data in MSFC-STD-267A was useful only sometimes.

Question 13

What is the major problem you have encountered in using MSFC-STD-267A?

Table 2 is a listing of the major problems encountered by the respondents in using MSFC-STD-267A. The most frequently listed are:

1. Data are not specific
2. Data are difficult to locate
3. Lack of zero gravity data

TABLE 3

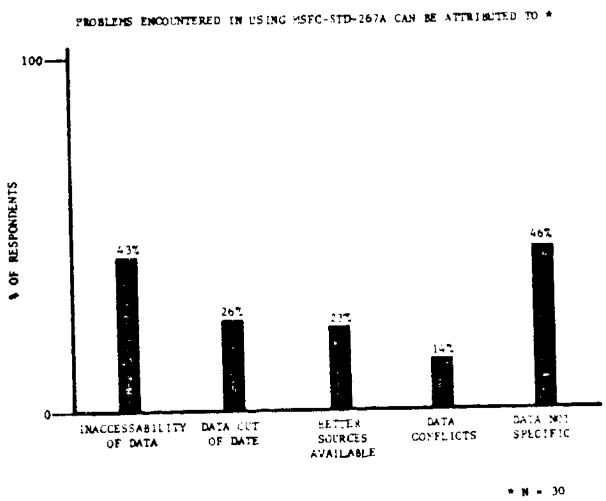
Responses to Question No. 13

5. Lack of transfer of lab research data to real world environments and problems.
7. Lack of material on cockpit layout.
10. Lack of data, especially in relationship to human strength in relationship to common work tasks, torque on hand tools, valve handles
13. In-house recognition and programs not specifying MSFC-STD-26[illegible] as a requirement. NASA programs should emphasize the use of MSFC-STD-267A and MIL-STD-1472A where applicable.
14. Like all standards it must be general for wide applicability and specific data is usually not found.
15. Finding relevant materials easily is an index action.
16. It is not as good as MSFC-STD-1472A or company standards.
19. Not specific, not oriented to the design engineer of the board.
20. Criteria Creditability.
22. Lack of specific data-guide lines do not hack it.
25. Does not help H. F. engineer designer problem
31. Much detail, but not applicable to specific problems.
32. The major problem I have encountered is the need to translate the standards into design recommendation the engineers can comprehend.
36. Required information not included in MSFC-STD-267A.
44. Data not applicable to real world problems in spacecraft design.
45. Only useful for earth applications, no 0-G data.
46. Not very applicable to zero-g, environments and not specific enough.
49. Have already indicated that if I can generalize from MSFC-STD-1472 the major problem is one of application to the specific design problem.
50. Not required by NASA on any of our spacecraft contracts.
56. Locating the desired data.
59. The difficulty in locating information. The index should use subject nouns for prime descriptors.
62. Its relevance to specialized unic. design issues.
63. Lack of situational parameters to define limits of relevance.

Question 15

The problems I have encountered in using MSFC-STD-267A can be attributed to:

A. Inaccessibility of data
B. Data out-of-date
C. Better sources available
D. Data conflicts
E. Data not specific

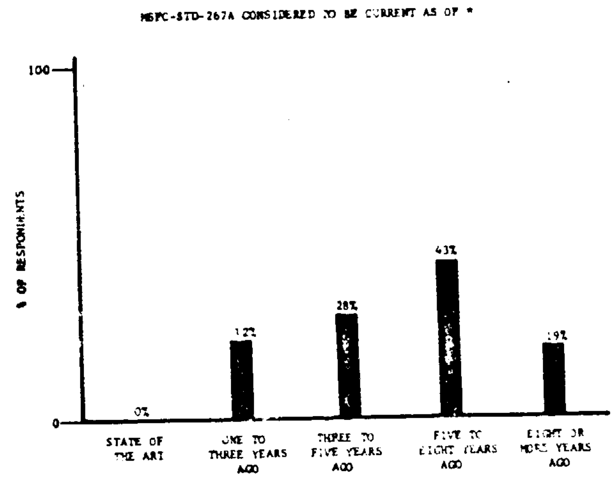


Similar results to Question 13 are indicated by the responses to Question 15. As shown in the figure, the most significant problems in using MSFC-STD-267A were considered to be the inaccessibility of data and that the data are not specific. Also, twenty-three (23) percent of the respondents felt that better sources were available.

Question 23

Do you feel the information in MSFC-STD-267A is current as of:

A. State-of-the-art
B. One to three years ago
C. Three to five years ago
D. Five to eight years ago
E. Eight or more years ago



As shown in the figure, the respondents considered MSFC-STD-267A to be current as of five to eight years ago. This is consistent with the publication date of 1966.

Question 21

The term "averaged normal range" as appears in the following figure indicates to me that the data are:

A. 50 percentile
B. 5 percentile
C. 95 percentile
D. Design limits

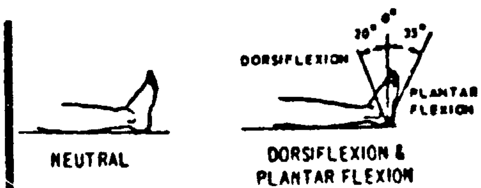
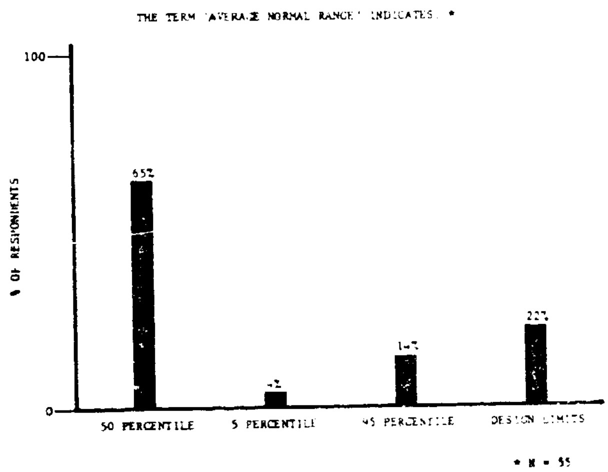


Figure 47. Average normal range of motion of the ankle.



The ambiguity of MSFC-STD-267A is illustrated by the responses to Question 21, as depicted in the figure. The data in Figure 47 of MSFC-STD-267A portrayed to the respondents four separate meanings.

<u>Questions 12, 18, and 22</u>

These questions were included as a validity check on the respondents. If they were familiar at all with MSFC-STD-267A, they would know that <u>no</u> data are included on these topics. These questions were included to detect careless responding as well as inadequate knowledge of the standard.

I feel that MSFC-STD-267A gives the designer sufficient data to design for extravehicular activity
Yes _______ No ________

Is the section in MSFC-STD-267A on light emitting diodes adequate for the selection of these devices over other displays
Yes________ No _________

The data contained in the maintainability section of MSFC-STD-267A adequately covers man operating in the space environment
Yes________ No _________

The responses to all three of these questions were nearly unanimous, no. Question 12 received one (1) yes response, and seventeen (17) no responses; question 18 received no yes responses and twenty-five (25) no responses; and question 22 received one (1) yes response and twenty-five no responses.

These results tend to validate the responses which were received.

Conclusions

The following conclusions can be drawn from the above results.

1. MSFC-STD-267A has several problems which tend to make it difficult to use. The most significant of these is the inaccessibility of the data and that the data are not specific.
2. MSFC-STD-267A is considered to be current as of five to eight years ago.

Hypothesis No. 4: Poor human engineering design is the result of several managerial problems in addition to poor human engineering standards.

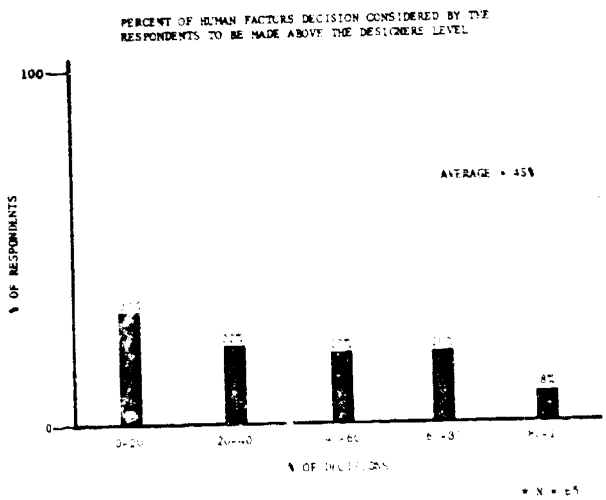
Summary Statement: This hypothesis was supported by the research findings.

Discussion of Applicable Questions:

Question 5

I feel that approximately ______ percent of human factors decisions are made above the designer's level. (0, 10, . . . 100)

The responses to question five are depicted in the figure. As shown, forty-five percent of human factors decisions were considered by the respondents to be made above the designers level.

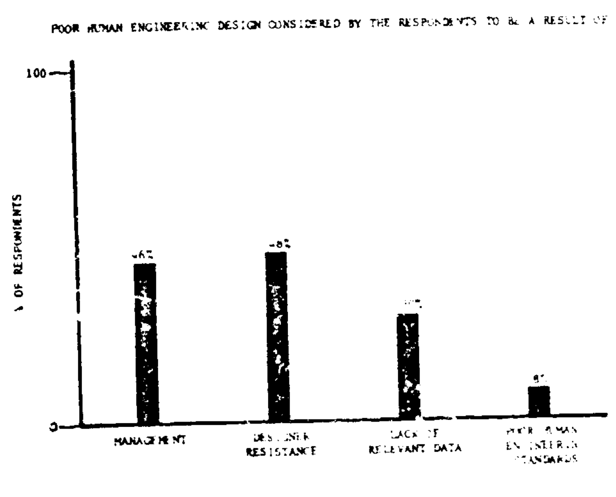


Question 6

I feel the majority of poor human engineering design is a result of:

- A. Management
- B. Designer resistance
- C. Lack of relevant data
- D. Poor human engineering standards

As shown in the figure, the majority of poor human engineering design is considered by the respondents to be a result of management and designer resistance. Only eight percent of poor human engineering design was considered to be a result of poor human engineering standards.

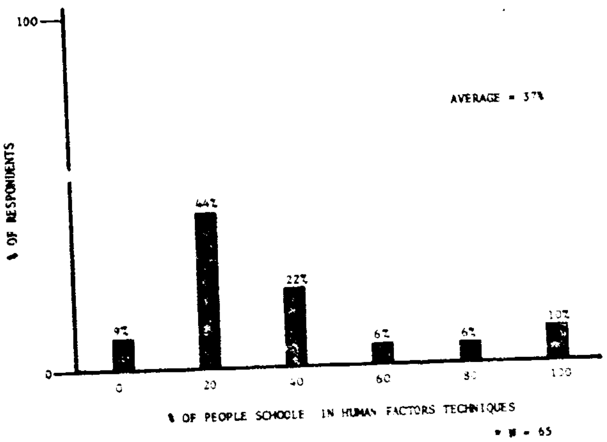


Question 4

What percent of people assigned to implement human factors standards are actually schooled in human factors techniques?
______% (0, 20, 40, 60, 80, 100)

The responses to question four are depicted in the figure. As shown, the respondents considered thirty-seven percent of the people assigned to implement human factors standards to be actually schooled in human factors techniques.

PERCENT OF PEOPLE ASSIGNED TO IMPLEMENT HUMAN FACTORS STANDARDS THAT ARE CONSIDERED BY THE RESPONDENTS TO BE SCHOOLED IN HUMAN FACTORS TECHNIQUES *



Conclusions

The following conclusions can be drawn from the above results:

1. Nearly half of human factors decisions are made above the designer's level.
2. Management and designer resistance are major factors in poor human engineering design.
3. A human engineering standard, in order to be effective, must include provisions for circumventing the management and designer resistance factors in human engineering design.

Hypothesis No. 5: The entire approach to a human engineering standard should be changed.

Summary Statement: This hypothesis was supported by the research results.

Discussion of Applicable Questions:

Question 14

List the areas which you feel should be added to MSFC-STD-267A.

Table 3 provides a listing of specific areas where the respondents felt that data should be added to MSFC-STD-267A. The comments generally indicate the need for an update and reformating of the data.

TABLE 4

Responses to Question No. 14

[illegible]. More on maintainability.
[illegible]. More material on hand controls and more detail on displays.
[illegible]. Need research and data on "common" work motions (perhaps a taxonomy) related to strength. Example, what is torque value for use of screwdriver, pliers, handvalves (not controls for panels).
11. Needs updated information based on Apollo, Skylab and Shuttle activities. Also updated references to this data although I realize much of it is not easily available to contractors when needed.
14. General update needed.
15. Detailed Design Criteria.
16. Look AFSC Design Handbook.
[illegible]. Eliminate it. Add space applications criteria to joint standard MSFC-STD-1472.
22. Improve what's there.
25. Reorganize for total specificity to individual subsystem.
31. 1. Anthropometric Data and Forces that apply to seated and standing operators.
2. Minimum space and volume for crews.
3. Personnel space and territory defined.
35. More detailed listing of acceptable (space qualified) controls and displays (State-of-the-Art
[illegible]. Those relating to design for suited crewmen, [illegible] conditions, other orbital space operational requirements relating to mass transfer, habitability, vision.
42. Revise astronaut population anthropometric data, expand on space vehicle operational constraints.
46. Zero-g applications both suited (EVA & IVA).
49. Again with reference to MSFC-STD-1472, the coverage is adequate in terms of the subject matter however, the details of the materials are lacking, which is not so much a problem of the standard as such as it is of the general paucity of relevant data.
56. Modified gravity information.
59. A complete new index in greater detail. Greater reliance on illustrations.

Question 17

Less narrative and more graphic data should be used in any revision of MSFC-STD-267A.
YES or NO

Two-thirds of the respondents felt that more graphic and less narrative data should be used in any revision of MSFC-STD-267A.

Question 19

I would like to see the following changes incorporated in a revision of MSFC-STD-267A.

Table 4 lists the respondents' changes to MSFC-STD-267A. As can be seen in the table, a large number of the respondents felt that more graphics and better organization would enhance the document. Several respondents felt that MSFC-STD-267A should be abolished and replaced by MIL-STD-1472A or by MIL-STD-1472A with a spacecraft specific addendum. Several respondents also specified the need for additional data and an update of existing data.

TABLE 5

Responses to Question No. 19

4. Too extensions to cover in time available.
[illegible]. Better index.
[illegible]. Data as mentioned in [illegible] and [illegible] but [illegible] what is known and what will come from Skylab on [illegible] environment related to task performance and work in general.
13. Mostly update and add data as supplement to MIL-STD-1472. Better still, work out agreement to use MSFC-STD 1472A on all projects with MSFC-STD-267A data as an addendum.
16. You are too far behind the AF or DOD specs.
14. General update required.
19. More examples of data utilization. More emphasis on the use of graphics.
20. Determine all data sources or verify validity. Eliminate common [illegible] data [illegible].
31. An easier to use document. Better index with tabs or separators for sections.
[illegible]. I would above all like to see more of an attempt to organize the data in terms of specific type of applications rather than to attempt to present essentially global standards.
35. Generally, improvement of all areas that directly affect a practicing Human Factors Specialist and the problems he will encounter in "System Design" Man System.
41. Update materials. Increase ease of locating data and design.
42. More graphics - one picture well presented better than 1,000 words.
44. More data given in charts, graphs, etc. Less information on ground based systems.
46. Section applicable to space design operations, color codes for connector materials equip. Color specifications for items (fire ext., tools, living quarters, hand rails, etc.). Decal identifications specifications for space habitats.
48. Set up human engineering requirements on contracts in such a manner that the general criteria is in a single document like the Data Book for Human Engineers, NASA CR- [illegible] and then provide special supplements for launch facilities, spacecraft, aircraft, ships, vehicles, subs, etc.
49. If MSFC-STD-267A is anything like MIL-STD-1472 (and it probably is) it requires a complete revision starting from the standpoint of what the design engineer needs to know to solve his problem.
50. Reference document with specific sections (space specific) called out by contrast to supplement MIL-STD-1472.
56. Make document more easy to get to the data.
59. Index should be more relevantly keyed to material in text.

Question 20

I would like to see the following data added to MSFC-STD-267A.

Table 5 provides a listing of additional data which the respondents felt should be added to MSFC-STD-267A. Only ten recipients of the questiornaire responded to this question.

TABLE 6

Responses to Question No. 20

10. Strength factors for work tasks and common tool use. A taxonomy on work motions and tool use.
13. More current electronic display on for especially flight displays and reformance management. Also keyboards, redundancy management, emergency detection, interface problems and solutions, in space orientation, habitability, all stress areas of impact including forces, displays, and control panel design integration.
16. Adopt MIL-STD-1472A.
20. Habitability.
31. 1. Forces, reaches, etc. that are directly useful instead of the reams of irrelevant data.
    2. Space suited operator data. There is a complete void here.
35. Statistical Data as a result of verified man systems design.
41. Zero-g data; women anthropometric data space suit data.
45. More pertinent data on exhaustion and advanced spacecraft.
57. Modified gravity information.
60. Human Tolerance to Acceleration.

Question 24

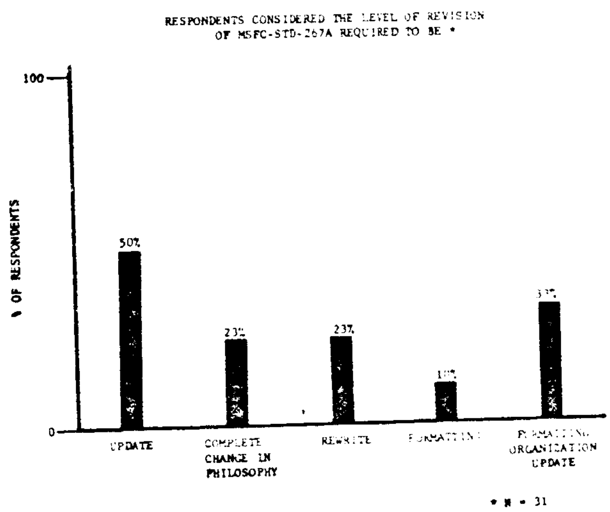
I have found MSFC-STD-267A to be more useful than MIL-STD-1472A. YES or NO

Sixty-three percent of the respondents answered NO.

Question 27

What level of revision of MSFC-STD-267A is required?

A. Update
B. Complete change in philosophy
C. Rewrite
D. Formating
E. Formating/organization update



Fifty percent of the respondents felt that the level of revision of MSFC-STD-267A required was a general update. Thirty-three percent felt that a formating/organizational update would suffice while twenty-three percent felt that a complete change in philosophy was required.

Question 28

If a single human engineering standard were adopted by all governmental agencies, I would prefer:

A. MSFC-STD-267A
B. MIL-STD-1472A
C. Other (Please specify)
Why?

As shown in the figure, over [illegible]lf the respondents felt that if a single standard were adopted for all governmental agencies, that it should be MIL-STD-1472A. Only fifteen percent of the respondents felt that MSFC-STD-267A should be adopted, however, one-third of the respondents felt that a standard other than MIL-STD-1472 or MSFC-STD-267A should be adopted. Table 6 lists the responses to this question as well as the respondents' reason for his preference.

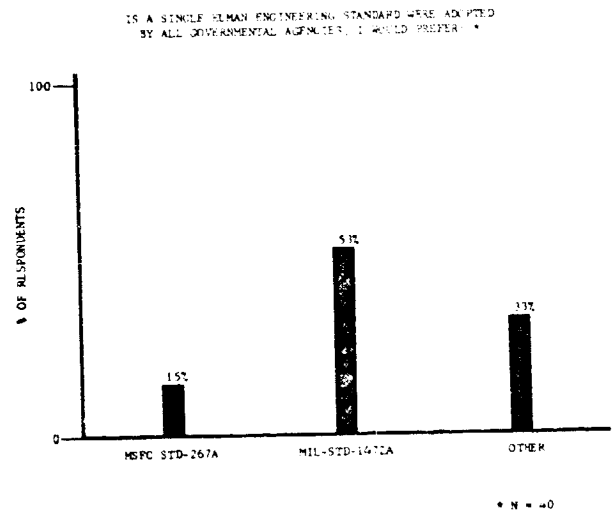


TABLE 7

Responses to Question No. 28

2. Availability and courage. (B)
3. Although spec if only a guide, it covers areas where human engineering inputs are most ignored. This broad coverage is required if only using a single spec. (B)
6. An Expanded MIL-STD-1472A. More detail than MIL-STD-1472A required. (C)
10. A. F. Handbook are best although have not used them since 1963. Good he is more an orientation and problem solving approach than a standard or checklist approach. So where data is lacking expertise is essential, this may best come from A. F. documentation than MSFC-STD-267A or other standards. (C)
12. Because it is the most useful document I employ. (B)
13. I realize MIL-STD-1472's weakness, but it can be improved. MSFC-STD-267 has considerable value as a guide but is not well known by military or industry. (B)
14. It is the most general MIL-STD available. (A)
15. DH 1-3 most comprehensive. (C)
16. AFSC Design Handbook series, Organization, graphics, accuracy, etc. (C)
17. It more clearly related to commercial aircraft design requirements. (B)
19. MIL-STD-1472A does not contain spacecraft information and MSFC-STD-267A does not contain sufficient aircraft introduction. Both lack specific design criteria. (C)
20. New Integrated Data Book. Current publications inadequate. (C)
22. More comprehensive even though hard to use, once familiarized with it the data is there. (A)
23. My concern is w/test of introt, functioning man-machine systems. The current standards are inadequate to provide criteria that are sufficiently dynamic.
24. A "standardized" standard should be inter-changeable to all services, NASA, etc. to eliminate.
25. Of the two, is more relevant to the situations encountered. (A)
28. Index of specialized H.E. standards. It's like having a single bible for all religions. Must pinpoint areas of application. Tremendous diversity. (B)
30. I think there are too many MIL-STDS specs - we need one comprehensive army-navy-AF MIL-STD handbook to reduce confusion as to which stds apply. (C)
31. A more comprehensive approach. Sub-divide into useful areas light, sound, space, etc. for specific products and environments. spacecraft, aircraft, etc. for rapid info retrieval. (C)
32. This source is more inclusive than MIL-STD-1472A and there are really no other reasonable candidates. (A)
34. MSFC-STD-267A has never been called out even on MSFC contracts that involve the manipulation by the human. (B)
36. Expanded to two volumes if necessary to cover all agency needs, if that requires a special volume or section of the volume devoted to the unique requirements of manned spacecraft, or naval ships, or rotary wing aircraft, etc., so be it. But make it complete and current. (B)
38. Something more comprehensive than MIL-STD-1472A and less than MSFC-STD-267A. MIL-STD-1472A needs more details, poorly organized. (C)
41. Updated MSFC-STD-267A, it has the potential just needs updating with some additional clarification. (C)
43. First fully developed one in this area other sections could be adopted into the document. Proliferation of document is not a desirable condition either for government or industry. (B) References include about everything ever put out in field of H/F up to about 1962. (A)
46. References include about everything ever put out in field of H/F up to about 1962. (A)
47. More comprehensive for projects other than space oriented. (B)
49. Obviously, the needs of the various governmental agencies do not differ extensively enough to warrant more than one comprehensive standard. Since MIL-STD-1472 is required on all military projects, it should take precedence over individual agency standards. In fact, unless it can be shown that MSFC-STD-267A contains material not included in MIL-STD-1472 (which I doubt), I cannot see why NASA should indulge itself in a special standard. If it does contain special material, that material should be added to MIL-STD-1472. (B)
50. A simple standard that can be anticipated and is used by vendors, subcontractors, so that OFF and off-shelf equipment is designed to a single requirement and is compatible when assembled into a system. STD is contractually useful. (B)
54. Only because I am not familiar with MSFC-STD-267A. However, I do not see how a single standard can meet all requirements without becoming so large as to be difficult to use by designers. (B)

A. MSFC-STD-267A, B. MIL-STD-1472 A, C. Other

Question 30

I feel that a NASA-wide human engineering standard should be generated.
YES or NO

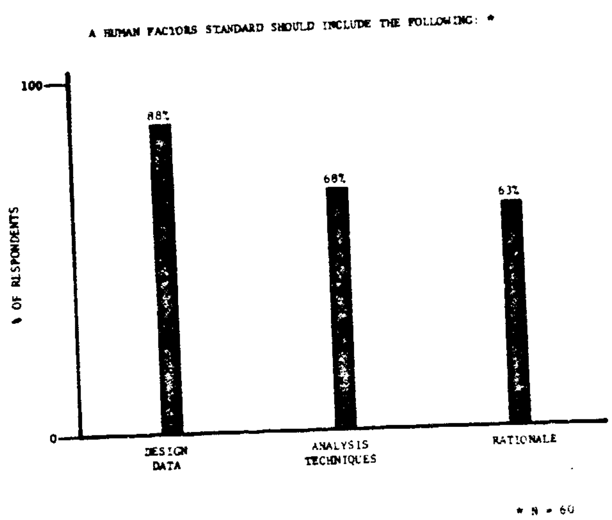
Fifty-eight percent of the respondents felt that a single NASA-wide human engineering standard should be generated. Several respondents, who answered no to this question, commented that a governmental wide standard should be adopted.

Question 31

A human factors standard should include the following:

- A. Design data
- B. Analysis techniques
- C. Rationale

As shown in the figure, eighty-eight percent of the respondents felt that a human factors standard should include design data, while sixty-eight percent felt that it should also contain analysis techniques and sixty-three percent felt that it should provide supporting rationale.



Question 32

I feel that a human engineering standard should be updated every ______ years.

The respondents felt that a human factors standard should be updated on the average every two to three years.

Question 33

How would you prefer human factors data to be presented?

A. All-inclusive standard
B. Separate standards for applications (e.g. aerospace, submarine, etc.)

Sixty-five percent of the respondents felt that separate standards for applications should be utilized as opposed to an all-inclusive standard.

Question 34

What procedures should be implemented to assure that human engineering standards are satisfied?

The responses to question thirty-four are delineated in accompanying Table 7. As can be seen from the table, the general consensus for procedures to ensure that human engineering standards are implemented is to impose the standard in the Statement of Work and to penalize contractors for not meeting the imposed standard. Several respondents also suggested implementing procedures for drawing "sign-off" by competent human factors engineers and management/designer reviews. It was noted by one respondent that no such procedures will assure that the standards are satisfied short of the dissemination of hard, convincing data that the consequences of disregarding the standards are or will be costly in terms of dollars and cents.

TABLE 8

Responses to Question No. 34

1. Governmental agencies should maintain greater cognizance over implementation of their human engineering standards.
2. Only one positive method, i.e. HE requirements are in compliance with appropriate document(s) in contract and negotiated work statement.
   STDL should be part of contract, implementation done by those personnel educated in human factors rather than a "double-duty" engineer.
4. Direction from highest Hqs. accompanied by funds giving Proj. Mgrs. prerogative for waivers.
8. Contractors should penalize not meeting imposed standard. Why pay for a product that does not meet spec.
9. Contractual requirement, particularly related to penalties or inventives.
10. A. F. used their own monitors to enforce the contractual obligation. Contracting management were forced to meet the contract.
11. HF quality inspection.
12. Close government monitoring by Human Factors Personnel and an aggressive personnel subsystem test and evaluation program.
13. Specs such as MIL-H-46855 or NASA 391 must put the requirement on the contractor early in the rep). Human engineering must be functionally represented on management side (NASA) at a high enough level to provide guidance and enforcement.
15. Contractual requirements enforced by formal performance evaluation like any other engineering requirement.
16. Document sign-off at least - By NFE. Most important the customer (NASA, AF, NAVY, etc.) should insist on human factors engineering and pay for this service and monitor (or audit) the contractor to see that they are getting what they are paying for.
17. Industry survey of needs, Professional Society survey of needs, Joint Military - Gov't symposia.
19. Comprehensive test and evaluation procedures any with drawing "sign-off" by competent HE.
20. Contractual obligation with penality.
22. Adequate procedures are now specified in MIL-H-46855 or Enforcement of these procedures is required for example demonstrations of compliance must be demanded rather than waived.
23. Strict contractor accountability coupled w/strict dynamic testing by knowledgeable personnel by the customer.
24. During contract definition or early, request for proposal (RFP) Human Engineering should be written in proposed work and requirements sections - get Human Engineering in early.
25. Make them part of the design standards, these are never ignored.
26. Include, with authority, the H. F. personnel as bonafied members of the design team. Insist on H.E. sign-off of proposed designs.
27. Do not know what to call it, but something like the [illegible] are forcing the auto industry to do - legislation?
28. Deal more with the types of people -- experience training -- in customer and vendor shops assigned to the human engineering tasks.
29. Evaluation based, contract specs.
30. Within each service, create and staff well, one HF agency with a research group, a design group (one or more HF specialists with each major equipment project) and a regulatory group (stratagems to keep tabs on contractors). Strongly down-grade proposals with poor HF [illegible] [illegible]. Support HF types in industry by giving HF proposal grading some teeth.
31. NASA-HF Personnel working with their contractor counterparts to insure the inclusion of [illegible] HF in the deliverable item. USAF used to do this very well. Currently there is responsibility without authority.
32. Such procedures will assure that these standards are satisfied short of the dissemination of hard, convincing data that the consequences of disregarding the standards are or will be costly in terms of dollars and cents.
34. 1. Contractual requirement for sign-off by qualified Human Factors Personnel.
    2. Customer has qualified HF personnel monitoring job and in his own house emphasizes meeting HF standards.
    3. Customer disqualifies vendor on poor HF program and management.
36. Development of Government management awareness that HE costs are significant and require adequate timely funding for implementation within govt. and contractor programs. Impress this compelling need on contractor management at time of definition phase (hopefully, before).
37. We tried the signoff route. Too bloody much trouble. I prefer to depend on our salesmanship.
38. Include in contracts for design, include in inspection, test, and documentation requirements in contract.
41. Adequate crosschecking of programs by disinterested parties to the programs.
44. Contractual requirement.
45. Not legible.
48. A positive statement requiring the application of human engineering criteria should be included in all applicable RFP's, the bidders response to this requirement should be evaluated and commented upon by the proposal evaluation team.
49. Are you saying whether government should control design? Obviously it should, and it should do so by assigning human factors specialists to develop projects with enough [illegible] that significant deviations from standards can be stopped. It is my understanding that as far as NASA projects are concerned, the only (final) criterion is whether or not the astronaut likes the design output. If so, it completely negates the notion of either a HE standards of human engineering in NASA system development.
51. A recheck of the design and furnished product by an equally qualified H.F. engineer.
53. Have a qualified human engineer or PS specialist assigned to the customer's program office.
54. Greater commitment on the part of the project managers (both gov't and contractor) to the importance of H.F.'s.
55. Test Revolution.
56. Made it a requirement for a human factors engineer to approve all designs and documentation prior to their approval and release.
57. Management - Design reviews.
58. Adequate funding at procurement.
59. Strict NASA/Contractor enforcement of MSFC-STD-391, "Human Factors Engineering Program," or MIL-H-46855, Human Engineering Requirements for Military Systems, Equipment or Facilities.
60. Monitoring by the procuring command.
61. Continuous assessment of design plans, slate mockings drawings, dynamic mockings, field tests, etc. Of qualified personnel with a firm design veto at each critical step in analysis, [illegible] development, test and evaluation.
63. Pre-procurement, performance, requirements stated and demonstrated prior to [illegible] acceptance.
65. The contracting agency should monitor closely the way HE is done [illegible] the contract and should have a team of qualified HE examiners to insure that the final product meets HE standards.

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Question 35

Which of the following statements do you consider appropriate for a human factors standard? (All of these statements are in MSFC-STD-267A)

A. Label orientation. Labels shall read horizontally and be oriented to read from left to right.

B. Ease of reading. Displays shall be easily and quickly read for quantitative, qualitative, or status information.

C. Consistency. Layout and relationship of controls and displays shall be consistent from panel to panel within the limits imposed by the requirements of each panel.

D. Display position and relation. Whenever possible, the controls shall always be on the same plane as their associated displays.

E. Other requirements. Long lever arms will be used for large displacements.

F. Testing. It is possible to test several of the larger muscle groups of the body and get a good overall picture of the individual's strength.

G. Exercise. The exercise of one limb will increase the strength of the contralateral limb.

H. Single (one) sense. Both eyes or ears shall be stimulated simultaneously for faster reaction time.

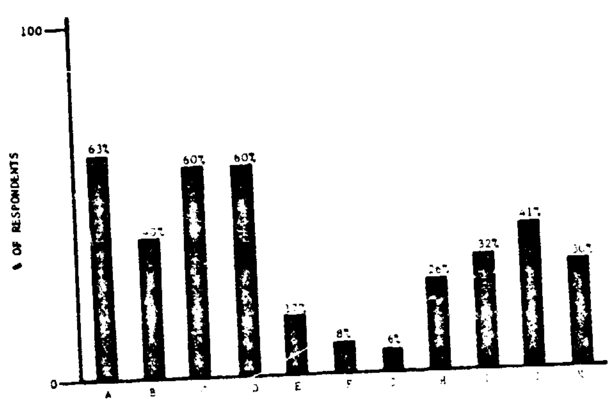
I. "Feel" of control. The controls used shall contain the minimum force consistent with proper "feel" condition.

J. General considerations. The layout and design of the equipment shall be such that the operator or technician is able to accomplish all of the necessary functions related to or involved in the task.

K. Minimum number of garments. Garments shall provide full range of protection for a normal work cycle in order to preclude multiple clothing changes in a short period of time, unless such changes are required to preclude the dangerous mixing of materials and it is impractical to use different individuals.

The responses to question thirty-five are depicted in the figure. The eleven statements were selected from MSFC-STD-267A, with the intent of representing a cross-section of the type of information presented in the standard. As can be seen in the figure, the statement receiving the largest concurrence of appropriateness was Statement A (63%). Only three (A, C, and D) of the eleven statements were considered by over half of the respondents to be appropriate for the standard. The general trend shown is that only specific criteria with direct application to design was considered by the majority of the respondents to be appropriate for a human engineering standard.

STATEMENTS CONSIDERED APPROPRIATE FOR A HUMAN FACTORS STANDARD.*



Conclusions

The following conclusions can be drawn from the above results.

1. MSFC-STD-267A requires a general update and reformating of data. This update should include more graphic and less narrative data and be reorganized to increase the accessibility of the data.
2. MIL-STD-1472A is preferred to MSFC-STD-267A.
3. Either separate human engineering standards for applications should be used or a single government-wide standard with addendums for specific applications (spacecraft, submarines, etc.). A NASA-wide standard is preferred to separate center standards.
4. The human engineering standard should be imposed in the Statement of Work and the contractor should be penalized for not meeting the standards.
5. The standard should be limited to specific criteria with direct application to design.
6. The standard should contain design data and to a lesser degree analysis techniques and supporting rationale.
7. Human engineering staff members should be involved in sign-off cycle for all design having a man-interface.

Summary

The results of the questionnaire tended to support all five hypotheses. The significant conclusion of the questionnaire survey is that MSFC-STD-267A is not widely used and has little impact on spacecraft design. The major problems with MSFC-STD- 267A are considered to be the unaccessibility of the data and that the data are not specific.

Management and designer resistance were cited as major contributors to lack of standardization in human engineering design. Therefore, if a human engineering standard is to be effective, it must include provisions for circumventing the management and designer resistance factors in human engineering design.

If MSFC-STD-267A is revised on the basis of the questionnaire results it should:

(1) Contain less narrative and more graphic data.

(2) Contain specific design criteria and to a lesser degree human factors techniques and supporting rationale.

(3) Be reformated/reorganized to facilitate data retrieval.

These recommendations have been implemented into the sample section rewrite, Section 7.0 of this report.

6.0 FORMAT RECOMMENDATIONS

6.1 INTRODUCTION

As the study progressed, format recommendations were generated from several tasks. The user survey, item-by-item review, and literature review resulted in definite recommendations concerning the content, organization, and format of a usable human engineering standard.

The responses to the user survey, discussed in section 5.3, indicated that the two major problems with MSFC-STD-267A were (1) the inaccessibility of the data and (2) the lack of specificity of the data. The respondents felt that most of their time in using MSFC-STD-267A was spent trying to locate the relevant section and interpreting narrative data.

The analytical or item-by-item review of MSFC-STD-267A provided the study team an in-depth knowledge of the content of the standard.

The problems encountered in the MSFC-STD-267A format, (reviewed in detail in section 5.1), centered around the following:

1. Overall organization
2. The same paragraph level assigned to minor as well as major criteria
3. Duplication of data in the tables and text
4. The spatial relationship between tables and supporting data
5. In some cases brevity to such an extent to cause loss of meaning
6. Voluminous information with low information density

The literature review provided insight into the format and content of supplemental data sources cited by many survey respondents as being key reference documents. The review included other standards, handbooks, textbooks, guidebooks and study reports. This allowed format and content to be compared with a number of documents with a variety of purposes.

The references considered during the literature review varied in general format depending on the objective of each document. All references made greater use of illustrations, pictures, charts and tables than MSFC-STD-267A. The system that most appealed to the investigators was the one in which an illustration of the concept was given with the pertinent data related to the subject located next to the picture.

The Human Engineering Guide Equipment Design, the maintainability handbooks, and the Data Book for Human Factors Engineers illustrated many of the requirements in a manner which not only indicated the acceptable criteria but also, what was unacceptable where it clarified the discussion. Both of these techniques are useful and should be considered.

The recommendations generated from the study are discussed below in a format which presents typical problems, then recommended format solutions.

6.2 DETAIL RECOMMENDATIONS

Detail versus General Data

Problem:

Considerable controversy exists as to the content of a human factors standard. MSFC-STD-267A presents some general information in addition to detail design requirements. The standard also presents some supporting rationale or justification for the requirements stated. The reports and handbooks reviewed in the literature review were found to present more rationale and general data than the standards. This was expected due to the intended uses of the various documents.

Recommendation:

The study effort resulted in the conclusion that some general or introductory information is useful. This conclusion is supported by the questionnaire results (section 5.3). The basis for this recommendation is that a variety of users is required to use the standard. However, the major portion of the document should be devoted to detail requirements.

The method of implementing this recommendation is displayed in the sample section writeup in section 7.0. The basic theme of this recommendation is that introductory material should be brief and only be provided to make the user aware of the general considerations or guidelines that should be taken into account in the subject area.

Guidelines and general criteria should be located at the beginning of each major section and should be easily distinguishable from detail design requirements. Distinguishability can be accomplished by publishing general information the entire page width and detail data in a narrow column with associated illustrations nearby. This technique is depicted in the sample section writeup, section 7.0.

Definitions

Problem:

Since a variety of users must interpret the standard, universal definitions are required for the terms used. The approach commonly used in the documents reviewed was to provide a list of definitions in the front or back section. This method rapidly became unmanageable and difficult to use.

Recommendation:

The solution to the definition problem was also implemented in the sample section writeup. The terms that are likely to cause confusion or abmiguity are underlined in the text. Definitions of each underlined term are then provided at the end of the subject section. This system allows the user who is familiar with terms such as "brightness contrast" or "control/display ratio" to not be hindered by definitions in the text. Similarly, users who are not familiar with terms are provided definitions near the topic under discussion.

Illustration Quantity

Problem:

A number of recommendations were made by the survey respondents that more illustrations be included in the standard. In most cases, illustrations significantly reduce the amount and complexity of the text material. Illustrations also have been shown to augment retention of the material provided.

Recommendation:

The study effort resulted in a recommendation that illustrations be used wherever they would be helpful in presenting design data. In most cases this can be accomplished by providing an example illustration of the required design. In some cases, however, it is necessary to illustrate the undesirable designs. When this is required, it is recommended that only two illustrations be provided--one "acceptable" and one "unacceptable." This should eliminate the "good, better, best" or "poor, better, preferred" systems which are too flexible for a design standard.

Illustration Location

Problem:

Considerable difficulty was experienced while reviewing MSFC-STD-267A in locating figures and tables referenced in the text. Both the numbering system and the illustration location contributed to this problem. At times the figure was located as much as four pages away from the text discussion.

Recommendation:

The recommendation resulting from an analysis of illustrations states that figures and tables should be located adjacent to the associated text. This recommendation is implemented in the sample section.

It is also suggested that figure and table numbers be eliminated unless it is impossible to locate the illustration in unambiguous proximity to the associated text.

It is further recommended that the emphasis of a particular illustration be highlighted by nomenclature or shading on the illustration.

Retrieval Logic

Problem:

Many survey respondents cited the difficulty in data retrieval as a major deficiency of MSFC-STD-267A. It was found that it was difficult to determine what the standard does and does not contain as well as to locate information that is known to be there. The survey responses are reinforced by the results of the literature and MSFC-STD-267A critical reviews.

Recommendation:

The method suggested by the study team to alleviate retrieval difficulties is to provide a logic diagram as a foldout at the end of each major section. The logic diagram depicts the contents of each section as well as the relationship between the sections. Decision points are illustrated which give the reader insight into the philosophy used to generate the standard and which should be used in retrieving data from it. The use of a foldout at the end of the section allows use of the flow chart while examining the text material without repeatedly flipping back from the text to the chart.

Illustration Formats

Problem:

The format of figures and tables used in MSFC-STD-267A, and some of the references, in many cases added to confusion and data retrieval time.

Recommendation:

It is recommended that standard figure and table formats be generated and used throughout the standard. The basic philosophy behind the format of these illustrations should be identical to that used in designing other displays. Namely, the data should be provided in a form which is directly usable by the user. For example, anthropometric data should be provided for personnel in garments that must be accommodated rather than in the form of nude measurements plus incremental factors for clothing.

References

Problem:

If the designer finds it necessary to determine the detail conditions surrounding a particular design requirement, he must be provided a means to isolate the source of that requirement.

Recommendation:

Where a specific reference (e.g. study reports, EIDs) can be identified for a requirement, it should be cited at the end of the subject paragraph. This philosophy will add very little to the length of the standard text and will provide valuable information. The same procedure should be used for illustrations in case the user would like to investigate a particular area further.

<u>Data Credibility</u>

Problem:

A variety of sources are used in the human factors field for requirements that are specified. In some cases, engineering judgment or design precedence is the only source available. Consequently, many users who have not studied human factors formally need a method by which to establish the credibility of the standard.

Recommendation:

To alleviate the credibility situation, it is recommended that "source type" be coded in at the end of each detail design requirement. That is, a coding system should be generated to define whether the requirement evolved from research or supporting data or precedence.

<u>Examples</u>

Problem:

Users have found it difficult to translate the design requirements stated in the standard to their design problems. In many cases, this is due to the use of out-of-date or inappropriate examples.

Recommendation:

It is suggested that since MSFC-STD-267A is to be used by spacecraft designers that spacecraft examples be used. This includes both textual examples such as parenthetical phrases, and figures or illustrations. This recommendation is implemented in the sample section writeup where most examples are from the Apollo, Skylab, and Lunar Roving Vehicle programs.

Section Referencing

Problem:

MSFC-STD-267A uses the military decimal system for referencing paragraphs within the standard. As used in MSFC-STD-267A, this system is somewhat long and cumbersome and in some cases confusing. This confusion largely results from minor and major criteria in some cases being given parallel significance by the decimal referencing system.

Recommendation:

It is suggested that the military decimal system for referencing paragraphs be used in the standard. Although this system has some disadvantages, it provides a simple means of providing section referencing. The disadvantage of minor and major criteria receiving the same paragraph level can be avoided if the paragraphs and subparagraphs are assigned in accordance with the levels shown on the retrieval logic chart.

Cross Referencing

Problem:

Many instances were cited in reviewing MSFC-STD-267A where various sections of text related to or augmented each other. Without an in-depth knowledge of the document contents, however, it is conceivable that a user would not discover all relevant data.

Recommendation:

The retrieval logic diagrams discussed earlier should relieve cross referencing requirements by illustrating the relationship between design items. However, extensive cross referencing should also be provided at the end of each requirments paragraph to designate related design information.

7.0 SAMPLE SECTION REWRITE

To demonstrate the format, organization, and content recommendations generated during the study, a single section was selected for rewriting. The section presented here depicts the recommendations stated in the Format Recommendations Section of this document. The section is not intended to present actual design values, but rather to demonstrate the manner in which design data should be presented to alleviate a number of problems (e.g. inaccessibility, ambiguities, etc.) with the current standard.

The section to be rewritten was selected on the following criteria:

- The sample section should be a frequently used section out of the existing standard. This would allow the reader of this report to compare the sample section with a section he is probably familiar with.
- The section should allow the format recommendations presented in Section 6.0 of this report to be displayed.
- The section should have direct applicability to current and future NASA Programs such as Space Shuttle, Space Stations, and RAM.
- The existing MSFC-STD-267A section must contain data (general and specific) which can be extracted and reformated for the sample section.

An evaluation of each MSFC-STD-267A section against these criteria resulted in the selection of the Display Criteria Section. The partially rewritten Display Criteria Section is presented below. No attempt was made to completely rewrite the entire section since this would have required considerable research to collect data not available in MSFC-STD-267A. However, examples of recommended formats are presented for comparison with MSFC-STD-267A. The subsections of the recommended Display Criteria Section that are included in the sample section rewrite are those that are shaded on the retrieval logic chart at the end of this section.

In isolated cases it was necessary to obtain data from other sources to present a complete illustration of the depth and breadth recommended for sample section. In these instances design data were selected somewhat arbitrarily. Priorities were assigned to source documents as follows:

- MSFC-STD-267A - Human Engineering Design Criteria, September 1966.
- 10M32447B - Human Engineering Design Requirements for AAP experiments Man-Systems Integration Branch Mechanics and Crew Systems Integration Division Astronomics Laboratory Science and Engineering Directorate MSFC.
- 10M32158 - Man/System Design Requirements for Orbital Workshop, Multiple Docking Adapter, Airlock Module and Apollo Telescope Mount
- MIL-STD-1472A - Human Engineering Design Criteria for Military Systems, Equipment and Facilities, May, 1970
- Woodson and Conover (W&C) - Human Engineering Guide for Equipment Designers

- Morgan, Cook, Chapanis, et al (Morgan) - Human Engineering Guide to Equipment Design

References are provided at the end of each section. Terms appearing with dual underlines are defined at the end of this section.

A source coding system was developed to distinguish between the various origins of the stated requirements. The code appearing at the end of each requirements section may be interpreted by the following:

(A) Supported by research findings

(B) Supported by design precedence

(C) Supported by engineering judgment

Examples used throughout the section are mostly from current space programs. It was felt that identifying the programs from which each illustration was derived would be instructive. The abbreviations are as follows:

ATM - Apollo Telescope Mount experiment panel from the Skylab Program

CSM - Apollo Command and Service Module

LRV - Lunar Roving Vehicle from the Apollo Program

5.2 DISPLAY CRITERIA

5.2.1* DISPLAY SELECTION GUIDELINES

In selecting the proper display type for a given application, the following factors must be considered:

- Type of information to be displayed
- Use of information
- Environment in which information is to be presented

The two most common display types make use of the visual and auditory senses. Considering the above factors, selection between these display types is made as follows:

Use Visual Displays:

If the message to be conveyed is long or complex, if the message deals with location in space, or if the auditory channel is overloaded.

Use Auditory Displays:

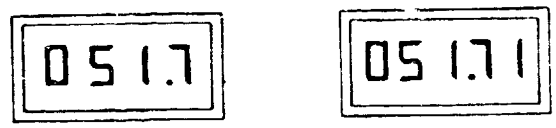
If the message is simple or short, if the message deals with location in time (not space), or if the visual channel is overloaded.

The other senses shall only be used when the visual and auditory channels are overloaded. Since tactual, gustatory, and olfactory displays are used only in extremely rare situations these design criteria will not be presented in this standard.

* This section is numbered to correspond to the section it would replace in MSFC-STD-267A.

5.2.2 GENERAL DISPLAY DESIGN CONSIDERATIONS

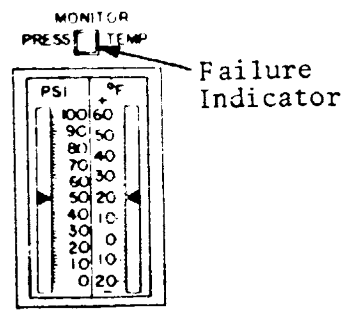
Precision - Display precision shall be commensurate with the task performed with the display and with control responses required on the basis of display readings. For example, if a sun sensor display reading is to be used to input an attitude command to the nearest tenth of a degree, the display should indicate tenths of a degree, not hundredths. (C)



Acceptable Unacceptable

ATM Digital Displays

Display Failure - Electrical failure of the display shall be indicated by an amber indicator light located above the display. (B)



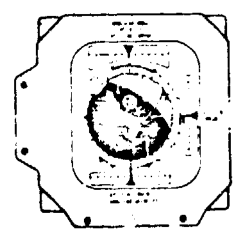
ATM Thermal Control System Indicator

5.2.3 SPECIFIC DESIGN CRITERIA

5.2.3.1 Visual Displays

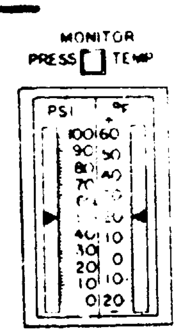
Visual displays can be divided into two major categories based on the manner in which information is presented. Symbolic and pictorial displays shall be selected on the basis of the following criteria:

- Pictorial displays shall be used in situations where spatial orientation must be presented. Navigation, piloting, and pointing situations are included in this category. (B)



Apollo CSM Attitude Indicator

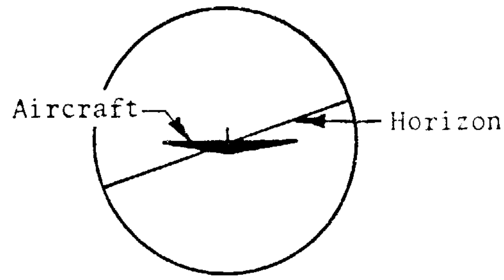
- Symbolic displays shall be used where the information to be presented is not pictorial or spatial in content. Temperature, pressure, and gimbal angle readouts are included in this category. (B)



ATM Thermal Control System Indicators

5.2.3.1.1 Pictorial Displays

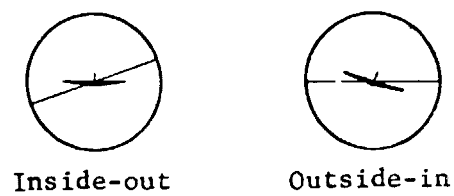
Pictorial displays shall be designed such that the object represented by the display is simply and clearly depicted in the display. (C)



Attitude Indicator (Right Turn)

The relationship between stationary (or reference) and moving parts on the display shall be analogous to the relationship between the objects they represent. (C)

<u>Inside-out displays</u> shall be used in all applications. That is, command inputs shall result in motion of the environment around the spacecraft as depicted in the display. (W&C 2-26) (A)



Attitude Indicator (Right Turn)

5.2.3.1.1.1 Cathode Ray Tubes (CRTs)

Target Size and Brightness

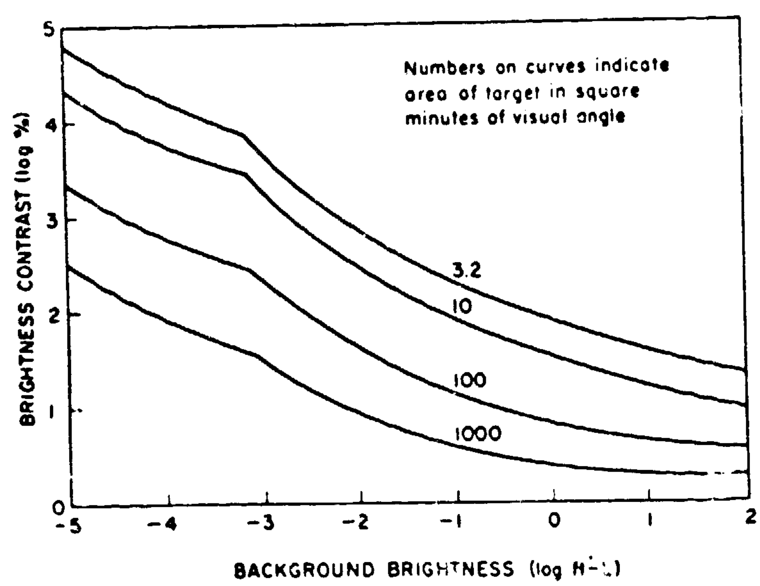
- CRT targets shall conform to the values presented in the adjacent figure. This will afford a 99% probability of detection under the following conditions: (Morgan 110) (A)

  a. The operator is <u>visually adapted</u> to the brightness level of the task.

  b. The target is either brighter or darker than the background.

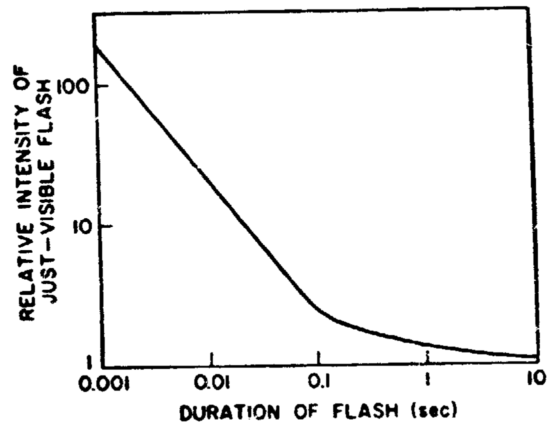
  c. The background brightness (noise) is distributed evenly.

  d. The operator has several seconds to detect the target and is alerted to the task.



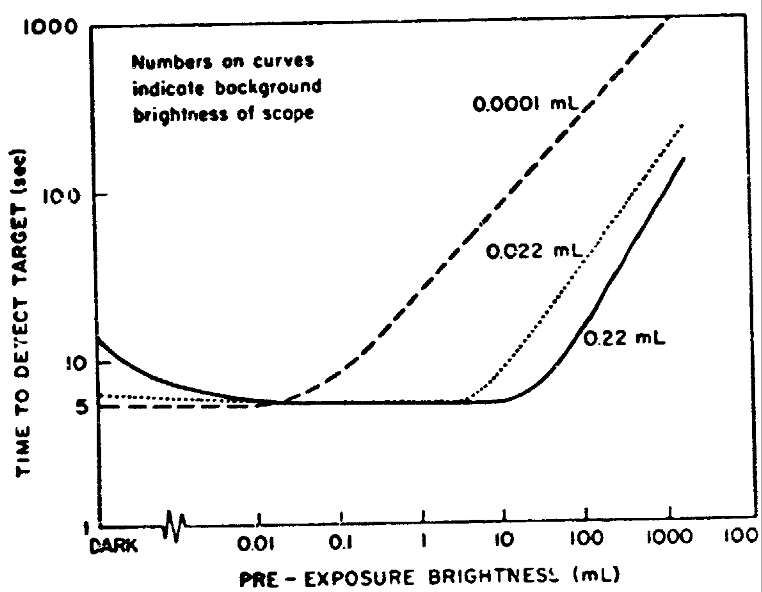
Signal Duration

● Signal Duration shall comply with the values presented in the adjacent figure as a minimum. (Morgan 111) (A)



Operator Adaptation

● The adjacent figure presents scope background brightness as a function of pre-exposure brightness. These values shall be used as design minimums for background brightness. (Morgan 111) (A)

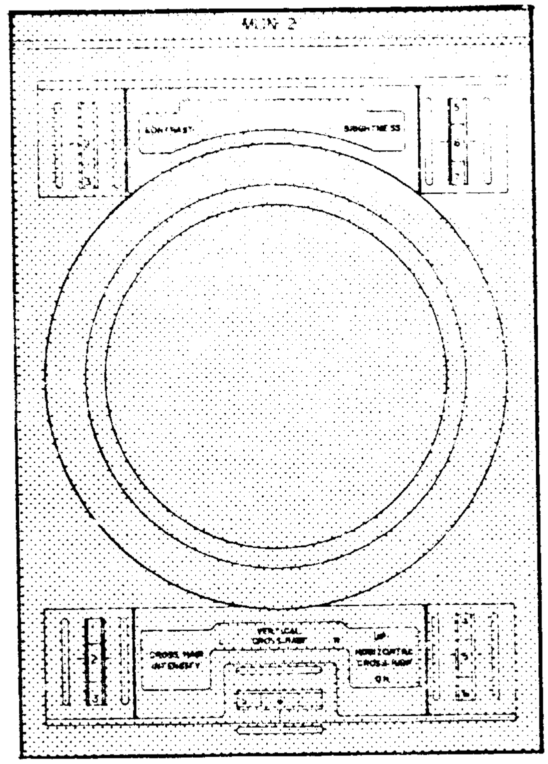


Contrast Direction

● Targets shall be bright spots or images on a dark background. (A)

Brightness Adjustment

● CRTs shall be provided with controls for brightness adjustment by the operator from the panel surface. (B)



ATM Video Monitor

Viewing Distance

● A minimum of 16 in. shall be provided for viewing distance to avoid visual fatigue. (A)

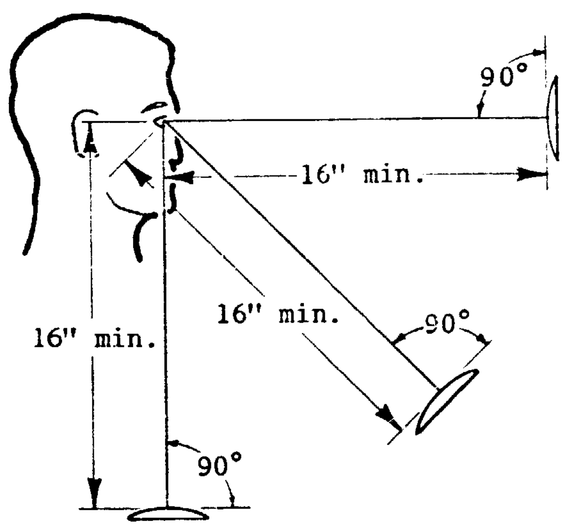
Scope Size

● CRT Scope size shall be consistent with the following formula: (A)

$$Din = 0.0058\ Vin\ \frac{R}{T}$$

where,

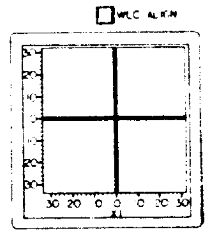
Vin = Viewing distance in inches
Din = Scope diameter in inches
R = range of recognition of a target of size T.
T = target size (actual) which must be recognized at range R.
R and T must be expressed in the same units



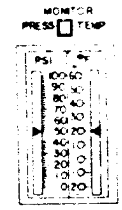
5.2.3.1.2 Symbolic Displays

Symbolic displays can be grouped into digital and analog devices.

- Analog devices (e.g. scale meters) shall be used for qualitative or check readings to determine trends in outputs, approximate values, and for tracking. (A)

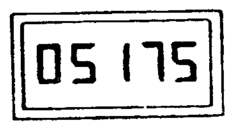


ATM Alignment Indicator



ATM Thermal Control System Indicator

- Digital devices shall be used where quantitative values are to be presented, where exact settings have to be made using display feedback, or where status indications are presented. (A)



ATM Frames Remaining Indicator

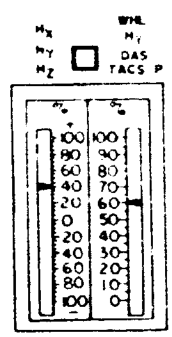
5.2.3.1.2.1 Analog Devices

Display type

- Linear moving pointer displays shall be used in all analog display applications. (B)

Scale Design

- Scale values shall increase to the right (horizontal display) or upward (vertical display). (A)



ATM Momentum Indicators

- The number of scale graduations between major scale intervals shall be less than ten. (A)

- Scale graduation intervals of 1, 2, or 5 and decimal subdivisions of these shall be used in all applications. (A)

5.2.3.1 3 Labeling

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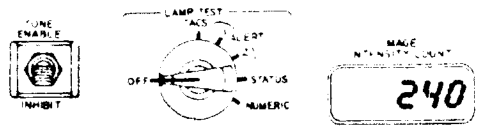
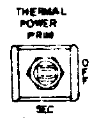
5.2.3.1.3.1 Label Location

Labels naming displays or controls shall be centered above their associated display or control. (B)



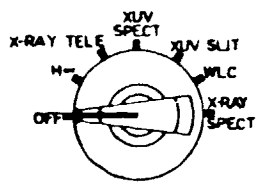
ATM Experiment Controls and Displays

Labels identifying the function of toggle switch positions shall be located adjacent to their respective positions (10M32447B-19). Labels for the center position of three position toggle switches shall be located on the right side of the switch. (B)



ATM Experiment Power Switch

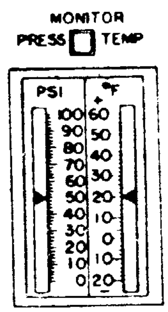
Labels designating positions on rotary controls shall be oriented horizontally and adjacent to their respective positions (10M32447B-19). (B)



ATM Experiment Selector Switch

Analog Display - Labels identifying measurement units (e.g. PSIA, LB, °F) shall be centered on the display above the scale markings (10M3244713-20). (B)

Labels identifying display parameters (e.g. PRESS, TEMP) shall be centered above the display (10M32447B-20). (B)



ATM Thermal Control System Indicator

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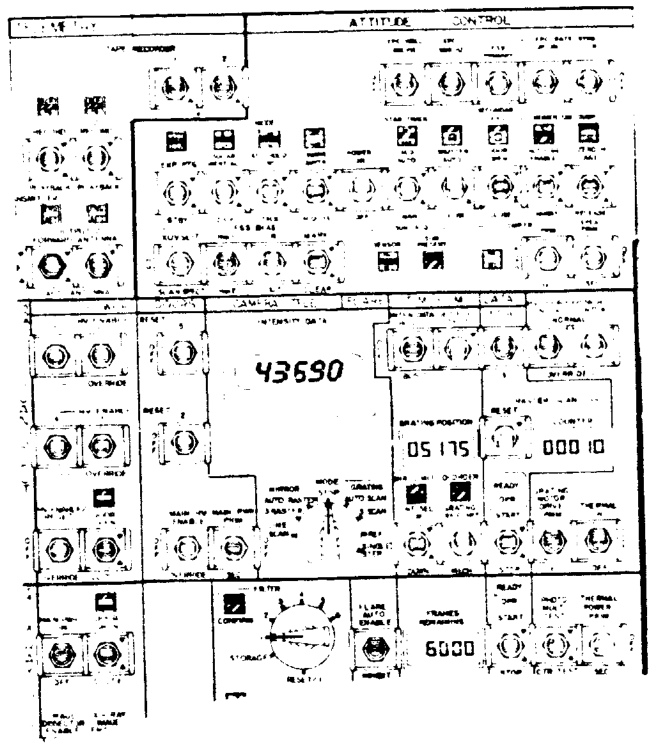
Labels identifying panel functional groups or sub-groups shall be centered at the top of the boundary for the components or in the bracket above the components. (10M32447B-21) (B)



Portion of ATM Control/Display Panel

5.2.3.1.3.2 Label Style

Futura Font shall be used for all letters and numerals (10M32447B-21) All capital letters shall be used. (B)

Labeling shall be light on a dark background. (A)

5.2.3.1.3.3 Label Size

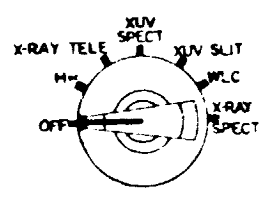
Major panel section labels shall be a minimum of .250 in height. (B)

Labels identifying functions or switch positions shall be a minimum of .112 in. in height (10M32447B-21). (A)

Annunciator labels (e.g. caution and warning) shall be a minimum of .125 in. in height (10M32447B-21). (A)

Labels on analog displays shall be a minimum of .120 in. in height (10M32447B-21). (A)

Rotary control indices shall be .20 inches wide and .12 inches long (10M32447B-22). (A)



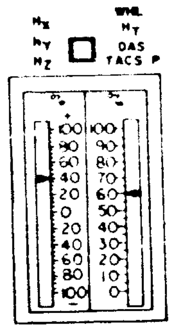
ATM Experiment Selector Switch

Graduation marks on dual vertical meters shall be as follows (10M32447B-23)

Long graduation marks shall be 0.25 inches long by .030 inches wide. (A)

Short graduation marks shall be .10 inches long by .02 inches wide. (A)

Centerlines for graduation markings on dual meters shall not be closer than .060 inches. (A)



ATM Momentum Indicators

5.2.3.1.3.4 Label Spacing

Spacing between words shall be equivalent to the width of the letter L (10M32447B-22). (A)

Vertical spacing between lines of labeling or between labeling and a panel component shall be .75 letter height (MSFC-STD-267A-94). (A)

5.2.3.1.3.5 Boundaries and Grouping

Marks and Indices - Panel Subsystem boundaries (e.g. Navigation, Communication, Experiments) shall be delineated with lines twice the stroke width of their respective labels. (B)

Grouping marking shall be equal in width to the stroke width of their respective labels (10M32447B-22). (B)

5.2.4 DEFINITIONS

Guidelines -

Information of a general nature which provides guidance in making decisions.

Tactual -

Perceptible by the sense of touch.

Gustatory -

Perceptible by the sense of taste.

Olfactory -

Perceptible by the sense of smell.

Symbolic -

Information which is presented in a manner which has no pictorial resemblance to the conditions of objects represented.

Pictorial -

Information which is presented in a manner which has a geometric or schematic resemblance to the conditions or objects represented.

Inside-out Displays -

Displays which present an illustration of the conditions in the environment (outside) from the point of view of an observer located in a dynamic object (inside). For example, an inside-out display would present an illustration of a tilted horizon rather than a tilted aircraft to indicate a banking attitude.

Visually Adapted -

In a condition such that the sensitivity of the eye is at its highest level for the impinging conditions. For example, adaptation to a dark environment after exposure to a bright environment requires approximately 30 minutes.

Pre-exposure Brightness -

The brightness level to which the eye has adapted immediately prior to attempting a display reading task.

Qualitative -

Descriptive information of a subjective, trend, or go/no-go nature.

Quantitative -

Descriptive information which is presented in the form of definite values in a selected measure.

Segemented Character -

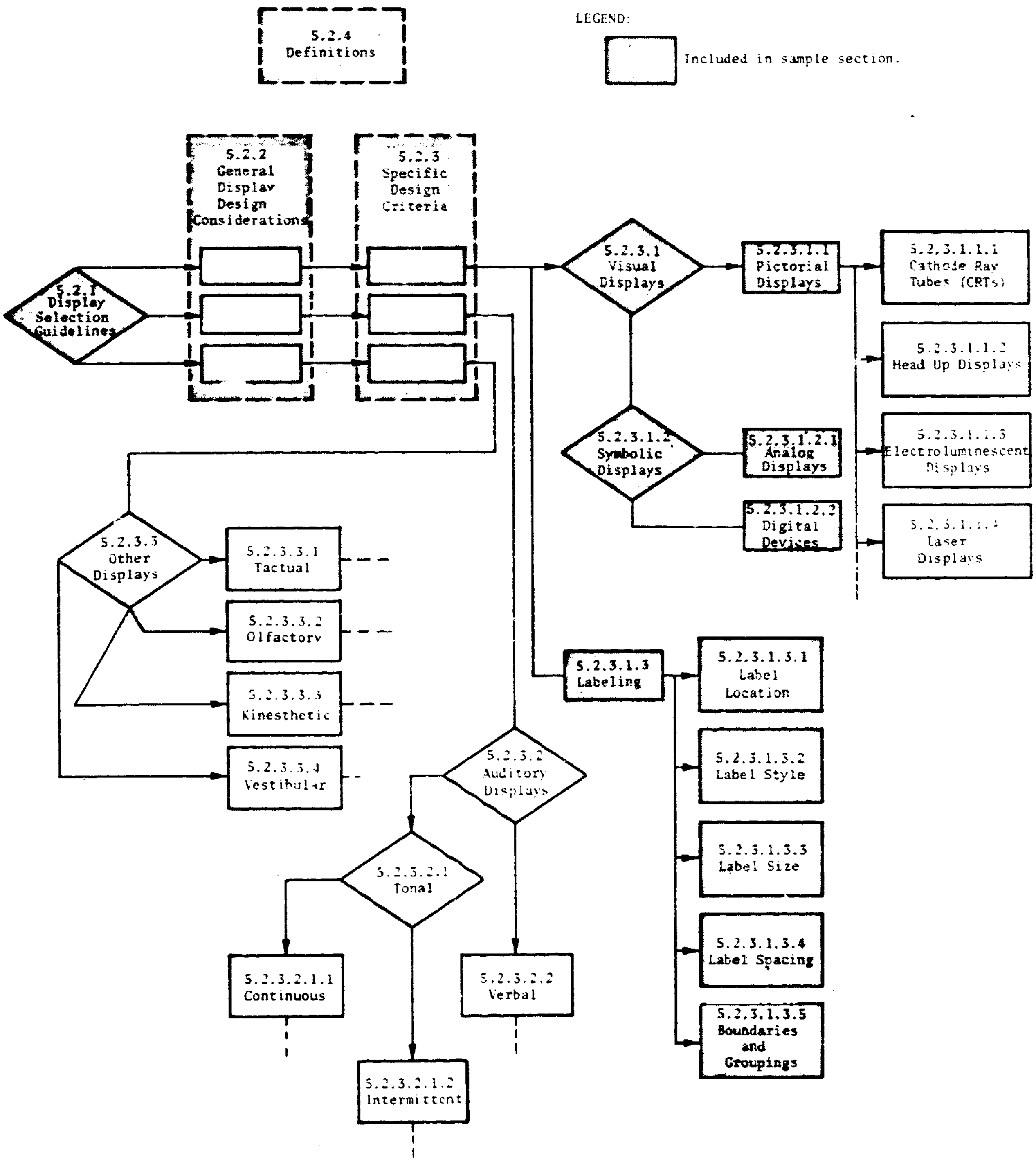
A display character composed of more than one display element (e.g. multi-element diode arrays).

Continuous Character -

A display character composed of one display element (e.g. projected character type).

Annunciator -

An electrically driven on-off indicator.



PARTIAL DISPLAY CRITERIA RETRIEVAL LOGIC DIAGRAM

END

DATE

FILMED

JAN 23 1973